

EXERCISE 3: CALCULATION OF RADON TRANSPORT IN THE ATMOSPHERE FROM URANIUM TAILING SITE AND RESULTING INHALATION DOSES TO REFERENCE INDIVIDUALS

1. General description of problem

In this exercise we use NORMALYSA to calculate inhalation doses to reference persons due to atmospheric dispersion of radon from the uranium tailing site.

1.1 Contamination source term (contaminated site)

The source of radioactivity releases to atmosphere is uranium mill tailing site containing radionuclides of U-238 decay series including Ra-226. The tailings site is not covered by soil cover. The radon gas (Rn-222 that is the progeny of Ra-226) exhales from the tailings surface and is transported in atmosphere to the downwind receptor location (FIG 1).

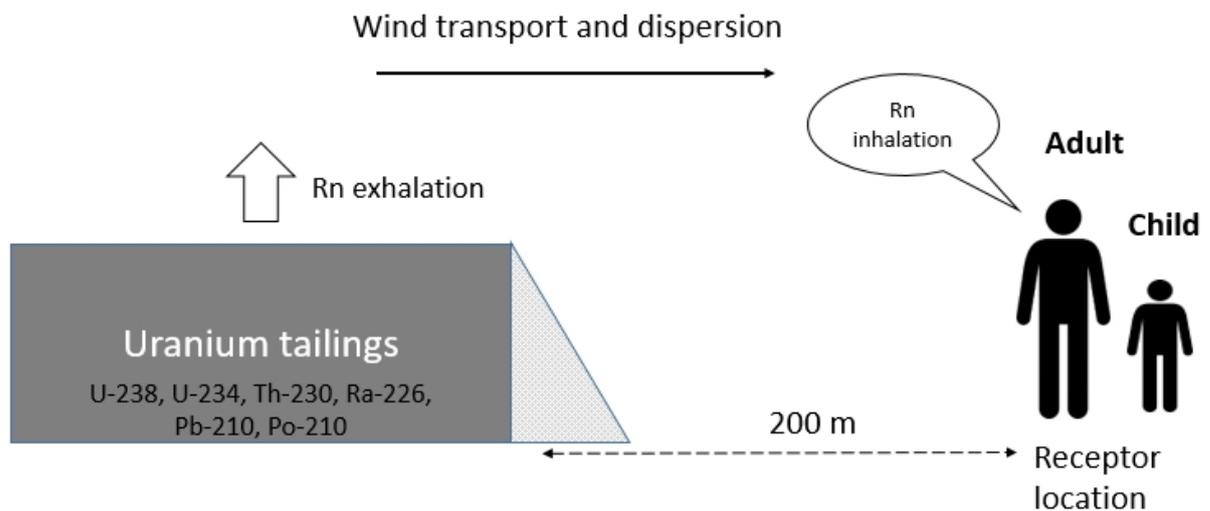


FIG 1. Illustrative scheme of atmospheric transport of radon from uranium tailing site.

1.2 Reference persons and exposure scenario

The reference individuals for dose calculations are: 1) an adult, and 2) a child, who are locals that are exposed to radon through inhalation pathway.

The exposure of reference persons occurs at outdoor location at the distance of 200 meters downwind from the tailings site (park area).

The adult is exposed to radon occasionally during a year, while the child spends more time outdoors in the receptor location. Additional details on exposure scenario are provided in Section 2.

1.3 Calculation end-points

The calculation end-points for this exercise are:

- Rn-222 concentration in the air above the source (uranium tailings) and at 200 m downwind receptor location;
- Annual effective doses from inhalation of Rn-222 received by reference individuals for the described above exposure scenario.

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 site (Table 1 and Table 2), parameters of atmospheric transport process (Table 3) and habits of reference persons (Table 4).

Table 1. Parameters of uranium tailings site

| Parameter | Value | Unit |
|---|----------|-------------------|
| Waste site area | 10000 | m ² |
| Thickness of waste layer | 5 | m |
| Waste moisture content | 0.15 | unitless |
| Waste bulk density | 2000 | kg/m ³ |
| Infiltration recharge rate | 0.3 | m/year |
| Average annual wind speed | 3 | m/s |
| Radon diffusion coefficient in source (soil) material | 0.000002 | m ² /s |
| Radon emanation coefficient from source (soil) material | 0.2 | unitless |

Table 2. Specific activity of waste and Kd values of different radionuclides.

| Radionuclide | Specific activity in waste, Bq/kg | Sorption distribution coefficient for waste (Kd), m ³ /kg |
|--------------|-----------------------------------|--|
| U-238 | 3000 | 0.1 |
| U-234 | 3000 | 0.1 |
| Th-230 | 15000 | 0.5 |
| Ra-226 | 15000 | 0.2 |
| Rn-222 | 0 | 0 |
| Po-210 | 15000 | 0.1 |
| Pb-210 | 15000 | 2.0 |

Table 3. Parameters of the atmospheric transport process

| Parameter | Value | Unit |
|---|-------|----------|
| Distance from the source of release to receptor point | 200 | m |
| The fraction of the time during the year that the wind blows towards the receptor | 0.25 | unitless |
| Height of release | 0 | m |
| The geometric mean of the wind speed at the height of release (yearly average) | 3 | m/s |
| Mixing height for Rn above the source | 2 | m |

Table 4. Habits of reference individuals.

| Reference person | Duration of exposure to Rn-222 |
|------------------|--|
| Adult | 6 weeks per year, 8 hours per day outdoors |
| Child | 4 hours per day during the whole 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 and radon release to atmosphere,
- ‘Atmosphere SR-19’ module from ‘Transports’ library – to model radon dispersion in atmosphere from source to receptor location, and
- ‘Dose from occupancy outdoors’ module from ‘Doses’ library to calculate doses to reference individuals from inhalation of radon at receptor location.

3.2 Model structure and data exchanges between modules

The structure of NORMAYSA model for Exercise 1a in the form of block-scheme is shown in FIG 2.

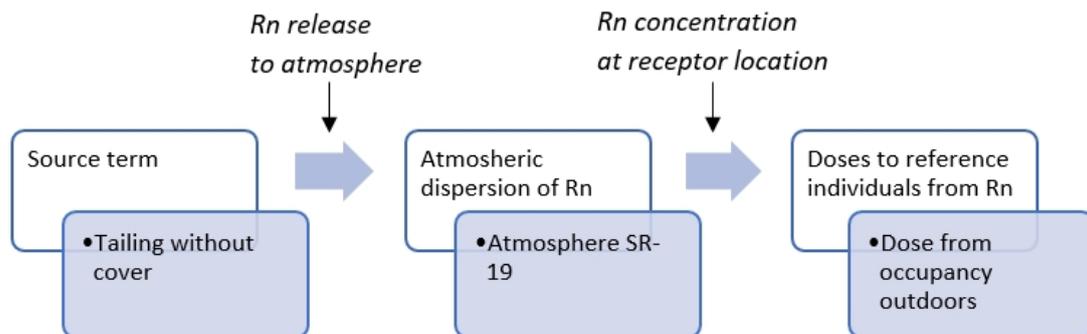


FIG 2. NORMALYSA model structure for Exercise 3.

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 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.

