EXERCISE 2: RADIONUCLIDE TRANSPORT TO GROUNDWATER FROM THE URANIUM TAILING

1. General description of problem

In this exercise we use NORMALYSA to calculate radionuclides transport in groundwater to the well situated downstream from the uranium tailing site. It is assumed that the well is used as a source of drinking water by the reference individual (FIG 1).

1.1 Contamination source term

The contaminant source term is the uranium mill tailing site. The area of the tailing site is 40000 m² (X=200 m × Y=200 m; here X and Y are coordinate axes along and perpendicular to groundwater flow direction). The body of tailing contains U-238, U-234 and its progenies: Th-230, Ra-226, Po-210, and Pb-210. The thickness of the waste body is 8 m. The tailing body is separated from the underlying sandy aquifer by 2 m thick unsaturated zone of soil. The thickness of the saturated zone in the aquifer is 10 m. It is assumed that at the beginning of simulation the unsaturated soil zone and aquifer immediately below the tailing site are contaminated due to the radionuclide leaching from the tailing body by infiltrating meteoric waters.
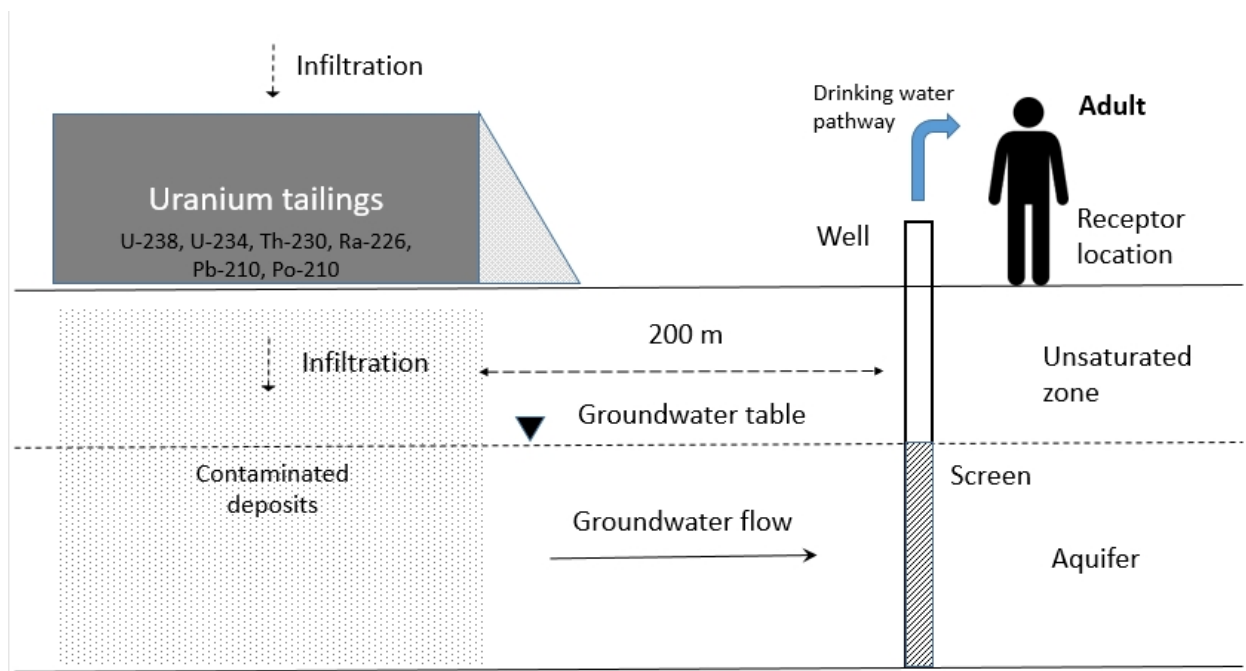

FIG 1. Scheme illustrating radionuclide transport in groundwater from the uranium tailing.

1.2 Reference person and exposure scenario

The modelled scenario considers radionuclide migration in the groundwater aquifer from the uranium tailing site to the well situated at 200 m downstream from the site. Radionuclides from the tailing body infiltrate the unsaturated zone and aquifer, and are transported by horizontal groundwater flow towards the downstream well.

The groundwater from well is occasionally used as a source of drinking water by the reference individual (adult). It is assumed that the well provides 25% of the yearly drinking water consumption to the reference individual.

1.3   Calculations end-points

The calculation end points are:

- Radionuclide concentrations in well;
- Annual effective dose received by reference individual through the drinking water pathway.

The calculations shall be carried out at the time scale of 1000 years. The calculation results shall be provided with the time step of 100 years.

2. Input data

The input data include characteristics of radioactivity source – term – uranium tailing (Table 1 and Table 2), parameters of the unsaturated zone (Table 3 and Table 4), parameters of the aquifer (Table 5 and Table 6) and habits of reference person – adult (Table 7).

Table 1. Parameters of uranium tailings site.

Parameter	Value	Unit
Waste site area	40000	m^2
Length of the site	200	m
Width of the site	200	m
Thickness of waste layer	8	m
Waste bulk density	1600	kg/m^3
Waste moisture content	0.15	unitless
Infiltration recharge rate	0.2	m/year

Table 2. Radionuclide-specific parameters of the tailing body.

Radionuclide	Initial specific activity of radionuclides in waste, Bq/kg	Waste Kd, m^3/kg
U-238	2500	0.005
U-234	2500	0.005
Ra-226	14000	6.3
Th-230	12700	10
Po-210	21000	2.5
Pb-210	17000	3.5

Table 3. Parameters of the unsaturated zone.

Parameter	Value	Unit
Thickness of the unsaturated zone	2	m
Moisture content	0.15	unitless
Soil bulk density	2000	kg/m^3

Table 4. Radionuclide-specific parameters of the unsaturated zone.

Radionuclide	Initial specific activity of soil, Bq/kg	Unsaturated zone soil Kd, m^3/kg
U-238	500	0.003
U-234	500	0.003
Th-230	510	3
Ra-226	435	0.2
Po-210	900	0.1
Pb-210	2200	0.5

Table 5. Parameters of the aquifer.

Parameter	Value	Unit
Thickness of the aquifer	10	m
Groundwater flow Darcy velocity	10	m/year
Porosity	0.3	unitless
Aquifer material bulk density	1600	kg/m^3

Table 6. Radionuclide-specific parameters of the aquifer.

Radionuclide	Aquifer material Kd, Bq/m^3	Initial radionuclide concentration in groundwater (below the tailing), Bq/m^3
U-238	0.01	2000
U-234	0.01	2000
Ra-226	0.2	200
Th-230	3	0
Po-210	0.1	0
Pb-210	0.5	0

Table 7. Habits of the reference individual (adult).

Parameter	Value	Unit
Fractional contribution of water from well to total ingestion of water	0.25	unitless
Ingestion rate of water	0.37	m^3/year

3. General description of implementation of problem in NORMALYSA

3.1 Modules used

In this exercise we will use the following NORMALYSA modules:

- 'Tailing without cover' module from 'Sources' library – to model radionuclide source-term for radionuclide transport in groundwater,
- 'Unsaturated zone' module from 'Transports' library – to model vertical radionuclide transport in the unsaturated soil zone below the tailing from the source (uranium tailing) towards the aquifer,
- 'Aquifer mixing' module from 'Transports' library – to model aquifer zone immediately below the contaminated site where vertical infiltration activity flux from the unsaturated zone mixes with the horizontal groundwater flow in the aquifer,
- 'Aquifer' module from 'Transports' library – to model horizontal radionuclide transport in the aquifer from the uranium tailing site to well location,
- 'Well'' module from 'Receptors' library – to model radionuclide concentrations in well extracting groundwater from the aquifer, and
- 'Dose from ingestion of water' module from 'Doses' ⇒ 'Doses from ingestion of different food types' library - to calculate doses to reference individual from drinking water pathway.

Zone of contaminated geological deposits immediately below the uranium tailing is modelled by means of assigning non-zero values of initial radionuclide concentrations in soil (or water) at the beginning of simulation to 'Unsaturated zone' and 'Aquifer mixing' modules.

