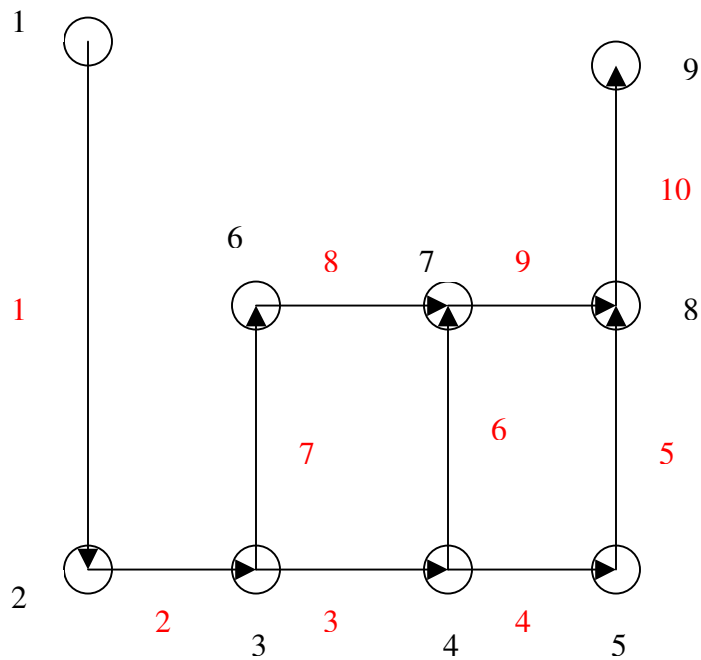


## Quick Start Guide

This guide is intended as a brief user manual for the Complex Mine Model radon model. The user is expected to be familiar with the subject of radon modeling. This manual is not intended as a textbook on radon modeling.

1. Draw a schematic of your mine on paper, indicating the direction of airflow. Put a node wherever you suspect point source radon inflows.
2. Assign a number to each node, starting with the fresh air intake. This is node 1.
3. Assign a number to each branch. While node numbers can be any value, branch numbers should be reasonably sequential and increase as you go from fresh air to exhaust

At this time your ventilation diagram looks like this, where the nodes are in black and the braches are in red. Here node 1 is the fresh air intake and node 9 is the exhaust:



4. Enter the initial node (iN) and final node (fN) associated with each branch on the form. (Note: that the branch numbers are pre-assigned and cannot be changed.) Enter the length of each branch in meters (L), its area (A) and its Perimeter (P). Enter the airflow in each branch on  $\text{m}^3/\text{s}$  (Q). Your form should now look like:

Complex Mine Model - Microsoft Internet Explorer

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## On-Line Radon Toolkit v2.0

### Complex Mine Model

Notes:

Branch	iN	fN	L (m)	A(m2)	P(m)	Q(m3/s)	RN(Bq/s)	RE(Bq/s/m2)
1	1	2	300	20	21	15	0	0
2	2	3	100	20	21	15	0	0
3	3	4	100	20	21	10	0	0
4	4	5	100	20	21	5	0	0
5	5	8	100	20	21	5	0	0
6	4	7	100	20	21	5	0	0
7	3	6	100	20	21	5	0	0
8	6	7	100	20	21	5	0	0
9	7	8	100	20	21	10	0	0
10	8	9	300	20	21	15	0	0
11	-1	1	100	20	21	5	0	0
12	-1	1	100	20	21	5	0	0
13	-1	1	100	20	21	5	0	0
14	-1	1	100	20	21	5	0	0
15	-1	1	100	20	21	5	0	0

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- Enter point source radon inflows in Becquerels per second (RN). The model assumes that these are located **immediately downwind of the initial node of the branch**. So, in our example, placing a source in branch 4 will not affect branch 6 values. Enter the radon emanation rates of the workings in Becquerels per second per square meter (RE). [You can arrive at that value using the Area Source model of the toolkit, or you can use measured values.] :

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Branch	iN	fN	L (m)	A(m <sup>2</sup> )	P(m)	Q(m <sup>3</sup> /s)	RN(Bq/s)	RE(Bq/s/m <sup>2</sup> )
1	1	2	300	20	21	15	0	0
2	2	3	100	20	21	15	1e5	0
3	3	4	100	20	21	10	0	0
4	4	5	100	20	21	5	1e4	0
5	5	8	100	20	21	5	0	0
6	4	7	100	20	21	5	0	0
7	3	6	100	20	21	5	0	300
8	6	7	100	20	21	5	0	0
9	7	8	100	20	21	10	0	0
10	8	9	300	20	21	15	0	0
11	-1	1	100	20	21	5	0	0