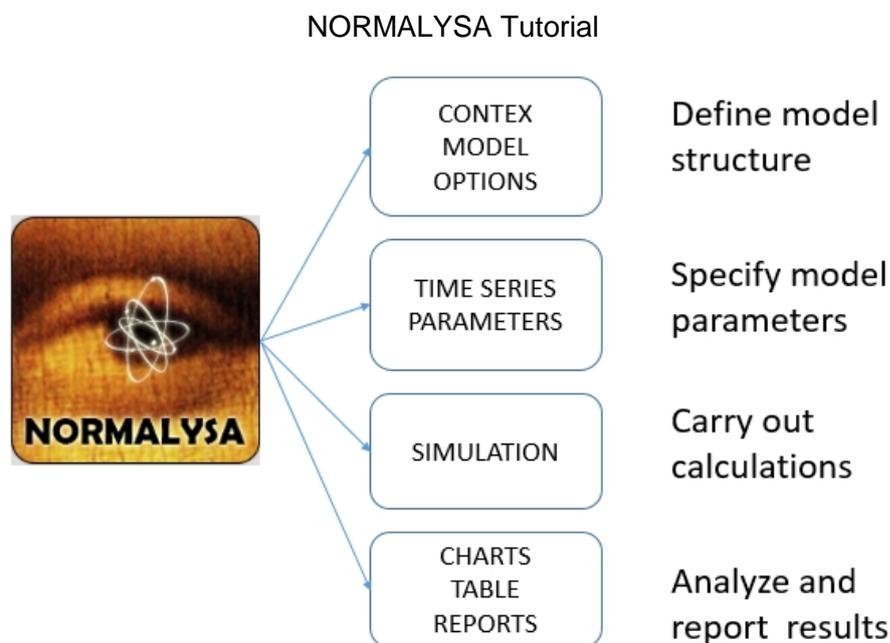


FIG 3. Sequence of modelling steps.

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 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 Content*' 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

As already discussed, in this exercise we will get experience in using the following modules: ‘Tailing without cover’ from ‘Sources’ library (for the source-term for Rn release to atmosphere), ‘Atmosphere SR-19’ from ‘Transports’ library (for Rn dispersion in atmosphere), and ‘Dose from occupancy outdoors’ from the ‘Doses’ library (for dose assessment).

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 3”), 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.

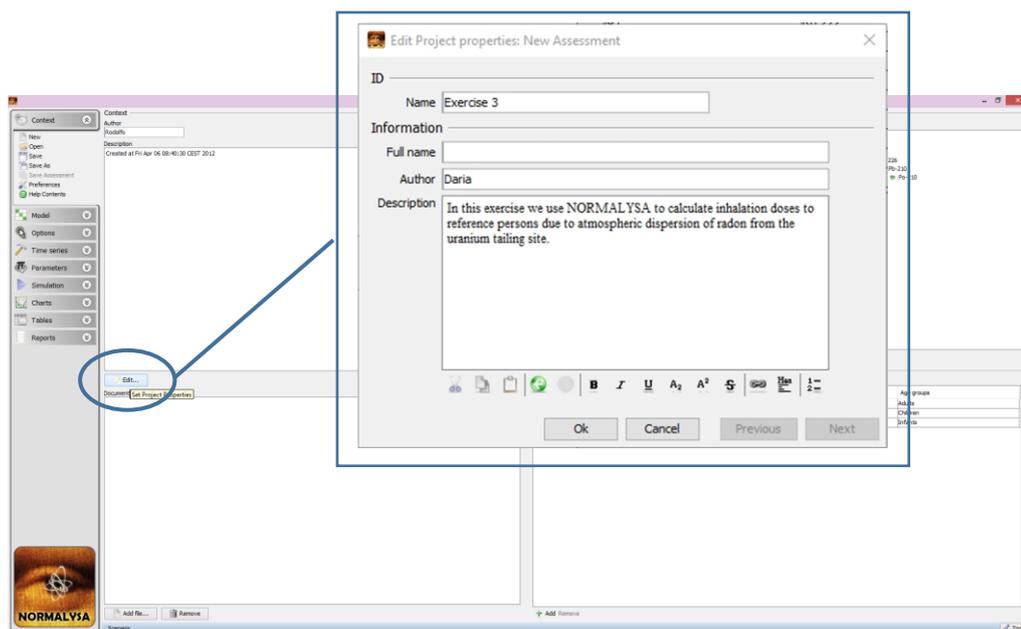


FIG 4. Editing ‘Project properties’ window.

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.

As Rn-222 belongs to U-238 decay chain, the whole radionuclide decay chain needs to be included to the considered model. To do so, first disable all radionuclides in the ‘Nuclides’ window. Then select U-238 (its whole decay chain will be selected automatically) and Rn-222 (FIG 5).

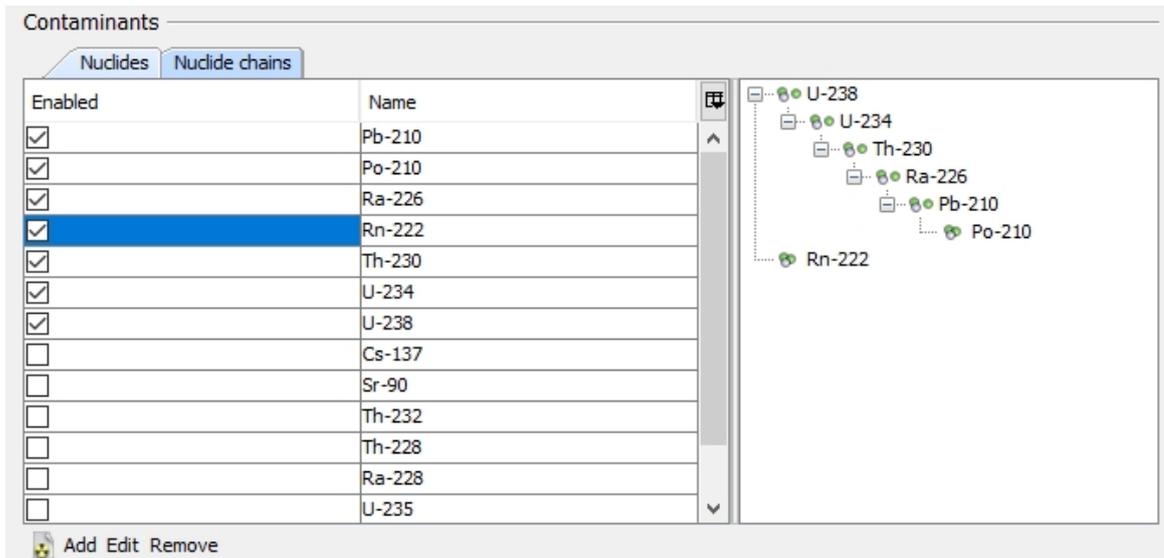


FIG 5. ‘Contaminants’ window with selected radionuclides for Exercise 3.

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).