3.2 NORMALYSA model structure and data exchanges between modules

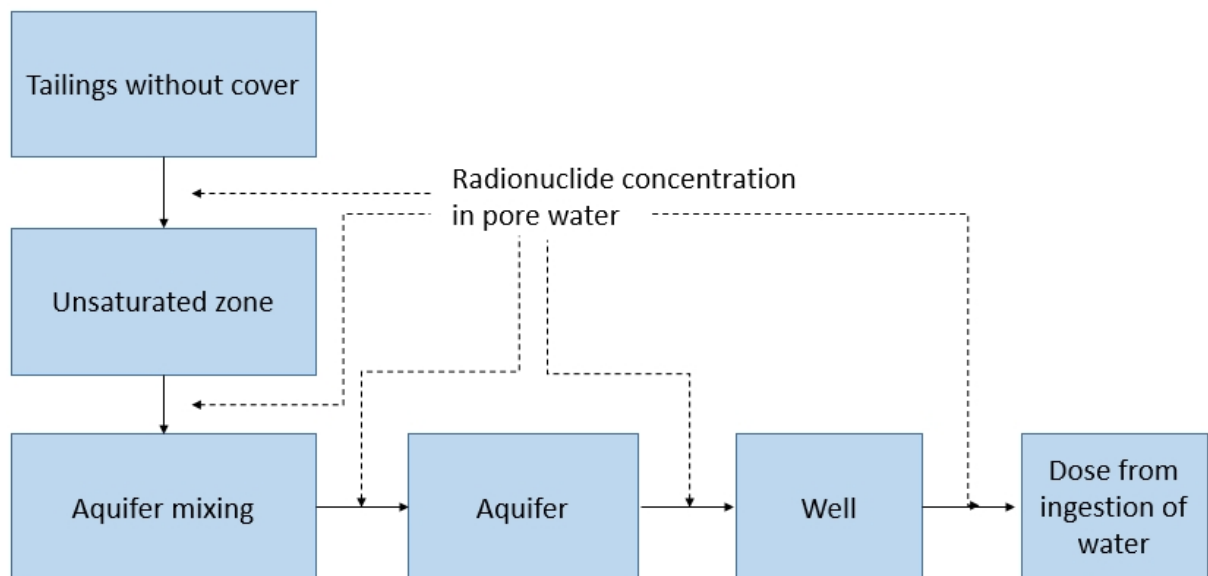The structure of NORMAYSA model for Exercise 2 is shown in the form of block-scheme in FIG 2.

FIG 2. NORMALYSA model structure for Exercise 2.

3.3 General description of modelling steps

To solve the described above problem using NORMALYSA, modeller needs to carry out the general sequence of steps shown in FIG 3. This is accomplished by going through different positions of the NORMALYSA main menu (shown to the left in the main software interface window).

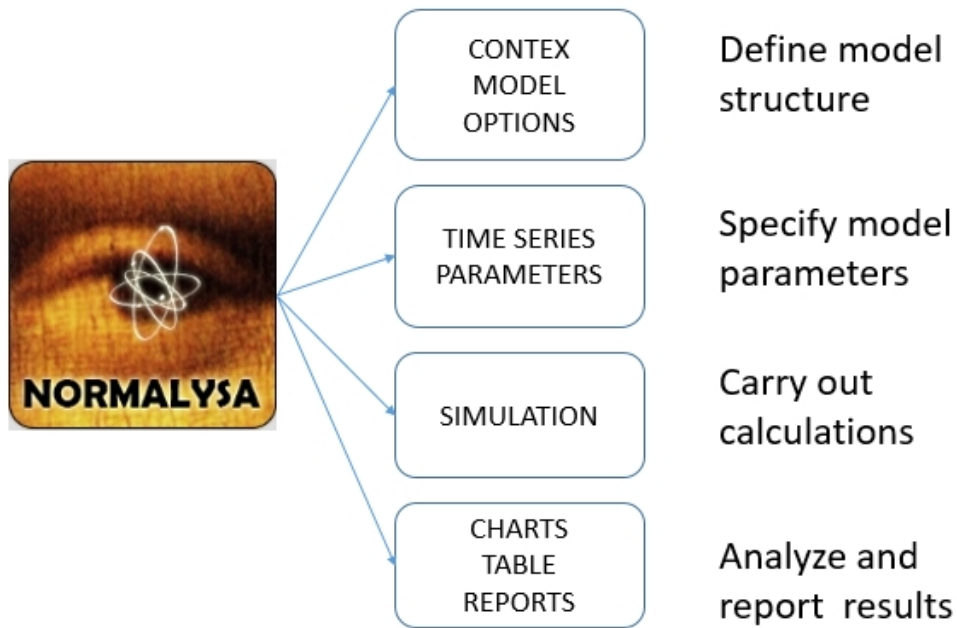The rationale of each NORMALYSA menu position (and respective modelling step) is briefly explained below.

FIG 3. 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.

Modeller also has a possibility to activate or de-activate specific index lists relevant to modeled case such as, for example, 'Exposed groups', 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 radiecological 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 modelling case, 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 4).
   Give a name to the model ("Exercise 2"), 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.
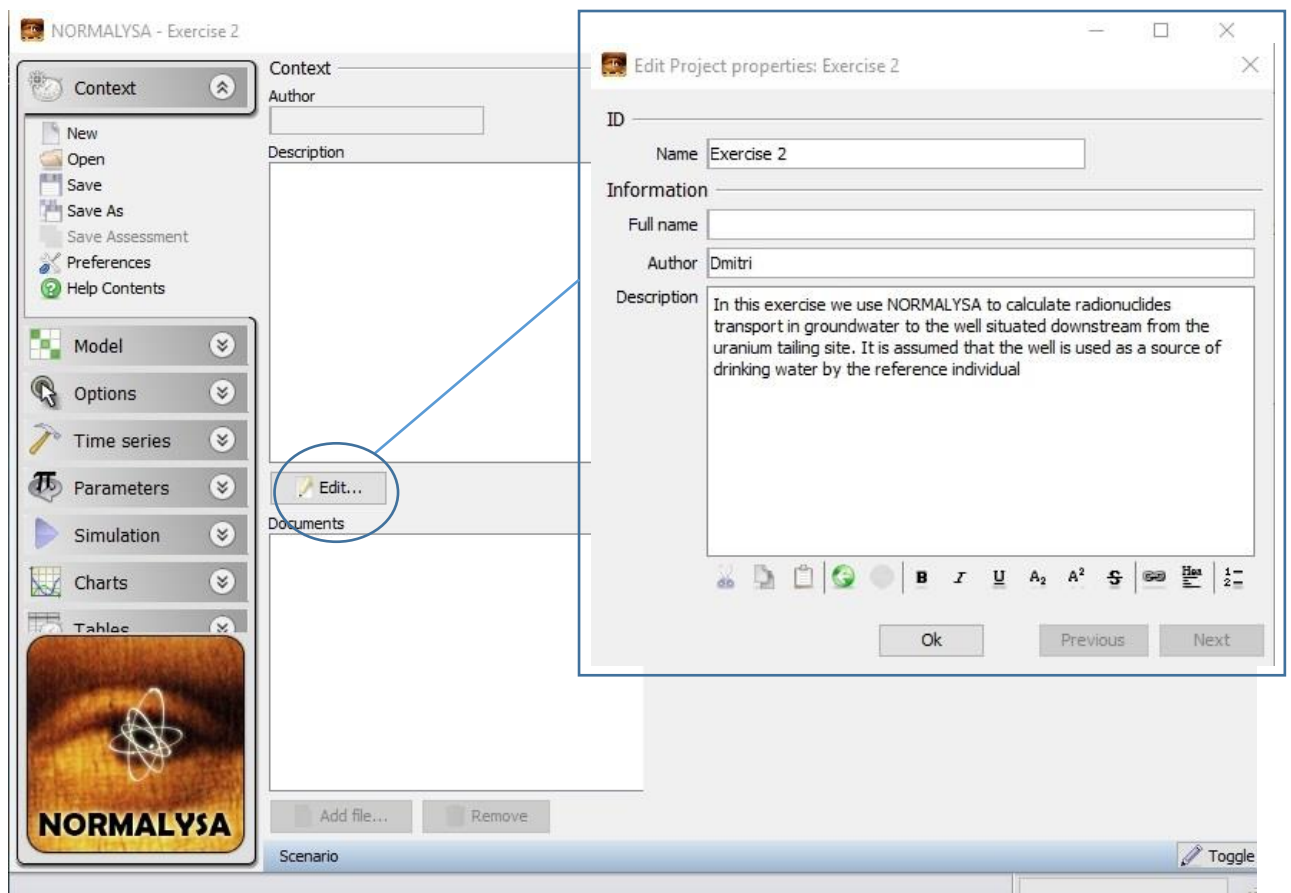

FIG 4. Editing '*Project properties*' window.