Done Internet

- Press 'Read these Values and Reset all Calculations' (if it is not grayed out). Press 'Do 50 iterations and display e.o. branch values.'
- The program now displays the radon concentration in Bq/m<sup>3</sup> (Rn222), the concentration of the individual radon progeny in Bq/m<sup>3</sup> (Po218, Pb214, Bi214), the potential alpha energy concentration in WL (WL) and the equilibrium factor (F) at the end of each branch.

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Branch	iN	fN	Rn222(Bq/m3)	Po218(Bq/m3)	Pb214(Bq/m3)	Bi214(Bq/m3)	WL	F
1	1	2	0	0	0	0	0	NaNNaN
2	2	3	6.66e3	2.66e3	8.16e1	2.09e0	8.68e-2	4.82e-2
3	3	4	6.66e3	4.80e3	3.96e2	2.61e1	1.93e-1	1.07e-1
4	4	5	8.65e3	7.82e3	1.40e3	2.00e2	4.35e-1	1.86e-1
5	5	8	8.65e3	8.47e3	2.49e3	5.55e2	6.40e-1	2.74e-1
6	4	7	6.66e3	6.26e3	1.24e3	1.87e2	3.68e-1	2.05e-1
7	3	6	1.33e5	6.73e4	4.58e3	3.05e2	2.56e0	7.16e-2
8	6	7	1.32e5	1.18e5	1.97e4	2.64e3	6.34e0	1.77e-1
9	7	8	6.95e4	6.62e4	1.50e4	2.62e3	4.20e0	2.24e-1
10	8	9	4.92e4	4.87e4	1.67e4	4.34e3	4.13e0	3.11e-1
11	-1	1	0	0	0	0	0	0

Done Internet

## You are now done!

Please note that, in our example, there was no radon or radon progeny in branch 1. Therefore, the equilibrium factor is undefined. JavaScript denotes that with 'NaNNaN'.

## Quality Assurance

It is easy to make data input errors. Therefore, the program contains some QA checks.

8. Press 'Display QA report'.

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Address <http://members.shaw.ca/eic/Tools/MineModel.htm> Go Links

Branch	iN	fN	Net QiN(m3)	Net QfN(m3)	Rn flux fN(Bq/	Ru flux fN(Bq/	mine Rn (Bq/s	Net Rn sink(B
1	1	2	-15	0	0	0	7.40e5	0
2	2	3	0	0	1.00e5	1.00e5	7.40e5	0
3	3	4	0	0	6.66e4	6.67e4	7.40e5	0
4	4	5	0	0	4.33e4	4.33e4	7.40e5	0
5	5	8	0	0	4.32e4	4.33e4	7.40e5	0
6	4	7	0	0	3.33e4	3.33e4	7.40e5	0
7	3	6	0	0	6.63e5	6.63e5	7.40e5	0
8	6	7	0	0	6.62e5	6.63e5	7.40e5	0
9	7	8	0	0	6.95e5	6.97e5	7.40e5	0
10	8	9	0	1.50e1	7.38e5	7.40e5	7.40e5	7.40e5
11	-1	1	0	0	0	0	0	0