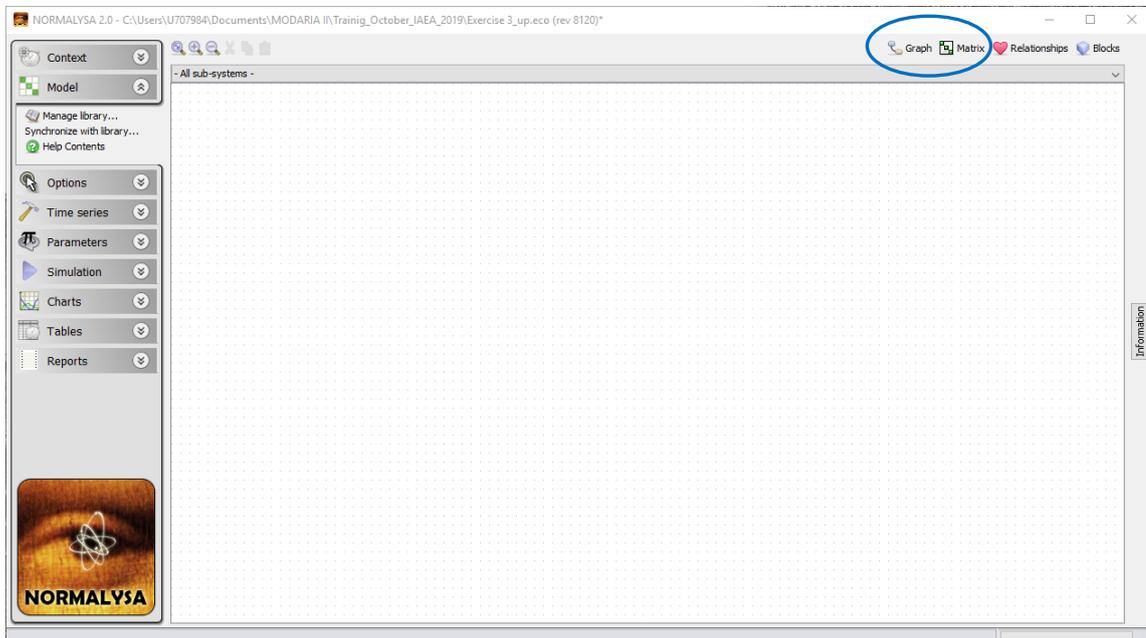


FIG 6. Tabs corresponding to different options (‘Graph’, ‘Matrix’) of model visualization.

Next to the ‘Graph’ button (which is selected by default), you find the ‘Matrix’ button. Click on it to select the “matrix view”.

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Now we will compose the NORMALYSA model for Exercise 3 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).
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 ‘*Atmosphere SR-19*’ module from ‘*Transports*’ library.
6. Repeat steps 1 – 4 to insert on the diagonal of the matrix the ‘*Dose from occupancy outdoors*’ module from the sub-folder ‘*Doses from occupancy*’ in ‘*Doses*’ library.

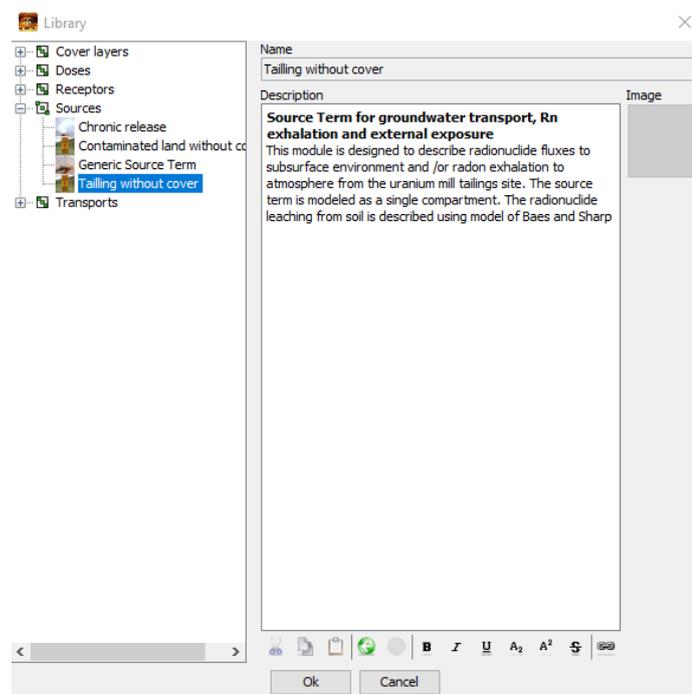


FIG 7. ‘*Library*’ window showing the explanatory text for the ‘*Tailings without cover*’ module from the ‘*Sources*’ library.

Now we need to connect individual modules in-between each other using “connector” blocks to exchange data. The “connector” blocks need to be inserted between ‘*Tailings without cover*’ and ‘*Atmosphere SR-19*’ modules, and between ‘*Atmosphere SR-19*’ and ‘*Dose from occupancy outdoors*’ modules. This shall be done to allow data exchanges in accordance with the block-scheme shown at FIG 2.

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.

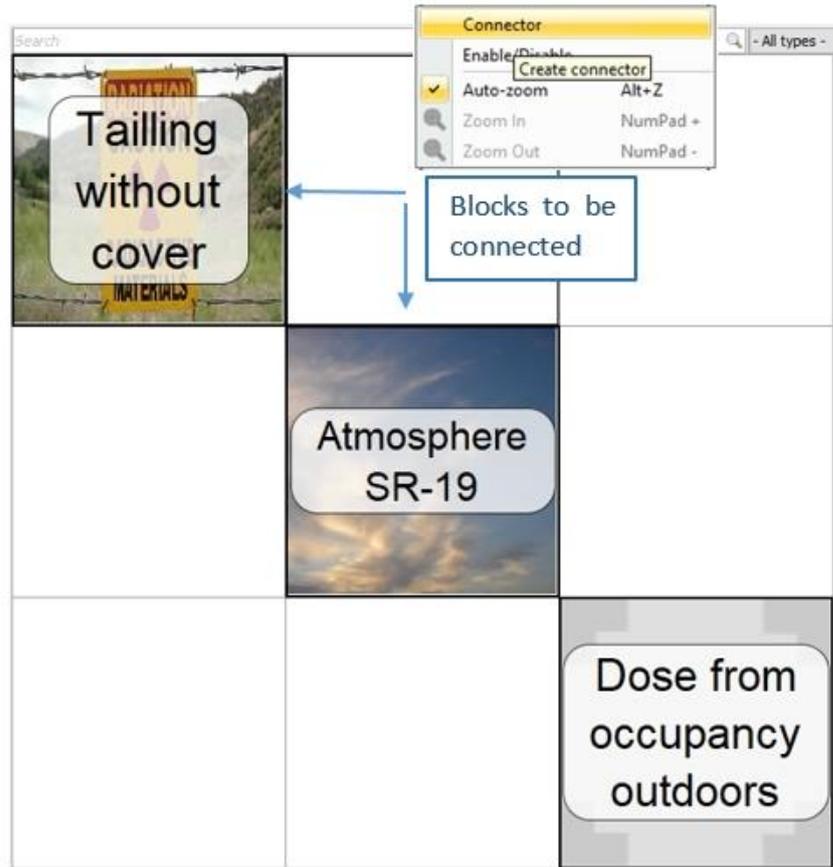


FIG 8. Connecting modules using “connector” blocks for data exchanges.

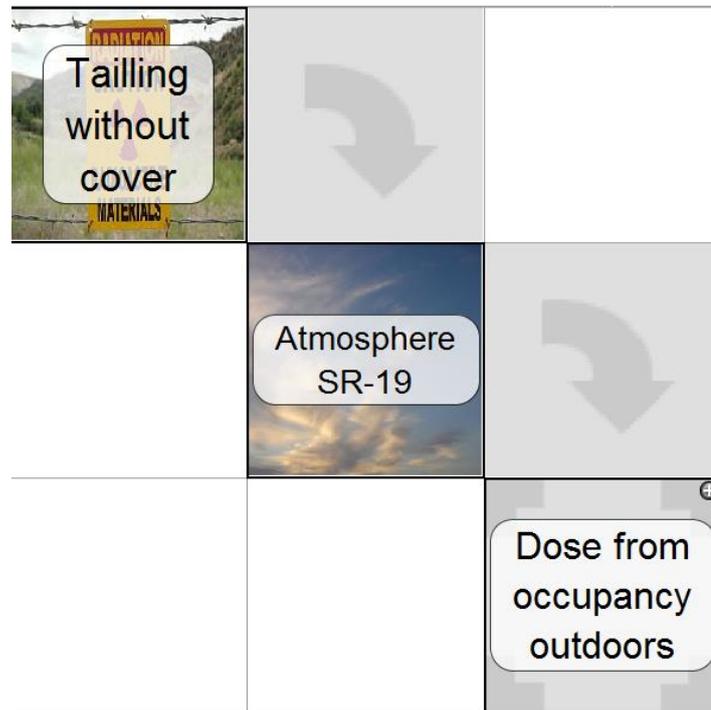


FIG 9. Full model for Exercise 3 including main modules and “connectors” in ‘Matrix’ view.