List of '*Contaminants*' (radionuclides) is 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.

In the considered exercise the whole U-238 decay chain needs to be included to the model. To do so, first disable all radionuclides in the '*Nuclides*' window. Then select U-238 (its whole decay chain will be selected automatically) (FIG 5).
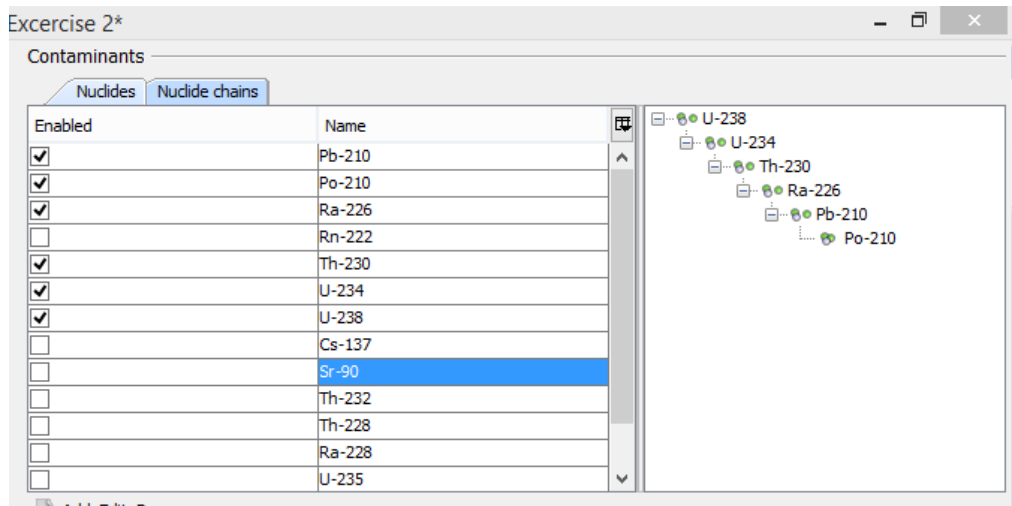
FIG 5. '*Contaminants'* window with selected radionuclides for Exercise 2.

4.2 'Model' menu button

Next, you will assemble the model. In this menu position, we will create the model by using the module libraries and "connectors" to exchange output and input data between 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 these two modes at any time by clicking on the tabs in the upper right corner of the '*Model'* window (FIG 6). Next to the '*Graph*' button (which is selected by default), you find the '*Matrix*' button. Click on it to select the "matrix view".
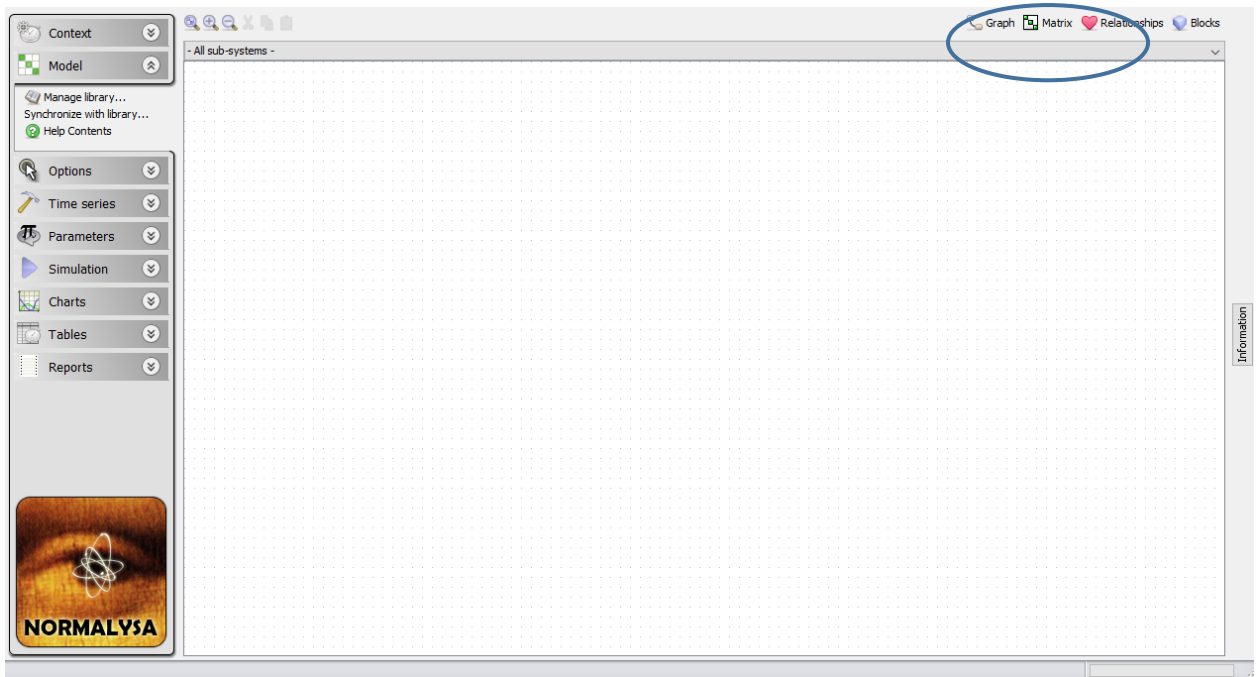

FIG 6. Tabs corresponding to different options ('*Graph*', '*Matrix*') of model visualization.

Now we will compose the NORMALYSA model for Exercise 2 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 *'Tailing without cover'* module from the *'Sources'* folder. You can read a short description of the selected model in the *'Description'* field of *'Library'* window (FIG 7).
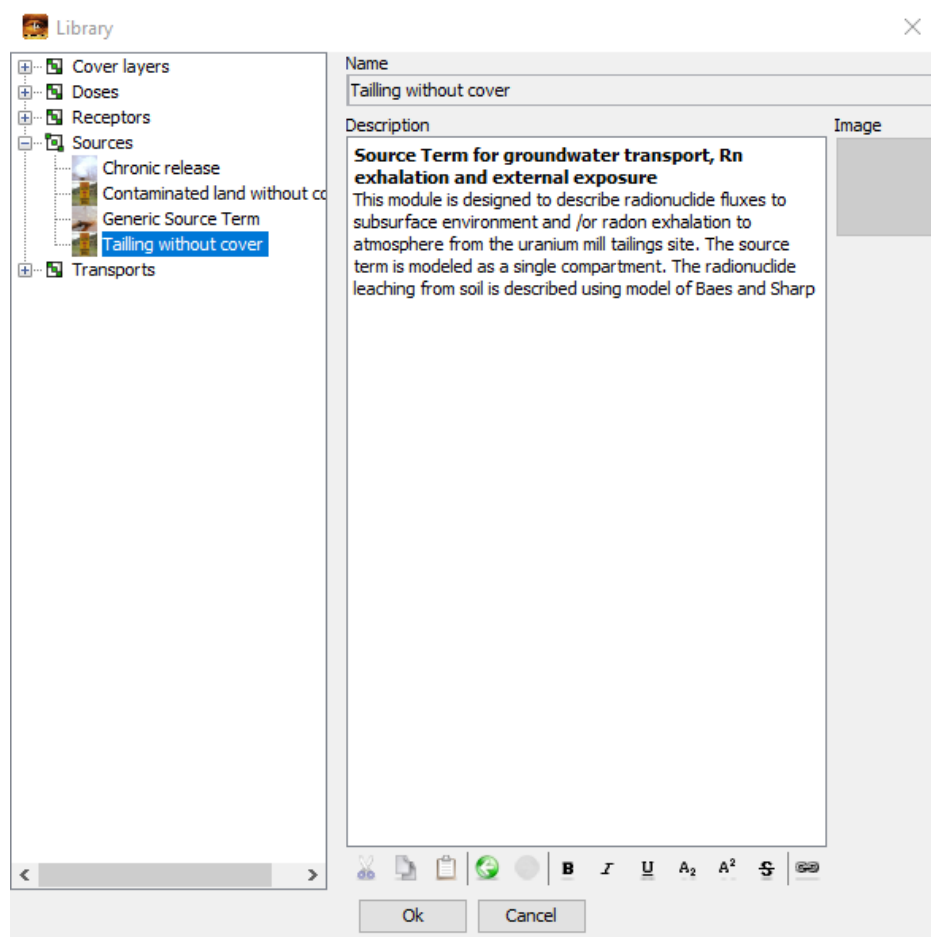

FIG 7. *'Library'* window showing the explanatory text for the 'Tailings without cover' module from the 'Sources' library.