Internet

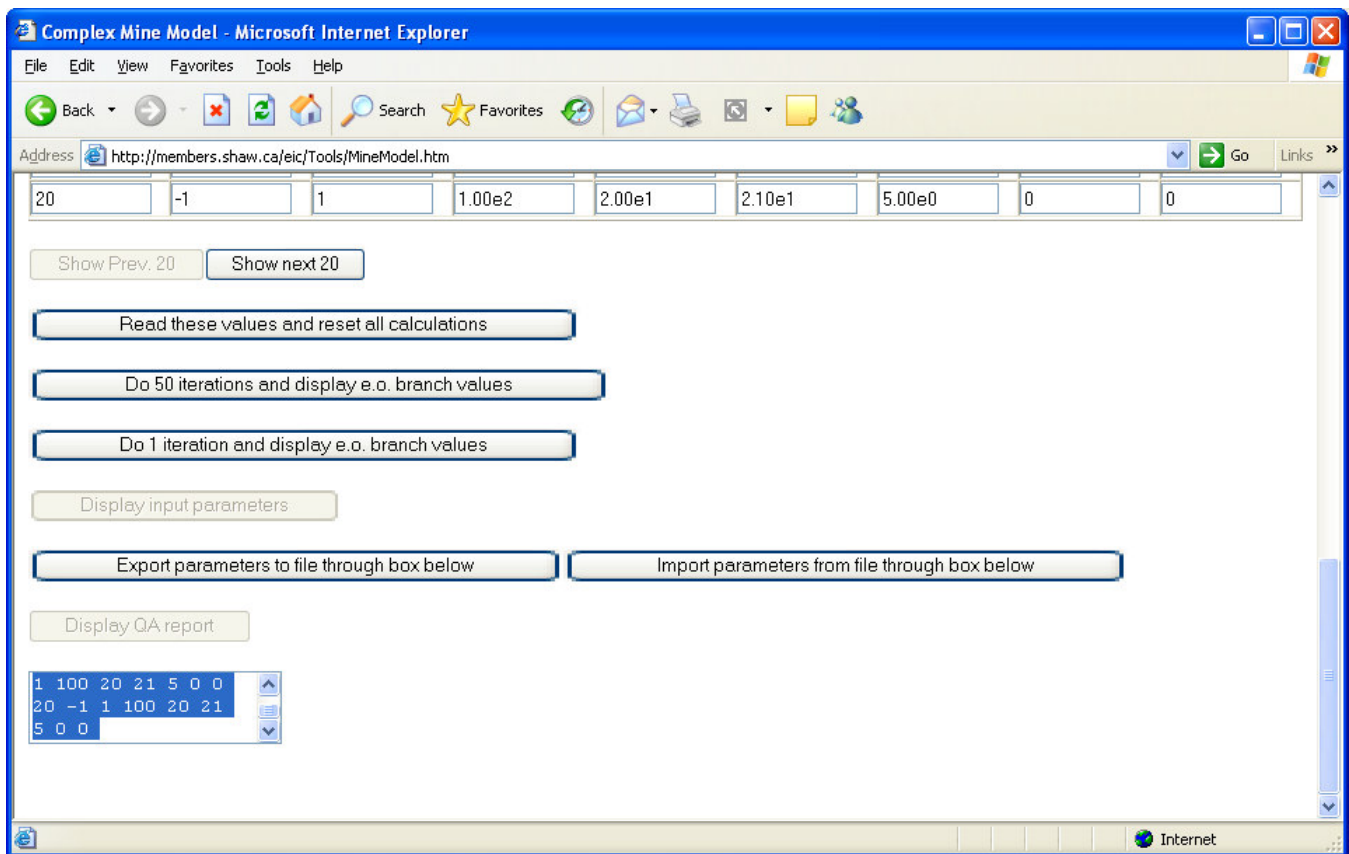
- 8.1. The NetQiN(m3) shows the net flow into each initial node and the NetQfN(m3) shows the net flow into each final node. If you started with a balanced ventilation system, all values should be 0 (you can't make air!) except fresh air intakes and exhausts.
- 8.2. The value in 'mineRn(Bq/s) is the total amount of radon that was released into the mine. The values in NetRn sink(Bq/s) show the net radon flow into each final node. Only exhaust nodes should have net radon flows into them. Also, the sum of all net radon flows (i.e. the amount of radon exhausted from the mine) should equal the amount of radon released into the mine, which is shown in 'mineRn(Bq/s). [Technically, this statement is only correct if we neglect radon decay. Therefore, for this check, the model neglects radon decay. The difference between the real radon flux and the 'undecayed' radon flux can be seen by comparing Rn and Ru.]