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 ‘Tailings without cover’ and ‘Atmosphere SR-19’ modules. The ‘*Edit Connector*’ window will be opened allowing setting 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 ‘Atmosphere SR-19’ 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 pair: ‘*Radionuclide release rate from the source to the atmosphere*’ and ‘*Release rate at the release point*’. Please note that connected parameters need to have same units.

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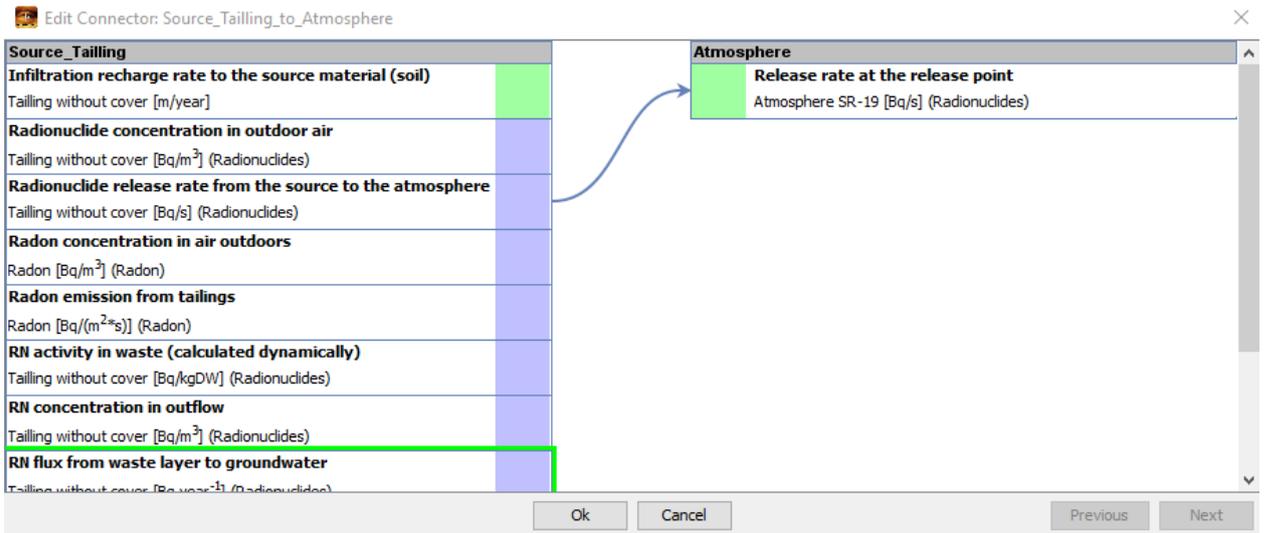


FIG 10. Using ‘*Edit Connector*’ window to set up data exchanges between modules

3. Repeat similar operations for the “connector” block between ‘Atmosphere SR-19’ 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 pair: ‘*Ground level air concentration*’ and ‘*Concentration of radionuclide in outdoor air*’.

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).

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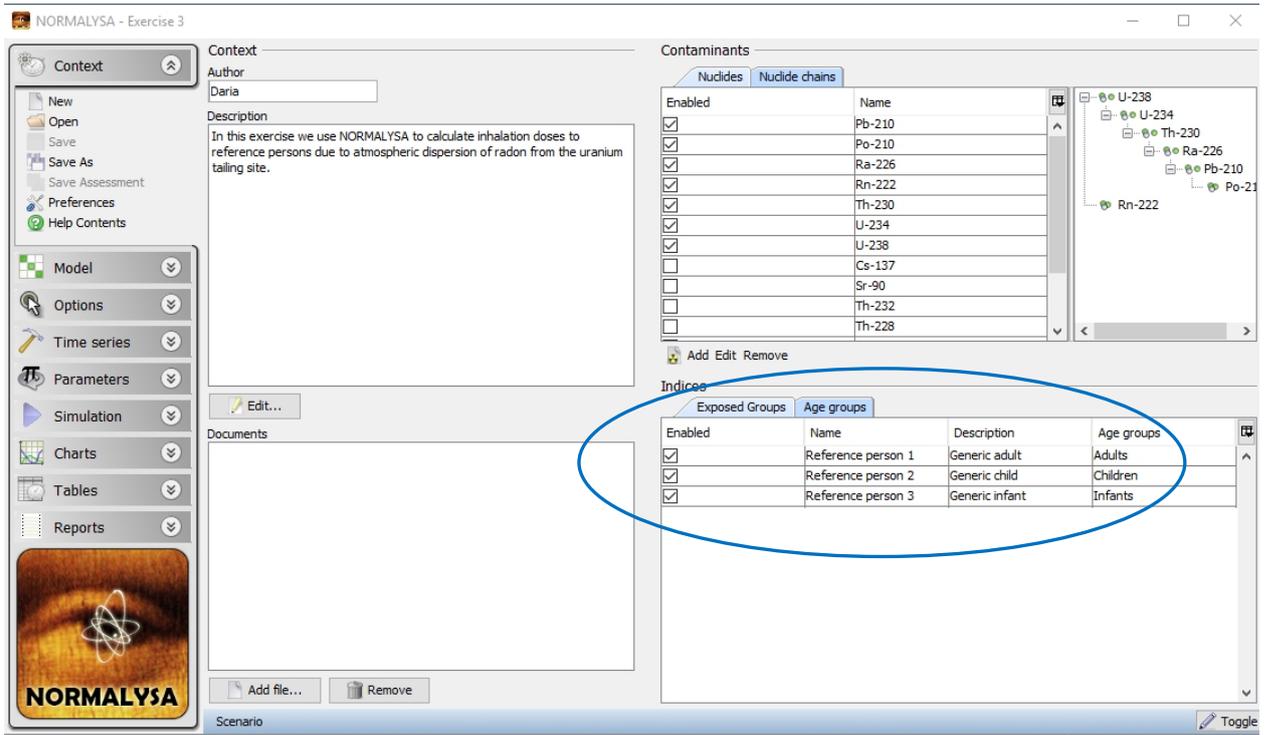


FIG 11. Viewing lists of 'Indices' of the newly created NORMALYSA model in 'Context' window.

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 3, we will need 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 resident". 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 resident". 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 is shown in FIG 12.

| Enabled | Name | Description | Age groups |
|-------------------------------------|--------------------|----------------|--------------------------------|
| <input checked="" type="checkbox"/> | Adult resident | Generic adult | <input type="radio"/> Adults |
| <input checked="" type="checkbox"/> | Child resident | Generic child | <input type="radio"/> Children |
| <input type="checkbox"/> | Reference person 3 | Generic infant | <input type="radio"/> Infants |

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’/’Tailings without cover – Radon’, ‘Atmosphere SR-19’, ‘Dose from occupancy outdoors’, and ‘Constants’ block where various constants used in the model such as dose conversion coefficients, inhalation rate, etc. are compiled).