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 'Unsaturated Zone' module from 'Transports' library.

6. Repeat steps 1 – 4 to insert on the diagonal of the matrix the ''Aquifer Mixing' module from 'Transports' library.

7. Repeat steps 1 – 4 to insert on the diagonal of the matrix the 'Aquifer' module from 'Transports' library.

8. Repeat steps 1 – 4 to insert on the diagonal of the matrix the 'Well" module from 'Receptors' library.

9. Repeat steps 1 – 4 to insert on the diagonal of the matrix the 'Dose from ingestion of water' module from 'Doses'/'Doses from ingestion of different food types' library.

Now we need to connect individual modules in-between each other using "connector" blocks to exchange data.

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 8).
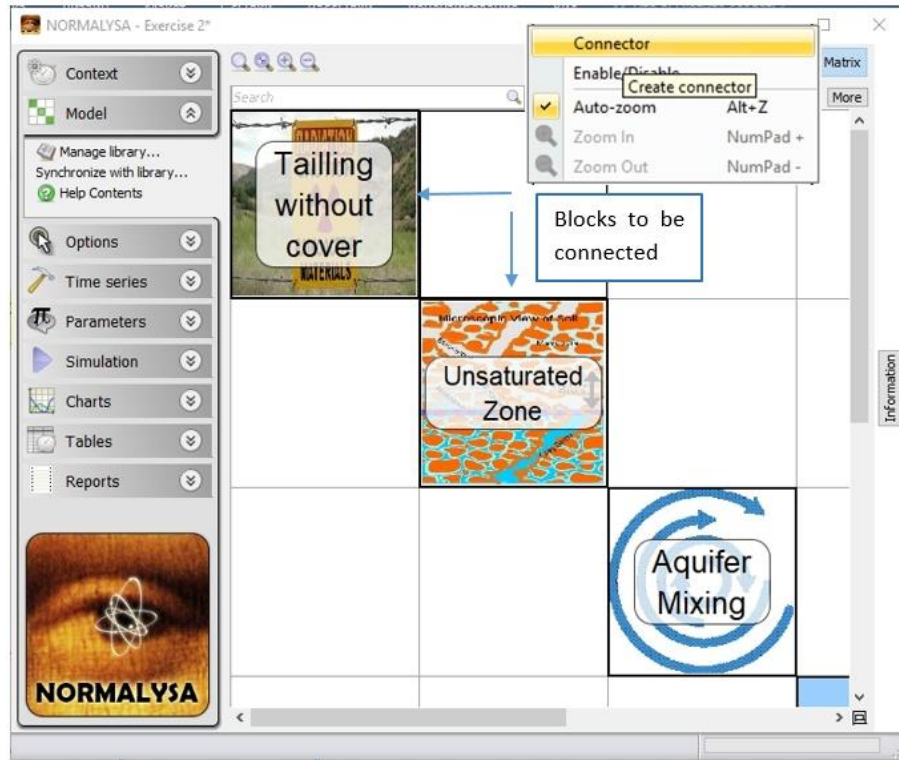2. Repeat the process of connecting modules until your model will look as in FIG 9.

FIG 8. Connecting modules using "connector" blocks for data exchanges.

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 'Tailings without cover' and 'Unsaturated Zone' modules. The '*Edit Connector*' window will be opened allowing to set up data exchanges between these modules (FIG 10). The left column of window lists output parameter of the 'Tailings without cover' module, while the right column lists the input parameters of the 'Unsaturated zone' module. You have to match 'output – input' parameter pairs 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 outflow*' and '*RN concentration in infiltration*';
    - '*Infiltration recharge rate to source material (soil)*' and '*Infiltration recharge rate to the unsaturated zone*';
    - '*Surface area of the modelled contaminated site*' and '*Surface area of the*

modelled unsaturated zone system (contaminated site)'.
Please note that connected parameters need to have same units.

FIG 9. Full model for Exercise 2 including main modules and "connectors" in '*Matrix'* view.
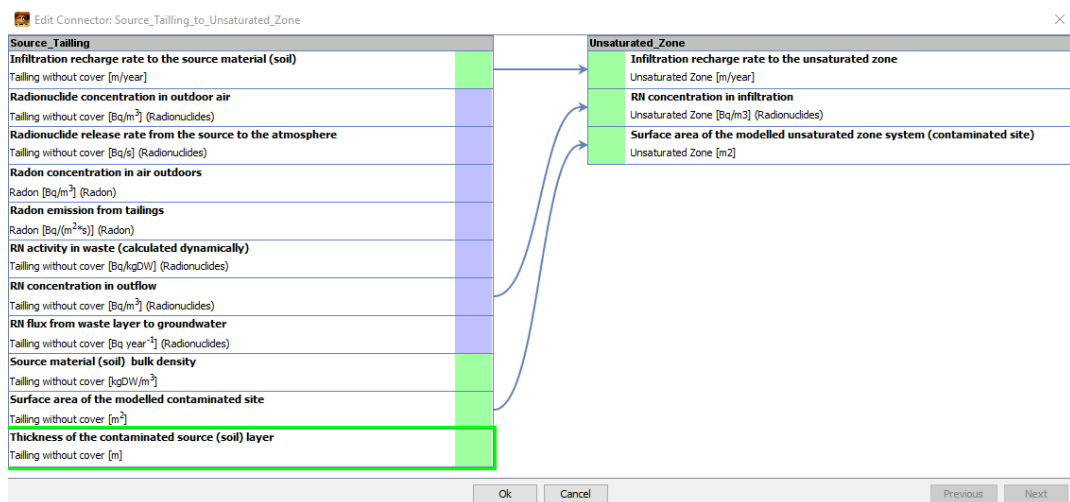

FIG 10. Using '*Edit Connector*' window to set up data exchanges between modules

Repeat similar operations for the "connector" block between **'**Unsaturated Zone' module and **'**Aquifer mixing' module.

3. For these last modules you have to connect the following 'output (left column) – input (right column)' parameter pairs:
    - '*RN concentration in outflow*' and '*RN concentration in infiltration*';
    - '*Infiltration recharge rate to the unsaturated zone*' and '*Infiltration recharge rate to the unsaturated zone*';
    - '*Surface area of the modelled unsaturated zone system (contaminated site)*' and '*Surface area of the modelled unsaturated zone system (contaminated site)*'.

4. Repeat similar operations for the "connector" block between **'**Aquifer mixing' module and **'**Aquifer' module.

5. For these last modules you have to connect the following 'output (left column) – input (right column)' parameter pairs:
    - '*RN concentration in groundwater*' and '*RN concentration in inflowing groundwater*';
    - '*Darcy velocity in the aquifer*' and '*Darcy velocity in the aquifer*';
    - '*Sorption distribution coefficient (radionuclide-specific)*' and '*Sorption distribution coefficient (radionuclide-specific)*';
    - '*flow tube area*' and '*Aquifer (flow tube) cross-section area*';
    Please do not connect the following parameters: '*Initial RN concentration in groundwater*'. You shall not connect these parameters, because these parameters need to have different values for these two modules.