## FAQ

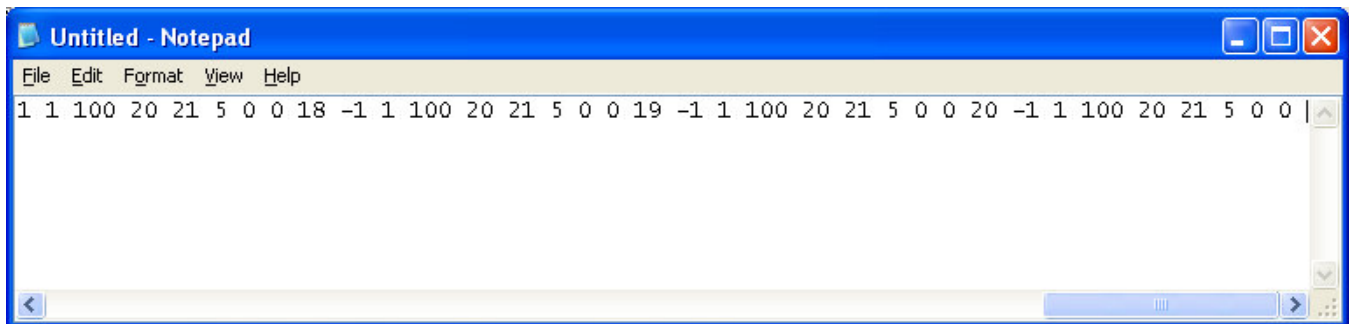
### 9. How do I save my data?

Internet Explorer makes it difficult for web sites to write directly to your hard drive. Therefore, we have to use a workaround:

- 9.1. Make sure your input parameters are displayed and not your calculated results or the QA report. (If required press 'Display Input Parameters') Press 'Read these Values and Reset all Calculations'. Press 'Export Parameters through Box Below'. Highlight **all** numbers in the box and hit 'Ctrl c', to copy them. (You can't see all of them at the same time. So, use the scroll bar to go to the top of the box, click and drag the mouse to the end of the box.)



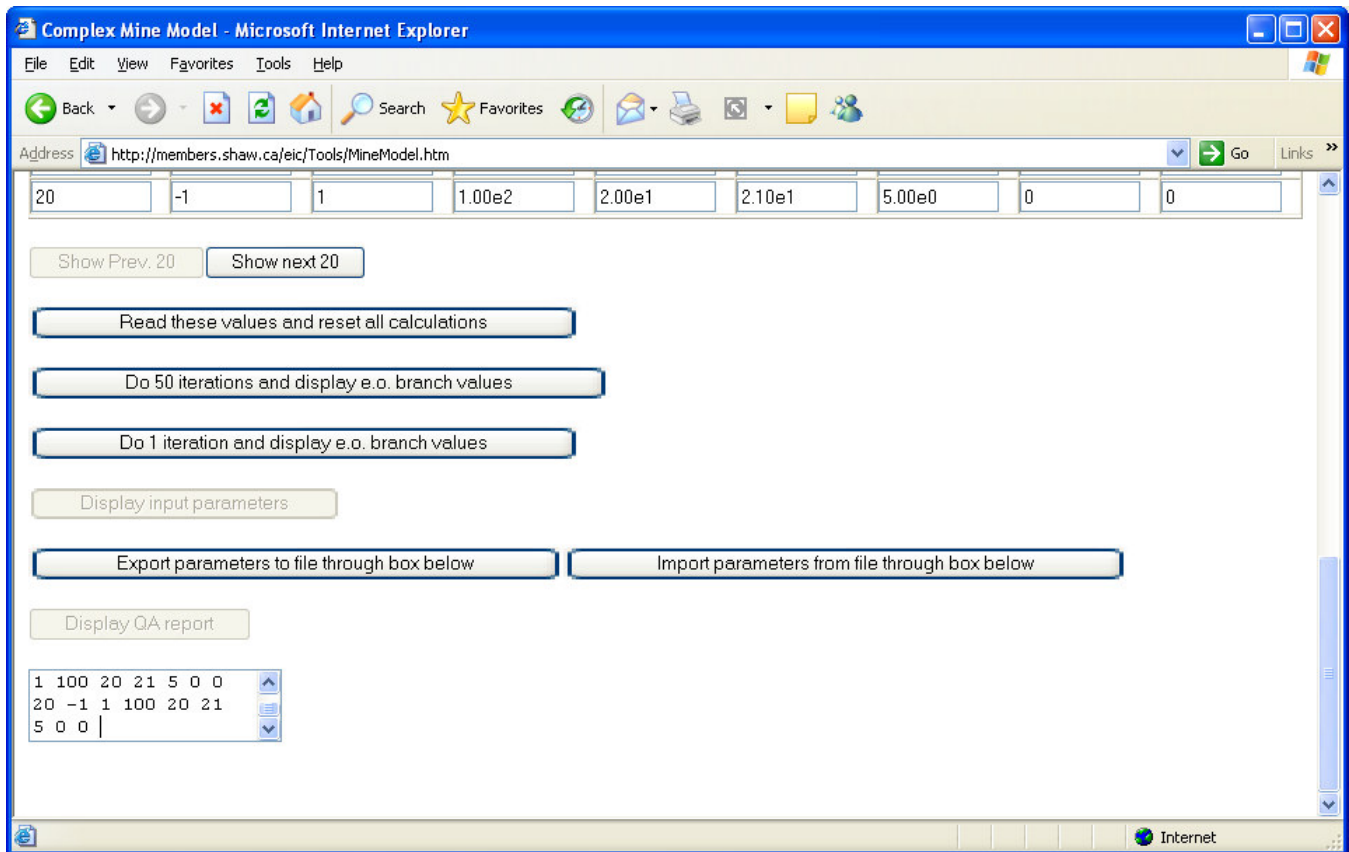
9.2. Open a new file in Notepad. Hit 'Ctrl v' to paste the numbers:



9.3. Save the Notepad file on your computer as 'mineData.txt'.

## 10. How do I enter saved data?

- 10.1. Open the file mineData.txt, highlight all numbers in the file and hit 'Ctrl c', to copy them. Click your mouse in the IO box and hit 'Ctrl v' to paste the numbers:

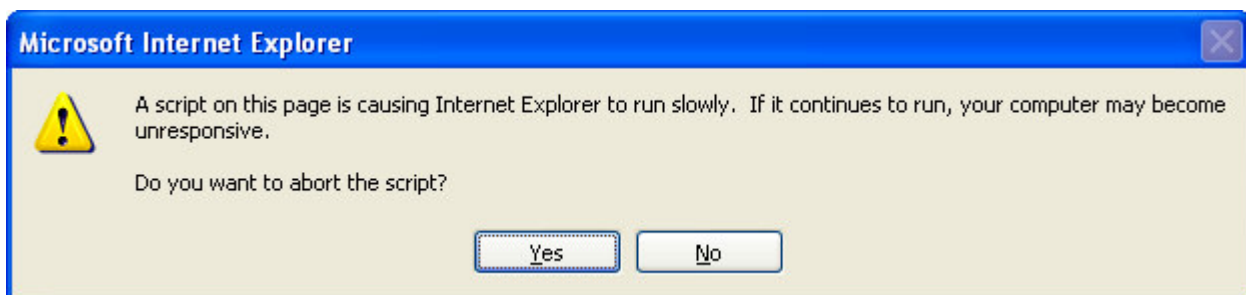


10.2. Hit 'Import parameters from file through box below'. Click 'Display input parameters' and click 'Read these values and reset all calculations'.

### 11. How do I edit my input parameters?

Whenever input parameters are displayed, you can edit them. Make sure you hit 'Read these values and reset all calculations' otherwise your edits will be ignored. If a drift has been back filled, **do not** enter a flow rate of 0. The program can't handle 0 flows. Instead, write '-1' in the iN field. That tells the program to ignore the branch.

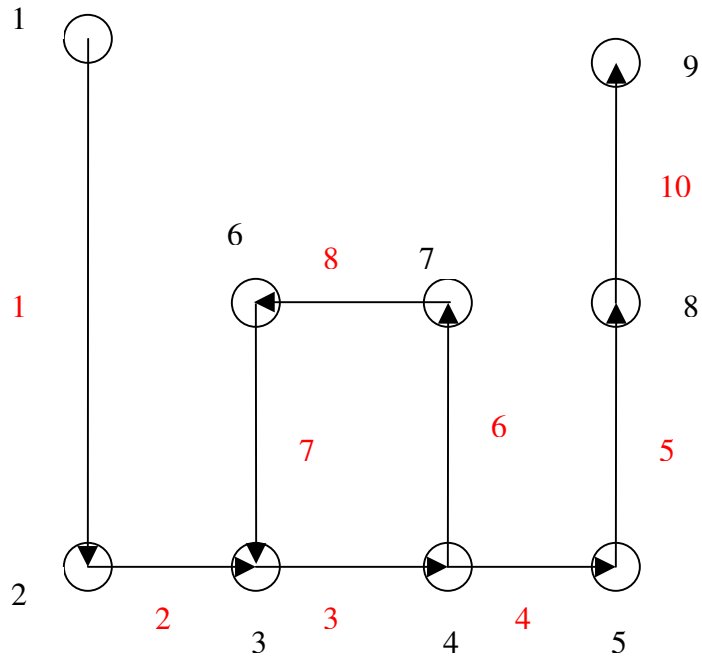
### 12. What does this error message mean?