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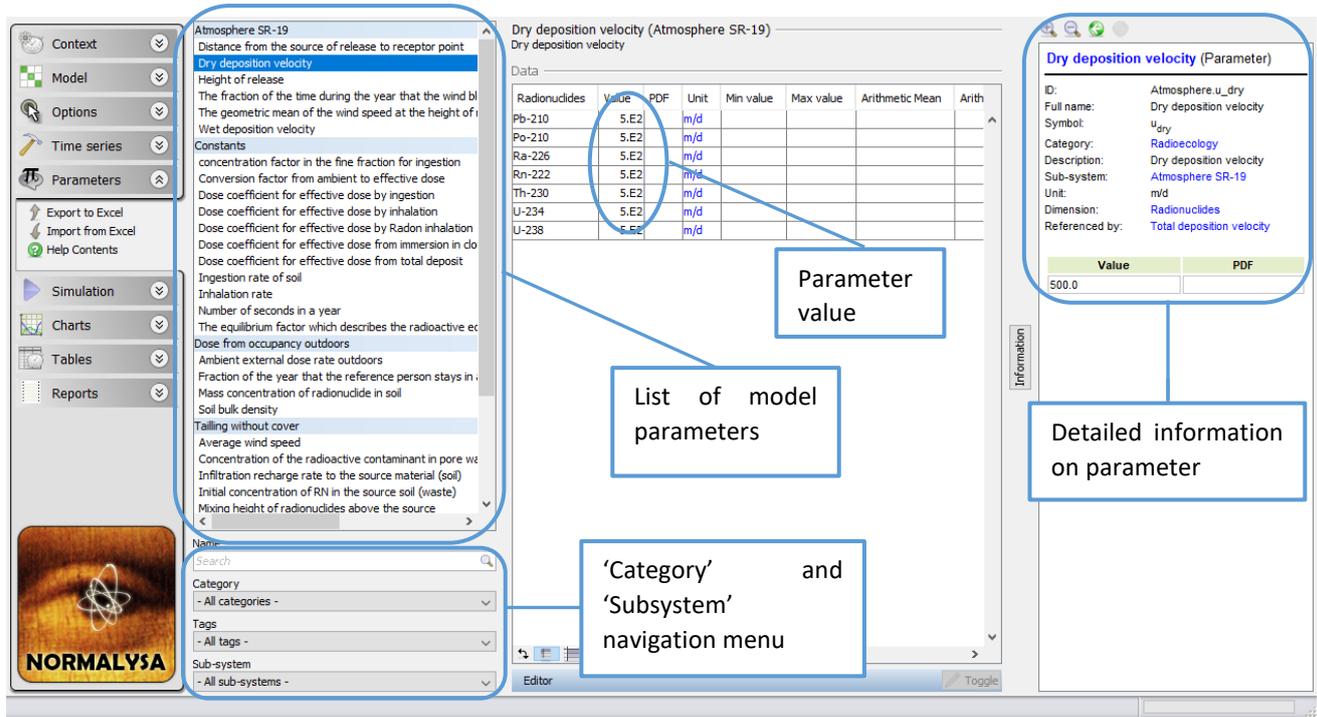


FIG 13. 'Parameters' window.

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

Conversion of units for time of exposure of reference persons

The NORMALYSA model for Exercise 3 requires as an input parameter defining the time of exposure of reference person is expressed as '*Fraction of the year that the reference person stays in a specific receptor*'.

Initially, time of exposure was provided as a number of hours (see Section 2). So, we have to recalculate this parameter to the needed unit.

For the "Adult resident" the resulting parameter value is:

$$Time_{fraction.year} [Adult\ resident] = (42\ days \times 8\ hours/day) / (365.25\ days/year \times 24\ hours/day) = 0.038$$

For the "Child resident" this parameter is calculated as follows:

$$Time_{fraction.year} [Child\ resident] = 4\ hours / 24\ hours = 0.17$$

Data input for Exercise 3

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

- Select the needed sub-system / module ('Tailing without cover'/'Tailings without cover – Radon', 'Atmosphere SR-19' or 'Dose from occupancy outdoors')
- 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

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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.

Table 5. Input parameter values for sub-system ‘Tailing without cover’.

| Name | Value | Unit |
|--|-------|-------------------|
| Average wind speed | 3 | m/s |
| Infiltration recharge rate to the source material (soil) | 0.3 | m/year |
| Mixing height of radionuclides above the source | 2 | m |
| Soil moisture content in the source material (soil) | 0.15 | unitless |
| Source material (soil) bulk density | 2000 | kg/m ³ |
| Surface area of the modelled contaminated site | 10000 | m ² |
| Thickness of waste layer | 5 | m |

Table 6. Input parameter values for sub-system ‘Tailing without cover’ that are radionuclide-specific.

| Radionuclide | Parameter and unit | |
|--------------|---|---|
| | Initial concentration of RN in the source soil (waste), Bq/kg | Sorption distribution coefficient (radionuclide specific) of source material (soil), m ³ /kg |
| U-238 | 3000 | 0.1 |
| U-234 | 3000 | 0.1 |
| Th-230 | 15000 | 0.5 |
| Ra-226 | 15000 | 0.2 |
| Rn-222 | 0 | 0 |
| Po-210 | 15000 | 0.1 |
| Pb-210 | 15000 | 2.0 |

Table 7. Input parameter values for sub-system ‘Tailing without cover - Radon’.

| Name | Value | Unit |
|---|----------|-------------------|
| Radon diffusion coefficient in source (soil) material | 0.000002 | m ² /s |
| Radon emanation coefficient from source (soil) material | 0.2 | unitless |

Table 8. . Input parameter values for sub-system ‘Atmosphere SR-19’.

| Name | Value | Unit |
|--|-------|----------|
| Distance from the source of release to receptor point | 200 | m |
| Height of release | 0 | m |
| The fraction of the time during the year that the wind blows | 0.25 | unitless |
| The geometric mean of the wind speed at the height of release (yearly average) | 3 | m/s |

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

| Reference person | Parameter: Fraction of the year that the reference person stays in a specific receptor (unitless) |
|------------------|---|
| Adult resident | 0.038 |
| Child resident | 0.17 |

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.

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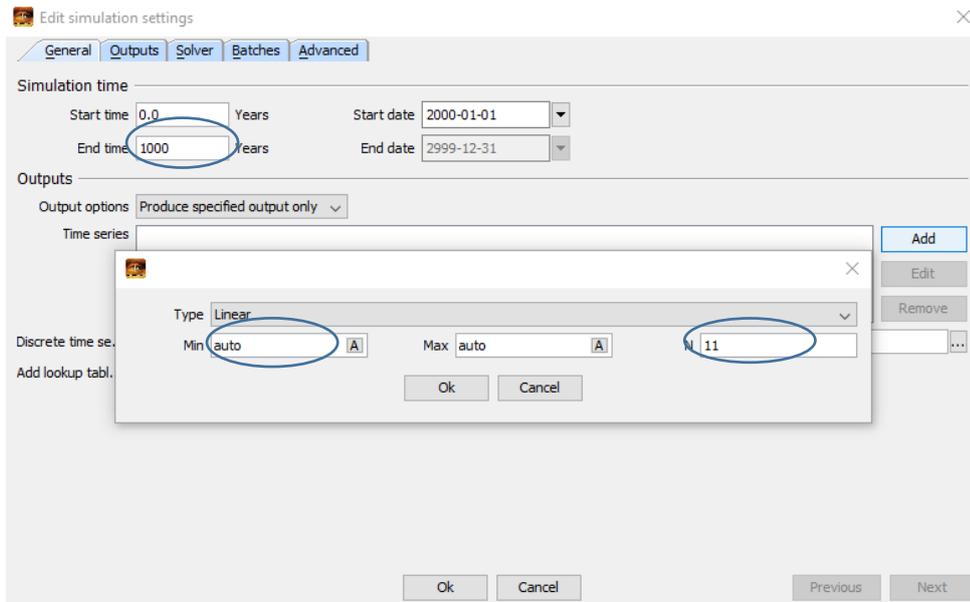


FIG 14. Adjusting of the ‘*Simulation time*’ and ‘*Outputs*’ parameters.