6. Repeat similar operations for the "connector" block between **'**Aquifer' module and **'**Well' module.

7. For these last modules you have to connect the following 'output (left column) – input (right column)' parameter pair:
    - '*RN concentration in outflow GW*' and '*Radionuclide concentration in groundwater originating from the contaminated site*';

8. Lastly, carry out similar operations for the "connector" block between **'**Well' module and **'**Dose from ingestion of water' module.

9. For these last modules you have to connect the following 'output (left column) – input (right column)' parameter pair:
    - '*RN concentration in water*' and '*Concentration of radionuclide in water*'.

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

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 (FIG 11).
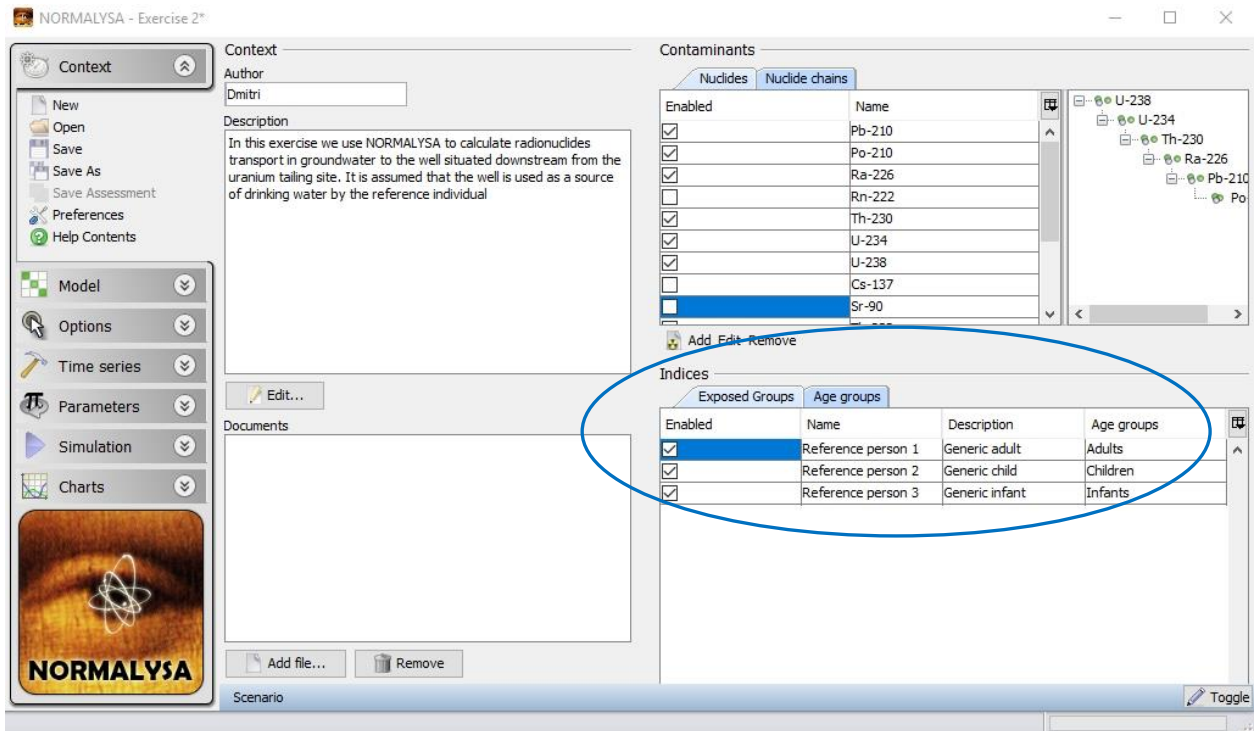
FIG 11. Viewing lists of '*Indices*' of the newly created NORMALYSA model in '*Context*' window.

Browse through the respective tabs to see which index lists have been added to NORMALYSA model. You will see two "index lists": '*Exposed Groups*' and '*Age Groups*'. By default, all available entries in index lists are selected (activated).

In case of Exercise 2, we will need now to use '*Exposed Groups*' index list to define age characteristics of reference persons considered in this exercise.

1. Click the '*Exposed Groups*' tab.
2. Rename the existing group "Reference person 1" to "Adult site visitor". By default, this reference person belongs to '*Age Group*' category '*Adults*'. Do not change this last setting.
3. Deselect remaining reference persons.

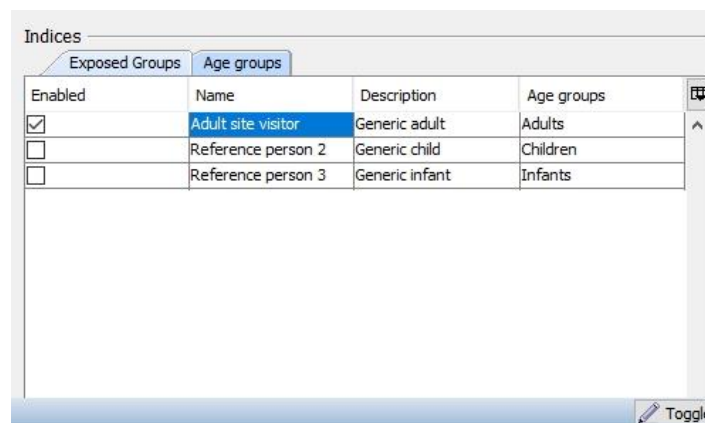The result of adjustments of '*Exposed Groups*' index list are shown in (FIG 12).

FIG 12. 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.

4.3 'Options' and 'Time series' menu positions

In the considered exercise, we do not need to make any inputs or adjustments in '*Options*' and '*Time series*' menu position.

4.4 "Parameters" menu position

Our next task is to define various model parameters. To do so, 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 13).

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 the default values, but for some others you may want to use values specific to your study, and these must be entered. When you input data be careful with parameter units.

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 'Tailing without cover', 'Unsaturated zone', 'Aquifer mixing', 'Aquifer' and 'Dose from ingestion of water', and 'Constants' block where various constants used in the model such as dose conversion coefficients, inhalation rate, etc. are compiled).

Data input for Exercise 2

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

- Select the needed sub-system / module ('Tailing without cover', 'Unsaturated zone', 'Aquifer mixing', 'Aquifer', 'Well' or 'Dose from ingestion of water')
- 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 8 - Table 16 in accordance with the respective sub-systems. 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.

FIG 13. '*Parameters*' window.
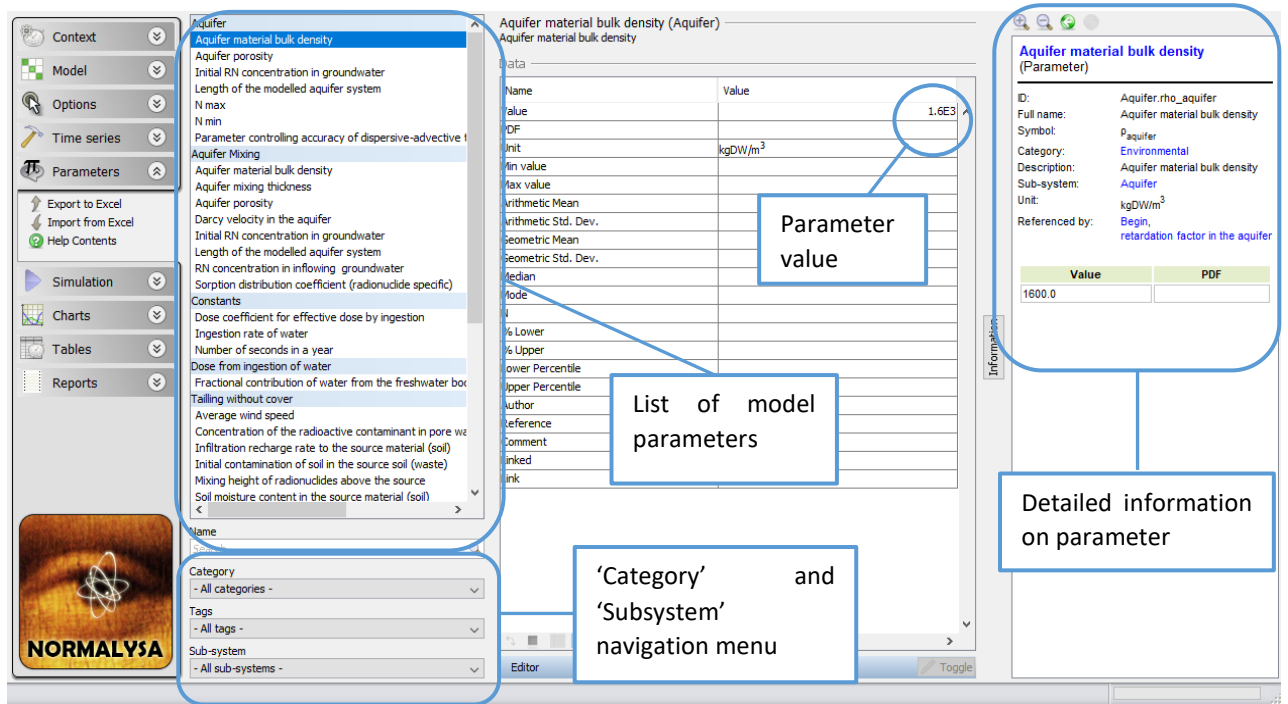
Table 8. Input parameter values for sub-system 'Tailing without cover'.