The program is taking longer to execute than Internet Explorer would like. This is probably because you used a very low flow rate in one of the branches. Just click 'No' and the program will eventually finish. Otherwise, click 'Yes' and use better input parameters.

### 13. Can the program handle complicated layouts with loops?

Yes, consider the layout below:



It is the same as our original example, except we have back filled branch 9 and reversed the flow in branches 7 and 8 and changed some flows so that they balance. So, our input screen becomes:





and a QA report shows that everything is OK:

Branch	iN	fN	Net QiN(m3)	Net QfN(m3)	Rn flux fN(Bq/	Ru flux fN(Bq/	mine Rn (Bq/s	Net Rn sink(B
1	1	2	-15	0	0	0	7.40e5	0
2	2	3	0	0	1.00e5	1.00e5	7.40e5	0
3	3	4	0	0	9.72e5	9.73e5	7.40e5	0
4	4	5	0	0	7.39e5	7.40e5	7.40e5	0
5	5	8	0	0	7.38e5	7.40e5	7.40e5	0
6	4	7	0	0	2.43e5	2.43e5	7.40e5	0
7	6	3	0	0	8.72e5	8.73e5	7.40e5	0
8	7	6	0	0	2.43e5	2.43e5	7.40e5	0
9	-1	8	0	0	0	0	0	0
10	8	9	0	1.50e1	7.38e5	7.40e5	7.40e5	7.40e5
11	-1	1	0	0	0	0	0	0
12	-1	1	0	0	0	0	0	0
13	-1	1	0	0	0	0	0	0
14	-1	1	0	0	0	0	0	0

This is a good scenario for showing how the program works. It calculates the radon and progeny concentrations at the end of each branch and uses these as input parameters for downstream branches. It starts at branch 1 and goes sequentially down the list, ignoring any branches with input node '-1'. Sometimes, as in the case of the recalculation loop, the input of one branch is affected by its output. This is resolved by using the output of each run as the input for the next run and repeating until a steady state solution is found.

If we, instead of pressing 'Do 50 iterations and display e.o. branch values', pressed 'Do 1 iteration and display e.o. branch values' in the above re-circulation example, the results would be:

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Branch	iN	fN	Rn222(Bq/m3)	Po218(Bq/m3)	Pb214(Bq/m3)	Bi214(Bq/m3)	WL	F
1	1	2	0	0	0	0	0	NaNNaN
2	2	3	6.66e3	2.66e3	8.16e1	2.09e0	8.68e-2	4.82e-2
3	3	4	5.00e3	2.95e3	1.65e2	7.50e0	1.07e-1	7.92e-2
4	4	5	5.66e3	4.03e3	3.54e2	2.54e1	1.65e-1	1.08e-1
5	5	8	5.66e3	4.68e3	5.80e2	5.72e1	2.18e-1	1.43e-1
6	4	7	4.99e3	4.55e3	7.69e2	9.93e1	2.45e-1	1.82e-1
7	6	3	1.26e5	6.15e4	3.77e3	2.18e2	2.28e0	6.71e-2
8	7	6	4.99e3	4.90e3	1.40e3	3.01e2	3.63e-1	2.70e-1
9	-1	8	0	0	0	0	0	0
10	8	9	5.66e3	5.45e3	1.31e3	2.38e2	3.59e-1	2.35e-1
11	-1	1	0	0	0	0	0	0
12	-1	1	0	0	0	0	0	0
13	-1	1	0	0	0	0	0	0
14	-1	1	0	0	0	0	0	0
15	-1	1	0	0	0	0	0	0

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Which is quite different than our 50 iteration result. Also, our QA report shows that the mine Rn (Bq/s) (7.4e5) is unequal to Net Rn sink(Bq/s) (8.5e4). That means we have not followed the radon through the mine enough, so that we can account for all the radon at the exhaust raise.