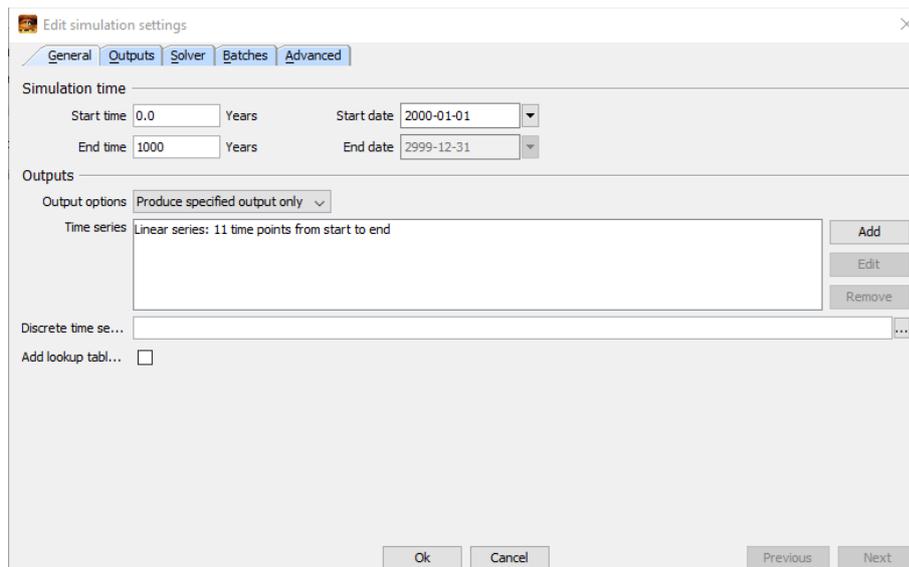


FIG 15. The resulting ‘*Simulation time*’ and ‘*Outputs*’ parameters settings.

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.

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3. Choose in the left window the module '*Tailings without cover*', then sub-tree '*Radon - Tailings without cover*', and select the '*Rn concentration in the air*' parameter, and click '>' button.
4. Repeat the same operations with the following parameters: '*Ground level air concentration*' (from the '*Atmosphere SR-19*' sub-system) and '*Dose from inhalation outdoors for each radionuclide*' (from the '*Inhalation - Dose from occupancy outdoors*' sub-folder from the '*Dose from occupancy outdoors*' sub-system).
5. The resulting '*Edit Simulation Settings*' window with selected list of output parameters is shown in FIG 16.

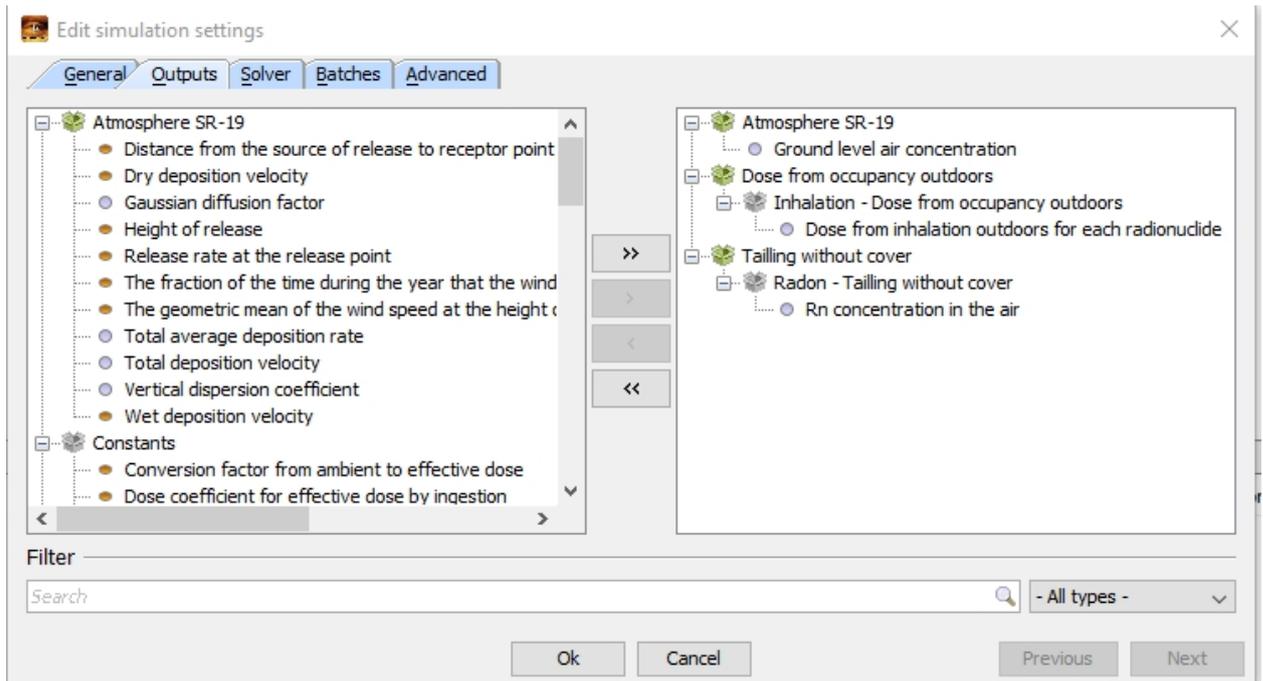


FIG 16. '*Edit Simulation Settings*' window with selected list of output parameters.

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.