Parameter	Value	Unit
Infiltration recharge rate to the source material (soil)	0.2	m/year
Soil moisture content in the source material (soil)	0.15	unitless
Source material (soil) bulk density	1600	kg/m^3
Surface area of the modelled contaminated site	40000	m^2
Thickness of the contaminated source (soil) layer	8	m

Table 9. Input parameter values for sub-system 'Tailing without cover' that are radionuclide-specific.

Radionuclide	Initial concentration of RN in the source soil (waste), Bq/kg	Sorption distribution coefficient (radionuclide specific) of source material (soil), m^3/kgDW
Pb-210	17000	3.5
Po-210	21000	2.5
Ra-226	14000	6.3
Th-230	12700	10
U-234	2500	0.005
U-238	2500	0.005

Table 10. Input parameter values for sub-system 'Unsaturated zone'.

Parameter	Value	Unit
Length (depth) of the modelled unsaturated zone system	2	m
Soil bulk density	2000	kg/m^3
Soil moisture content in the unsaturated zone	0.15	unitless

Table 11. Input parameter values for sub-system 'Unsaturated zone' that are radionuclide-specific.

Radionuclide	Initial specific activity of soil, Bq/kg	Sorption distribution coefficient for the Unsaturated zone, m^3/kg
Pb-210	2200	0.5
Po-210	900	0.1
Ra-226	435	0.2
Th-230	510	3
U-234	500	0.003
U-238	500	0.003

Table 12. Input parameter values for sub-system 'Aquifer mixing'.

Parameter	Value	Unit
Aquifer material bulk density	1600	kg/m^3
Aquifer mixing thickness	10	m
Aquifer porosity	0.3	unitless
Darcy velocity in the aquifer	10	m/year
Length of the modelled aquifer system	200	m

Table 13. Input parameter values for sub-system 'Aquifer mixing' that are radionuclide-specific.

Radionuclide	Sorption distribution coefficient (radionuclide specific), Bq/m^3	Initial RN concentration in groundwater, Bq/m^3
Pb-210	0.5	0
Po-210	0.1	0
Ra-226	0.2	200
Th-230	3	0
U-234	0.01	350000
U-238	0.01	350000

Table 14. Input parameter values for sub-system 'Aquifer'.

Parameter	Value	Unit
Aquifer material bulk density	1600	kg/m^3
Aquifer porosity	0.3	unitless
Length of the modelled aquifer system	200	m

Table 15. Input parameter values for sub-system 'Well'.

Parameter	Value	Unit
Well debit fraction formed by contaminated groundwater originating from the contaminated site	1.0	unitless

Table 16. Input parameter values for sub-system 'Constants'.

Parameter	Value	Unit
Ingestion rate of water (Exposed group: '*Adult site visitor*')	0.37	m^3/year

Table 17. Input parameter values for sub-system 'Dose from ingestion of water'.

Parameter	Value	Unit
Fractional contribution of water from the freshwater body receptor to the total ingestion of water (Exposed group: '*Adult site visitor*')	0.25	unitless

4.5 '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

We need to adjust the simulation time to 1000 years, and the time step of the output needs to be set to 100 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. Set '*End time*' to 1000.0 ('*Years*') (FIG 14).
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 14). (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 15.
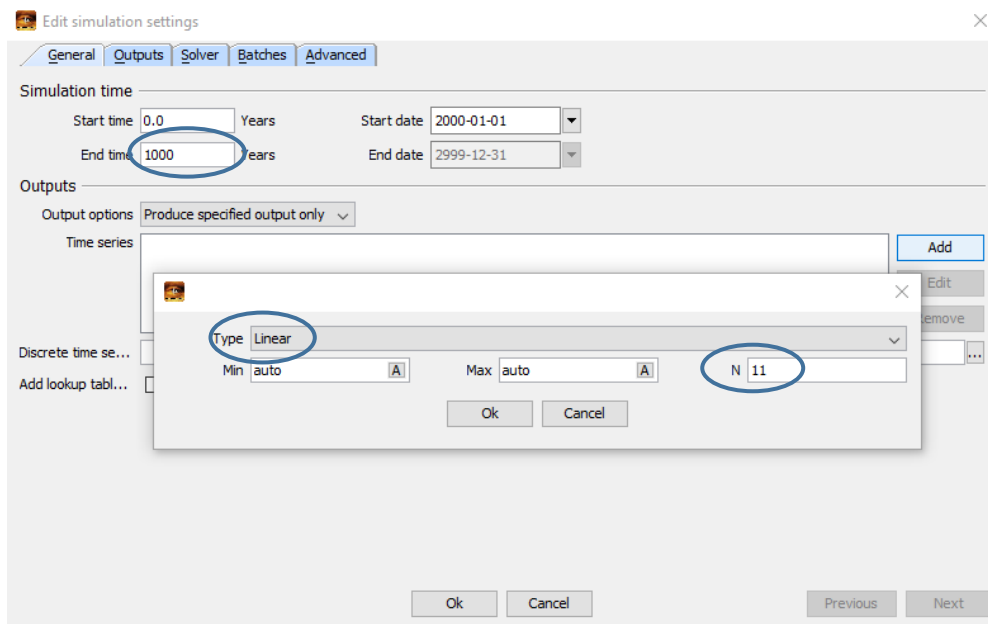

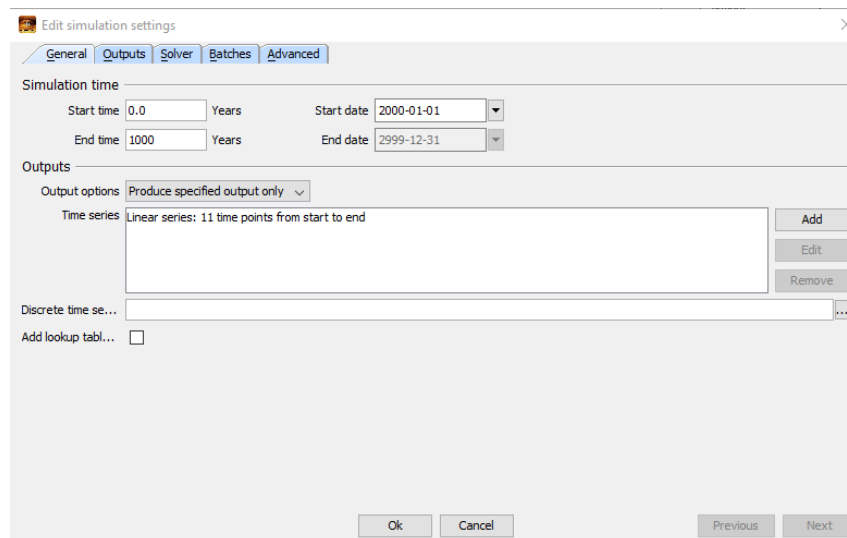FIG 14. Adjusting of the '*Simulation time*' and '*Outputs*' parameters.