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<http://www.eic.nu>

Notes:

Branch	iN	fN	Net QiN(m3)	Net QfN(m3)	Rn flux fN(Bq/	Ru flux fN(Bq/	mine Rn (Bq/s	Net Rn sink(B
1	1	2	-15	0	0	0	7.40e5	0
2	2	3	0	0	1.00e5	1.00e5	7.40e5	0
3	3	4	0	0	1.00e5	1.00e5	7.40e5	0
4	4	5	0	0	8.49e4	8.50e4	7.40e5	0
5	5	8	0	0	8.49e4	8.50e4	7.40e5	0
6	4	7	0	0	2.50e4	2.50e4	7.40e5	0
7	6	3	0	0	6.30e5	6.30e5	7.40e5	0
8	7	6	0	0	2.49e4	2.50e4	7.40e5	0
9	-1	8	0	0	0	0	0	0
10	8	9	0	1.50e1	8.48e4	8.50e4	7.40e5	8.50e4
11	-1	1	0	0	0	0	0	0
12	-1	1	0	0	0	0	0	0

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Running another iteration gives:

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Branch	iN	fN	Rn222(Bq/m3	Po218(Bq/m3	Pb214(Bq/m3	Bi214(Bq/m3)	WL	F
1	1	2	0	0	0	0	0	NaNNaN
2	2	3	6.66e3	2.66e3	8.16e1	2.09e0	8.68e-2	4.82e-2
3	3	4	3.65e4	2.34e4	1.83e3	1.29e2	9.29e-1	9.43e-2
4	4	5	3.71e4	2.89e4	3.21e3	3.01e2	1.29e0	1.29e-1
5	5	8	3.71e4	3.22e4	4.75e3	5.66e2	1.62e0	1.62e-1
6	4	7	3.64e4	3.36e4	6.30e3	9.21e2	1.91e0	1.95e-1
7	6	3	1.31e5	6.64e4	5.74e3	8.00e2	2.75e0	7.79e-2
8	7	6	3.64e4	3.58e4	1.09e4	2.48e3	2.77e0	2.82e-1
9	-1	8	0	0	0	0	0	0
10	8	9	3.71e4	3.60e4	9.50e3	1.90e3	2.53e0	2.52e-1
11	-1	1	0	0	0	0	0	0
12	-1	1	0	0	0	0	0	0
13	-1	1	0	0	0	0	0	0
14	-1	1	0	0	0	0	0	0

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and the QA report shows that we are now accounting for most of the radon, but not all:

Complex Mine Model - Microsoft Internet Explorer

Address: <http://members.shaw.ca/eic/Tools/MineModel.htm>

Canada Inc. Complex Mine Model  
<http://www.eic.nu>

Notes:

Branch	iN	fN	Net QiN(m3)	Net QfN(m3)	Rn flux fN(Bq/	Ru flux fN(Bq/	mine Rn (Bq/s	Net Rn sink(B
1	1	2	-15	0	0	0	7.40e5	0
2	2	3	0	0	1.00e5	1.00e5	7.40e5	0
3	3	4	0	0	7.30e5	7.30e5	7.40e5	0
4	4	5	0	0	5.57e5	5.57e5	7.40e5	0
5	5	8	0	0	5.57e5	5.57e5	7.40e5	0
6	4	7	0	0	1.82e5	1.82e5	7.40e5	0
7	6	3	0	0	6.55e5	6.55e5	7.40e5	0
8	7	6	0	0	1.82e5	1.82e5	7.40e5	0
9	-1	8	0	0	0	0	0	0
10	8	9	0	1.50e1	5.56e5	5.57e5	7.40e5	5.57e5
11	-1	1	0	0	0	0	0	0

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After 10 iterations we can account for about 99.8% of the radon:

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Address: <http://members.shaw.ca/eic/Tools/MineModel.htm>

Branch	iN	fN	Net QiN(m3)	Net QfN(m3)	Rn flux fN(Bq/	Ru flux fN(Bq/	mine Rn (Bq/s	Net Rn sink(B
1	1	2	-15	0	0	0	7.40e5	0
2	2	3	0	0	1.00e5	1.00e5	7.40e5	0
3	3	4	0	0	9.71e5	9.72e5	7.40e5	0
4	4	5	0	0	7.38e5	7.39e5	7.40e5	0
5	5	8	0	0	7.38e5	7.39e5	7.40e5	0
6	4	7	0	0	2.43e5	2.43e5	7.40e5	0
7	6	3	0	0	8.71e5	8.72e5	7.40e5	0
8	7	6	0	0	2.42e5	2.43e5	7.40e5	0
9	-1	8	0	0	0	0	0	0
10	8	9	0	1.50e1	7.37e5	7.39e5	7.40e5	7.39e5
11	-1	1	0	0	0	0	0	0