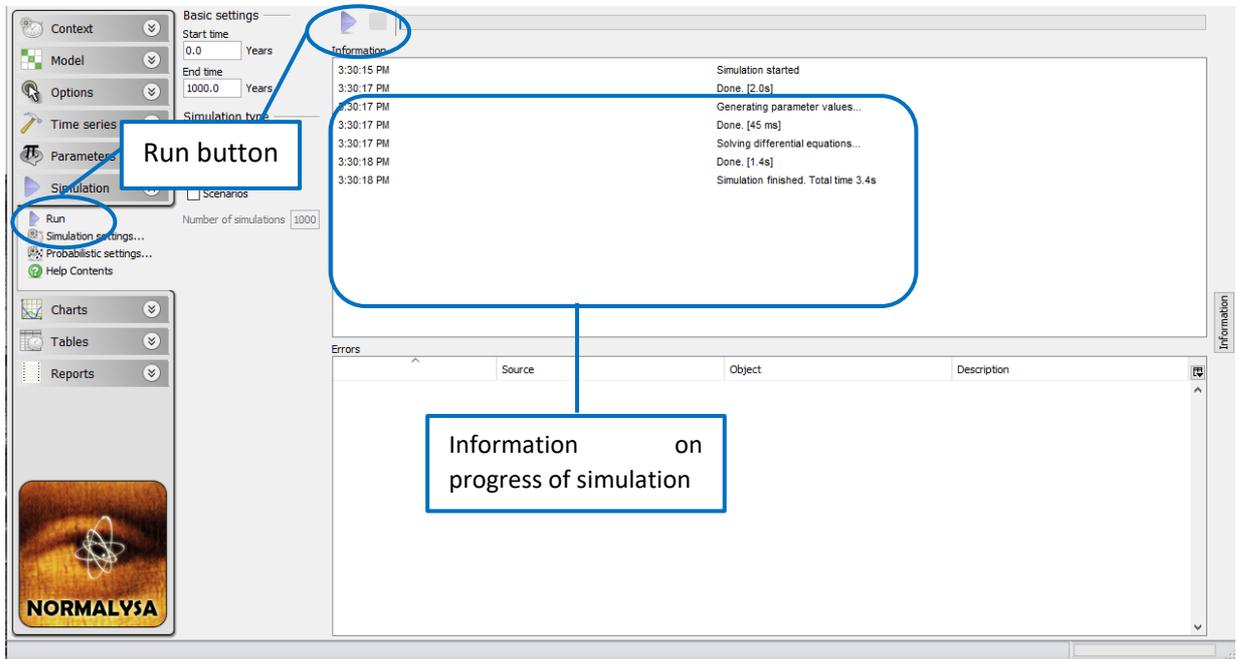


FIG 17. Running the NORMALYSA model.

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 inhalation doses from radon to reference persons at receptor location considered in this exercise.

1. Select with the left mouse button in the window of simulation results the output parameter ‘*Doses from inhalation of each radionuclide*’ inside the ‘*Dose from occupancy*’ folder.
2. Tag ‘*All*’ (from the index list of exposed groups) and ‘*Rn-222*’ (from the index lists of radionuclides) that will be displayed immediately below the window with the simulation results.
3. The time table displaying results of dose calculations from radon 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 can be carried out to display in table format simulation results for radon concentrations in the air at the source of release and in the receptor point. To do so, the following output parameters have to be selected: ‘*Rn concentration in the air*’ (‘*Tailings without cover*’ sub-system) – for radon concentration above the uranium tailings, and ‘*Ground level air concentration*’ (‘*Atmosphere SR-19*’ sub-system) – for radon concentration in the air at receptor location. The ‘*Rn-222*’ radionuclide needs to be tagged in the index list of nuclides.

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.

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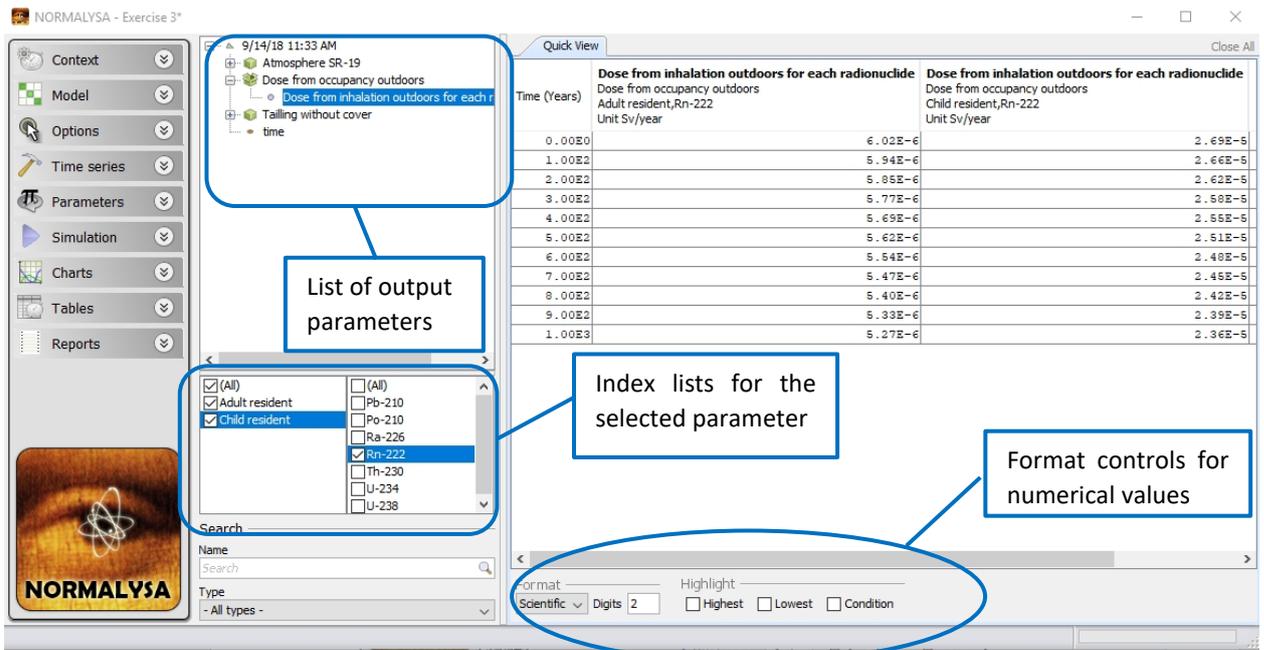


FIG 18. Displaying the table with the calculated inhalation doses from radon to reference persons considered in Exercise 3.

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 radon concentrations in the air at the source of release (uranium tailing) and receptor location considered in this exercise.

1. Select with the left mouse button in the window of simulation results the output parameter 'Ground level air concentration' inside the 'Atmosphere SR-19' folder.
2. Press and hold 'Ctrl' button on keyboard and select the second parameter to be plotted – 'Rn concentration in the air' in the 'Tailing without cover' folder.
3. Tag twice 'Rn-222' (from the index lists of radionuclides) that will be displayed immediately below the window with the simulation results.
4. The time graph displaying radon concentrations in the selected locations (sub-systems) will be shown in 'Quick View' window.
5. Now we will make a number of adjustments to the format of the displayed graph. To do so right click the graph area and select 'Edit...' from the pop-up menu that appears.
6. The 'Edit Time Chart' window will be opened. Make the following chart format adjustment in this window. In the 'Legend' field select the 'Bottom' option from the

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drop-down list for displaying the chart legend. For the ‘Y-axis’ set of options: deselect ‘Auto range’ and ‘Logarithmic’ boxes, type in “0.0” value to ‘Min’ field, and “120.0” to ‘Max’ field (FIG 19). Press ‘Ok’.

The resulting time graph of radon concentrations in the air is shown in FIG 20.