FIG 15. 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 modelling results upon completion of simulation.

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 '*Well'* sub-system, select the '*RN concentration in water*' parameter, and click '**>**' button.

4. Repeat the same operations with the following parameters from the '*Dose from ingestion of water*' sub-system: '*Dose from ingestion of water for each radionuclide*' and '*Dose from ingestion of water summed over all radionuclides*'.

5. The resulting '*Edit Simulation Settings*' window with selected list of output parameters is shown in FIG 16.
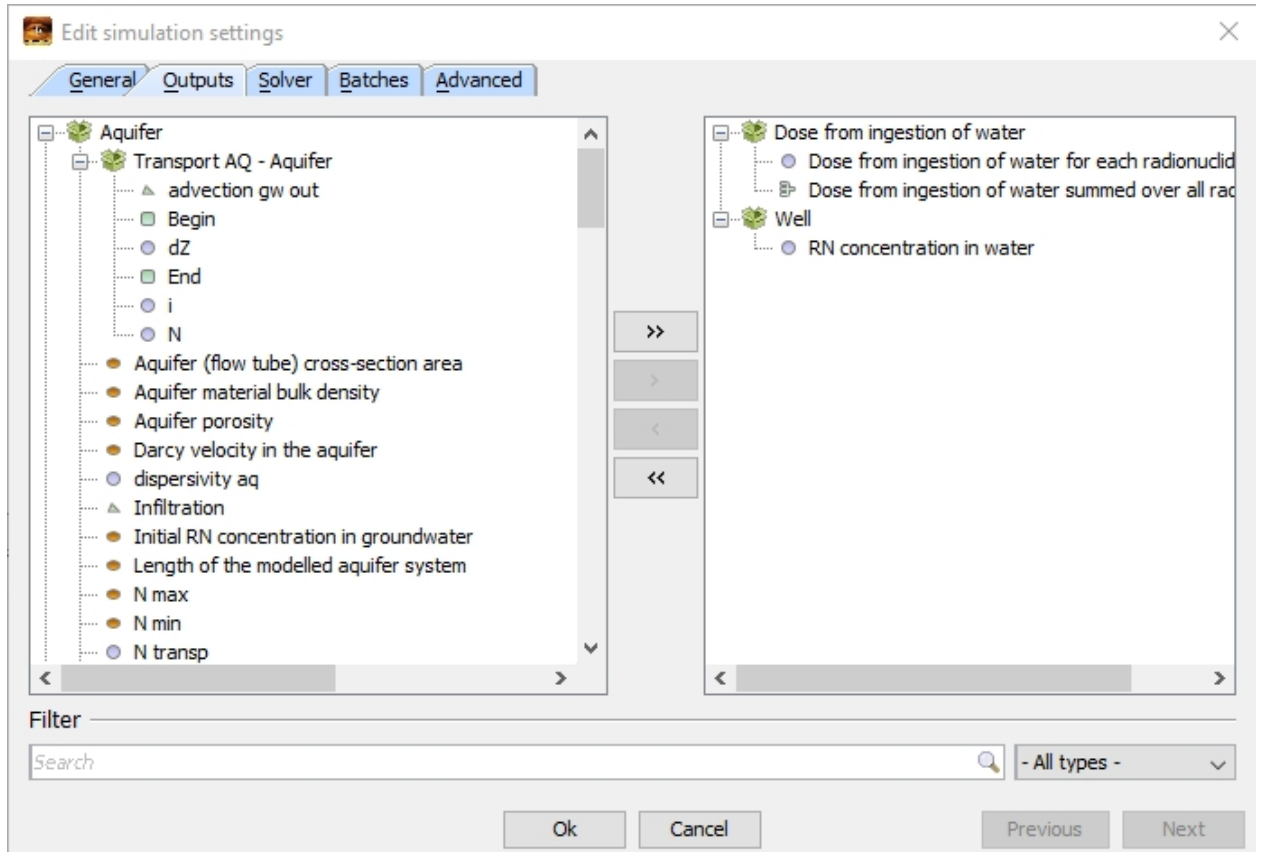

FIG 16. '*Edit Simulation Settings*' window with selected list of output parameters.

Running the model

Click the '*Run*' button in the upper corner to perform the simulation (FIG 17).

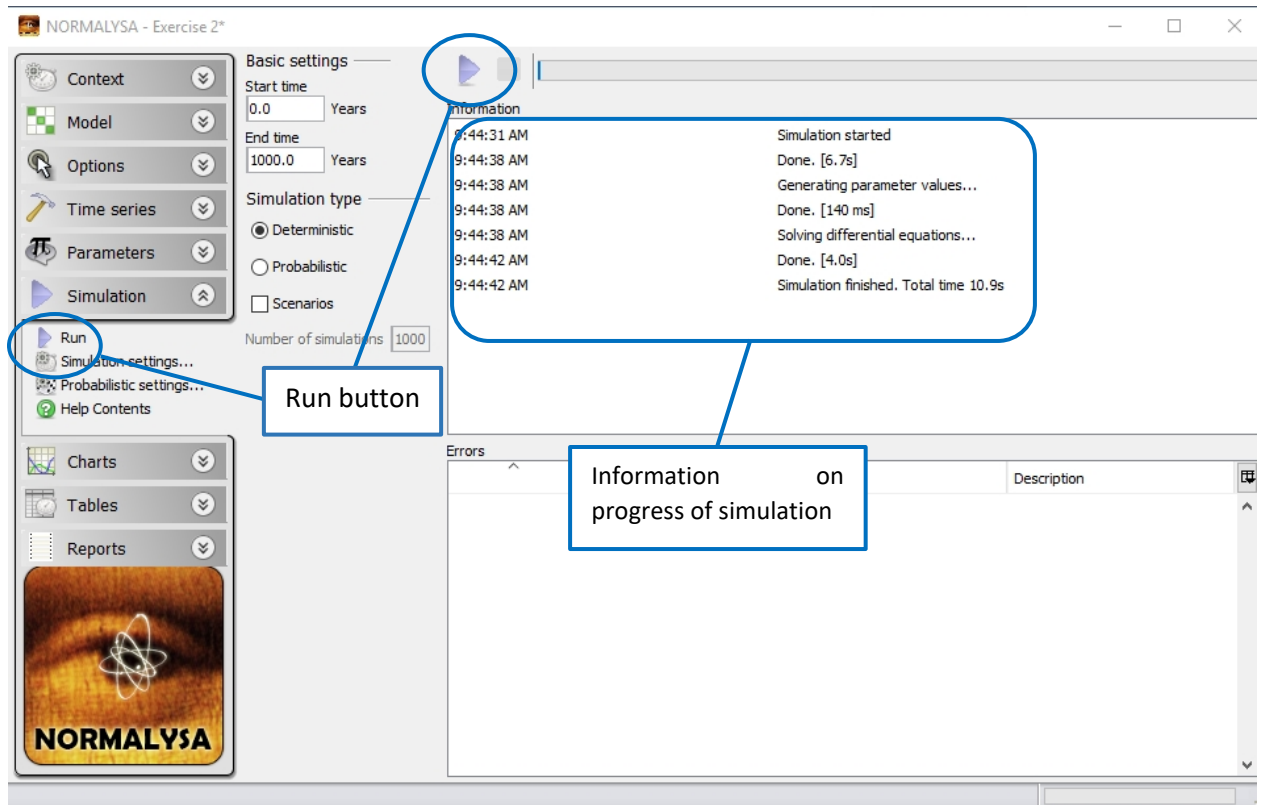The '*Information*' window will display information on the progress of simulation process.

FIG 17. Running the NORMALYSA model.

4.6 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*', 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 calculated dose from ingestion of water to reference person considered in this exercise.