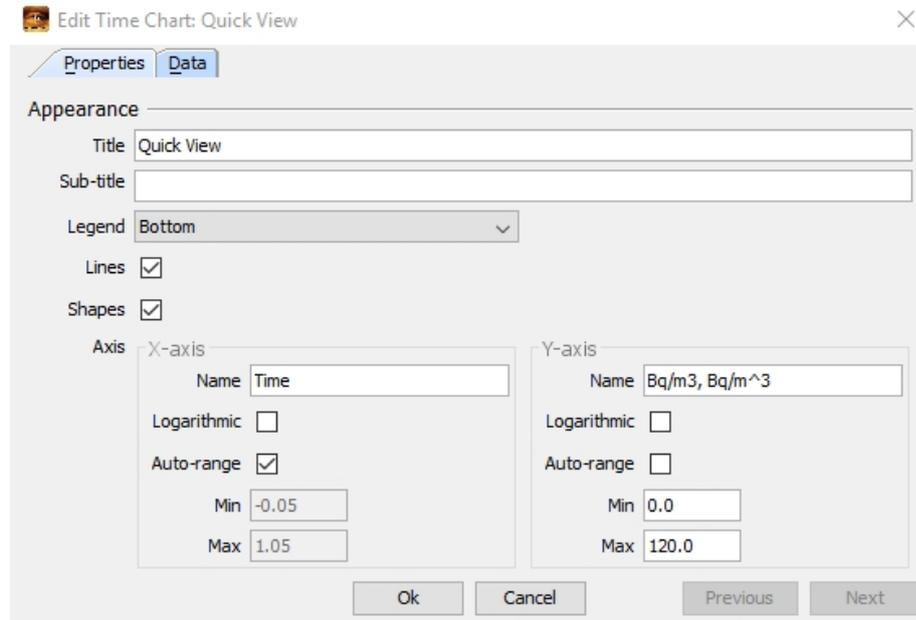


FIG 19. Adjustment of the format of the displayed chart with the simulation results (radon concentrations in the air) for Exercise 3.

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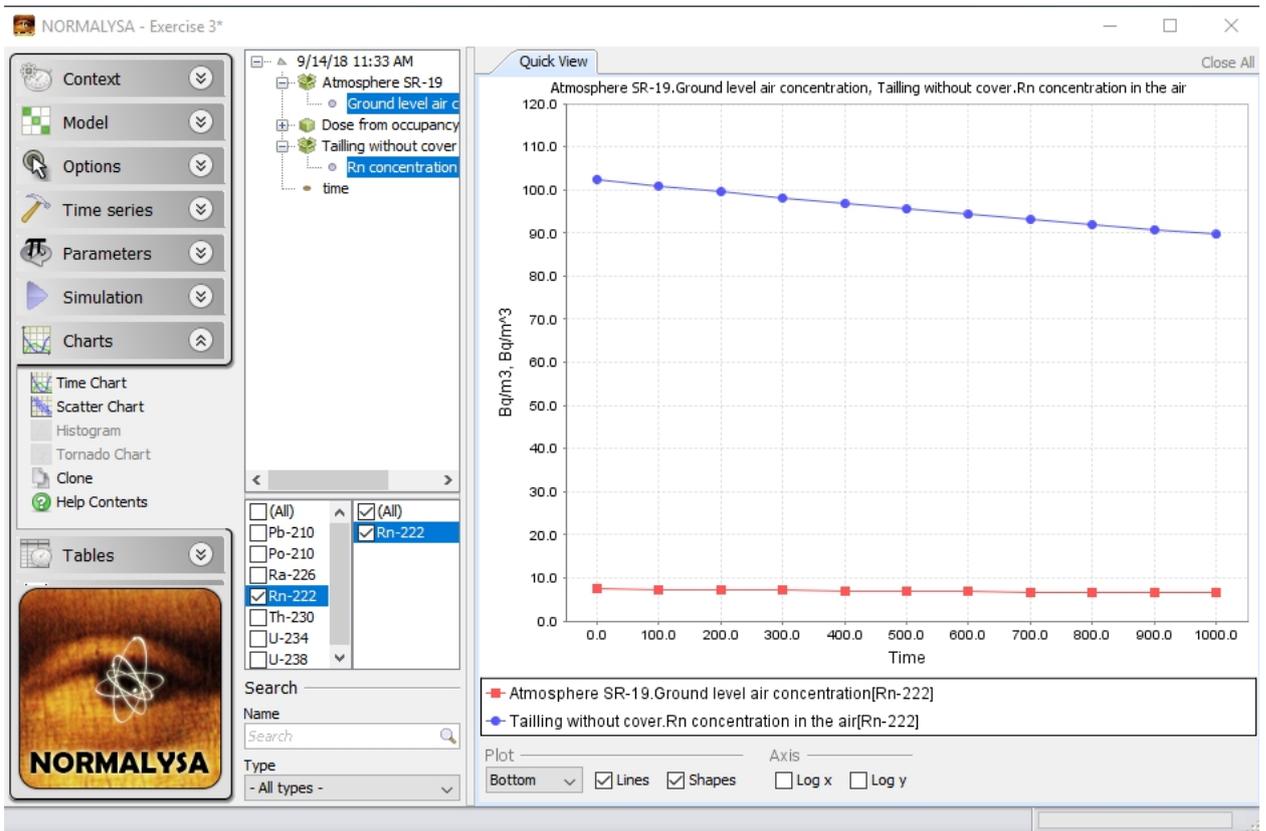


FIG 20. Displaying in chart format simulated radon concentrations in the source of release and at receptor location for Exercise 3.

5. Results of calculations

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

5.1. Radon concentrations in the air

Radon concentrations in the air in the source of release (uranium tailings) and at the downwind receptor location are shown in Table 10. Radon (Rn-222) concentrations in the air decrease in time due to decrease of concentration of parent radionuclide – Ra-226 – in the body of tailings. The decrease of Ra-226 is due to radioactive decay and radionuclide leaching to deeper layers by infiltration recharge. Radon concentrations at 200 m distance from the source decrease by a factor of ≈ 14 compared to the source due to dispersion process in the air.

Table 10. Simulated radon concentrations in the air above the source ('Tailings without cover' subsystem) and at receptor point ('Atmosphere SR-19' subsystem), Bq/m³

| Time, years | <i>Rn concentration in the air</i> (‘Tailing without cover’ subsystem) | <i>Ground level air concentration</i> (‘Atmosphere SR-19’ subsystem) |
|-------------|---|---|
| 0 | 102.4 | 7.4 |
| 100 | 100.9 | 7.3 |
| 200 | 99.5 | 7.2 |
| 300 | 98.1 | 7.1 |
| 400 | 96.8 | 7.0 |
| 500 | 95.5 | 6.9 |
| 600 | 94.2 | 6.8 |
| 700 | 93.0 | 6.7 |
| 800 | 91.9 | 6.7 |
| 900 | 90.7 | 6.6 |
| 1000 | 89.6 | 6.5 |

5.2. Dose from inhalation of radon

Doses from inhalation of Radon for respective reference individuals are shown in Table 11. These doses are generally low. Annual doses to an adult resident are in micro Sievert range. Doses to a child resident are higher due to larger time of exposure, and are of an order of 30-20 $\mu\text{Sv}/\text{year}$. Doses decrease in time following the gradual lowering of radon concentrations in the air.

Table 11. Simulated doses to reference individuals at receptor point, Sv/year

| Time, years | Adult resident | Child resident |
|-------------|----------------|----------------|
| 0 | 6.0E-06 | 2.7E-05 |
| 100 | 5.9E-06 | 2.7E-05 |
| 200 | 5.9E-06 | 2.6E-05 |
| 300 | 5.8E-06 | 2.6E-05 |
| 400 | 5.7E-06 | 2.5E-05 |
| 500 | 5.6E-06 | 2.5E-05 |
| 600 | 5.5E-06 | 2.5E-05 |
| 700 | 5.5E-06 | 2.4E-05 |
| 800 | 5.4E-06 | 2.4E-05 |
| 900 | 5.3E-06 | 2.4E-05 |
| 1000 | 5.3E-06 | 2.4E-05 |

6. Exercise for independent work

Estimate how distance from the source of release influences inhalation doses from radon. Calculate doses to reference individuals assuming receptor location is situated at 100 m, 300 m and 500 m distance.