1. Select with the left mouse button in the window of simulation results the output parameter '*Doses from ingestion of water summed over all radionuclides*' inside the '*Dose from ingestion of water'* folder.
2. Tag '*All*' box (from the index list of exposed groups) that will be displayed immediately below the window with the simulation results.
3. The time table displaying results of dose calculations for drinking water pathway will be shown in '*Quick View*' window (FIG 18).
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 cab be carried out to display in table format simulation results for radionuclide concentrations in groundwater. To do so, the following output parameters have to be selected: '*RN concentration in water*' ('Well' sub-system), and '*All*' box needs to be tagged in the index list of nuclides 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.
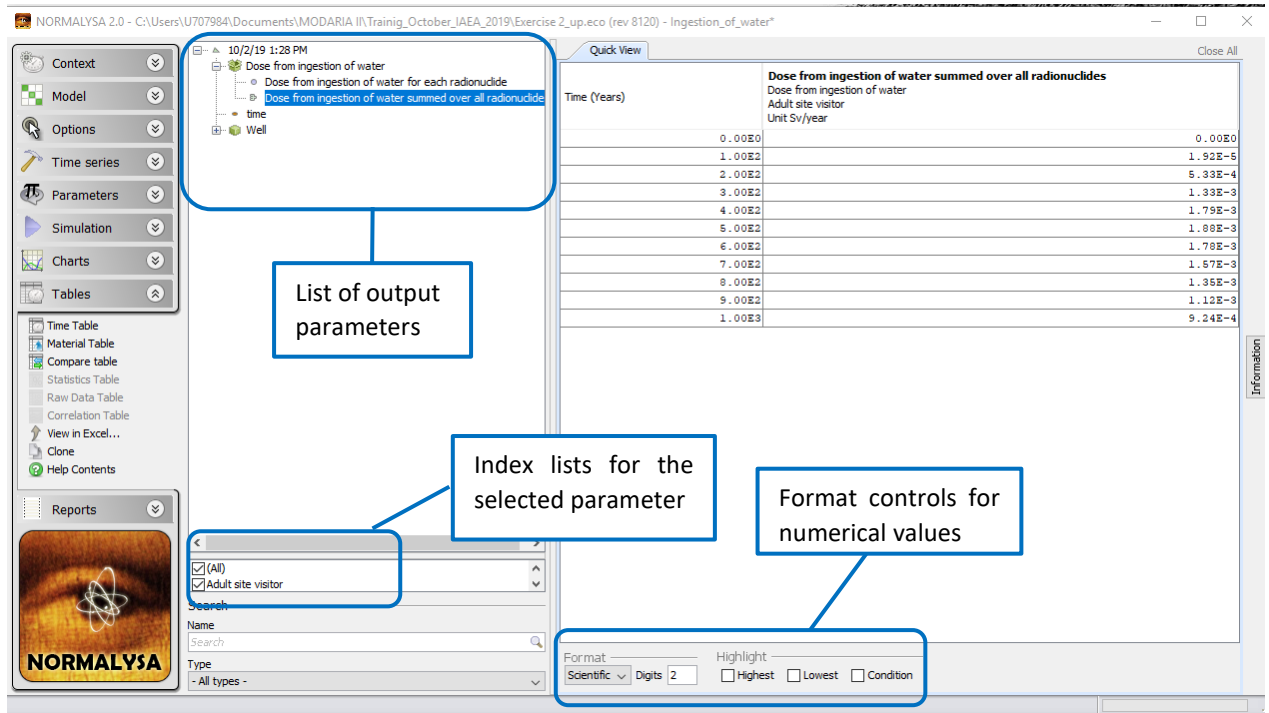
FIG 18. Displaying the table with the calculated doses from ingestion of water to reference persons considered in Exercise 2.

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*', 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 radionuclide concentrations in the well water.

1. Select with the left mouse button in the window of simulation results the output parameter '*RN concentration in water*' inside the '*Well*' folder.
2. Tag '*All*' box (in the index lists of radionuclides) that will be displayed immediately below the window with the simulation results.
3. The time graph displaying radionuclide concentrations in well will be shown in '*Quick View*' window.
4. Select the '*Bottom*' option for legend location in '*Plot*' window below the chart.'
5. Select the '*Log Y*' option below the chart.

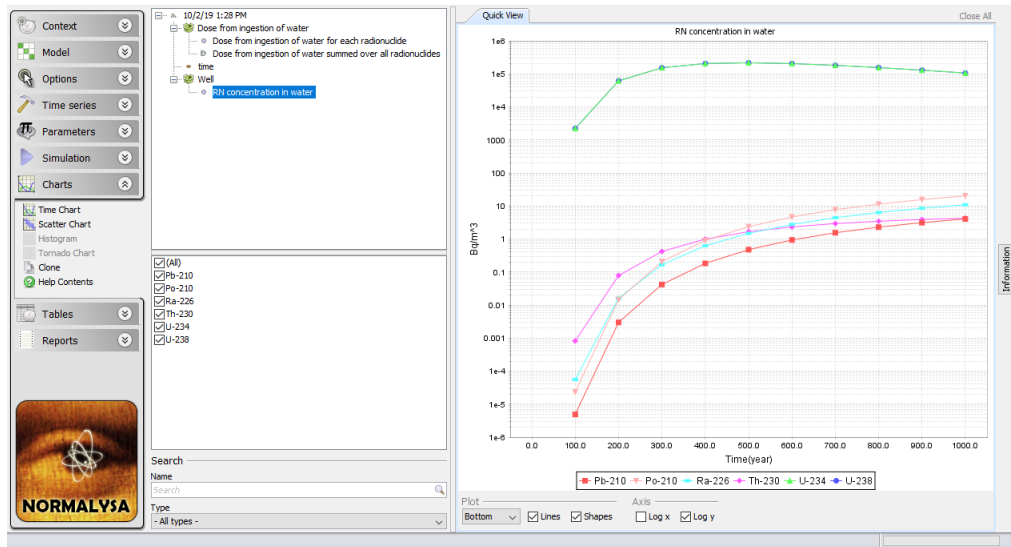The resulting time graph of radionuclide concentrations in well is shown in FIG 19 .

FIG 19. Displaying in chart format simulated radionuclide concentrations in the well water for Exercise 2.

5. Results of calculations

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

5.1 Radionuclide concentrations in well

Simulation results for radionuclide concentrations in well are shown in Table 18. It can be seen that groundwater concentrations (and respectively doses for drinking water pathway, see next paragraph) are dominated by uranium isotopes. Maximum U-238 and U-234 concentrations in well water reach ~ 2.2E5 Bq/m^3 (220 Bq/L) in 500 years from the beginning of simulation.

Table 18. Simulated radionuclide concentrations in well water for Exercise 2.

Time, years	Radionuclide concentration, Bq/m^3					
	Pb-210	Po-210	Ra-226	Th-230	U-234	U-238
0	0.0	0.0	0.0	0.0	0.0	0.0
100	0.0	0.0	0.0	0.0	2.21E+03	2.21E+03
200	0.0	0.0	0.0	0.1	6.14E+04	6.14E+04
300	0.0	0.2	0.2	0.4	1.53E+05	1.53E+05
400	0.2	0.9	0.6	1.0	2.05E+05	2.05E+05
500	0.5	2.4	1.5	1.7	2.17E+05	2.17E+05
600	0.9	4.6	2.8	2.3	2.04E+05	2.04E+05
700	1.5	7.7	4.4	2.9	1.81E+05	1.81E+05
800	2.3	11.4	6.3	3.4	1.55E+05	1.55E+05
900	3.1	15.6	8.5	3.9	1.29E+05	1.29E+05
1000	4.0	20.2	10.9	4.3	1.06E+05	1.06E+05

5.2 Dose from ingestion of water

Simulation results for total dose are shown in Table 19. It can be seen that the maximum dose to reference individual due to drinking water from well is 1.9 mSv/year (in 500 years).

Table 19. Simulated total dose from drinking water pathway in Exercise 2.

Time, years	Dose, Sv/year
0	0
100	1.92E-05
200	5.33E-04
300	1.33E-03
400	1.79E-03
500	1.88E-03
600	1.78E-03
700	1.57E-03
800	1.35E-03
900	1.12E-03
1000	9.24E-04

6. Exercise for independent work

Include to the list of exposed groups a child (in addition to adult). Calculate doses to these exposed groups (adult, child) assuming fractional contribution of water from well to their yearly drinking water consumption is 50%, and that the distance from the radionuclide source (tailings) to well is 300 m.