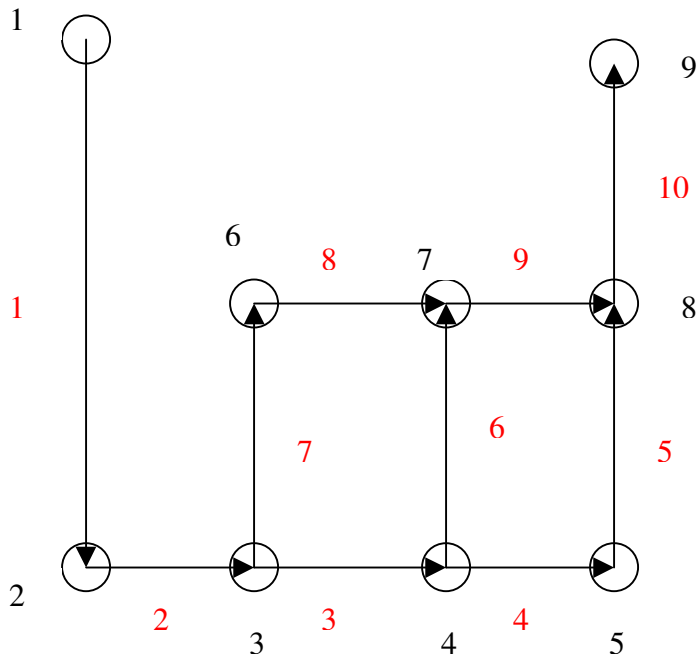
Internet

The easiest way to make sure that enough iterations have been done is to run 50 iterations and then check the QA report. One could also run another 50 iterations to see if there are any changes.



**14. What if I just want to model a part of the mine with known radon and progeny in the intake air?**

The program always assumes that the air coming into the mine is clean. We can work around this by starting our actual model at node 2 in our original example.



Suppose you know the air at node 2 will have  $\sim 1000 \text{ Bq/m}^3$  of radon and about 0.2 WL. We can then guess at the source term in branch 1 and the size of branch 1 to produce these values at node 2. Since radon has a long half life, it is easy to get the radon gas correct. Since the flow through branch 1 is  $15 \text{ m}^3/\text{s}$  we need to put in slightly more than  $15\,000 \text{ Bq/s}$  to end up with  $1000 \text{ Bq/m}^3$ :

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## On-Line Radon Toolkit v2.0

### Complex Mine Model

Notes:

Branch	iN	fN	L (m)	A(m2)	P(m)	Q(m3)	Rn(Bq/s)	RE(Bq/s/m2)
1	1	2	3.00e2	2.00e1	2.10e1	1.50e1	15000	0
2	2	3	1.00e2	2.00e1	2.10e1	1.50e1	1.00e5	0
3	3	4	1.00e2	2.00e1	2.10e1	1.00e1	0	0
4	4	5	1.00e2	2.00e1	2.10e1	5.00e0	1.00e4	0
5	5	8	1.00e2	2.00e1	2.10e1	5.00e0	0	0
6	4	7	1.00e2	2.00e1	2.10e1	5.00e0	0	0
7	3	6	1.00e2	2.00e1	2.10e1	5.00e0	0	3.00e2
8	6	7	1.00e2	2.00e1	2.10e1	5.00e0	0	0
9	7	8	1.00e2	2.00e1	2.10e1	1.00e1	0	0
10	8	9	3.00e2	2.00e1	2.10e1	1.50e1	0	0
11	-1	1	1.00e2	2.00e1	2.10e1	5.00e0	0	0
12	-1	1	1.00e2	2.00e1	2.10e1	5.00e0	0	0
13	-1	1	1.00e2	2.00e1	2.10e1	5.00e0	0	0
14	-1	1	1.00e2	2.00e1	2.10e1	5.00e0	0	0
15	-1	1	1.00e2	2.00e1	2.10e1	5.00e0	0	0

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And the results show that we can expect about 0.037 WL at node 2.

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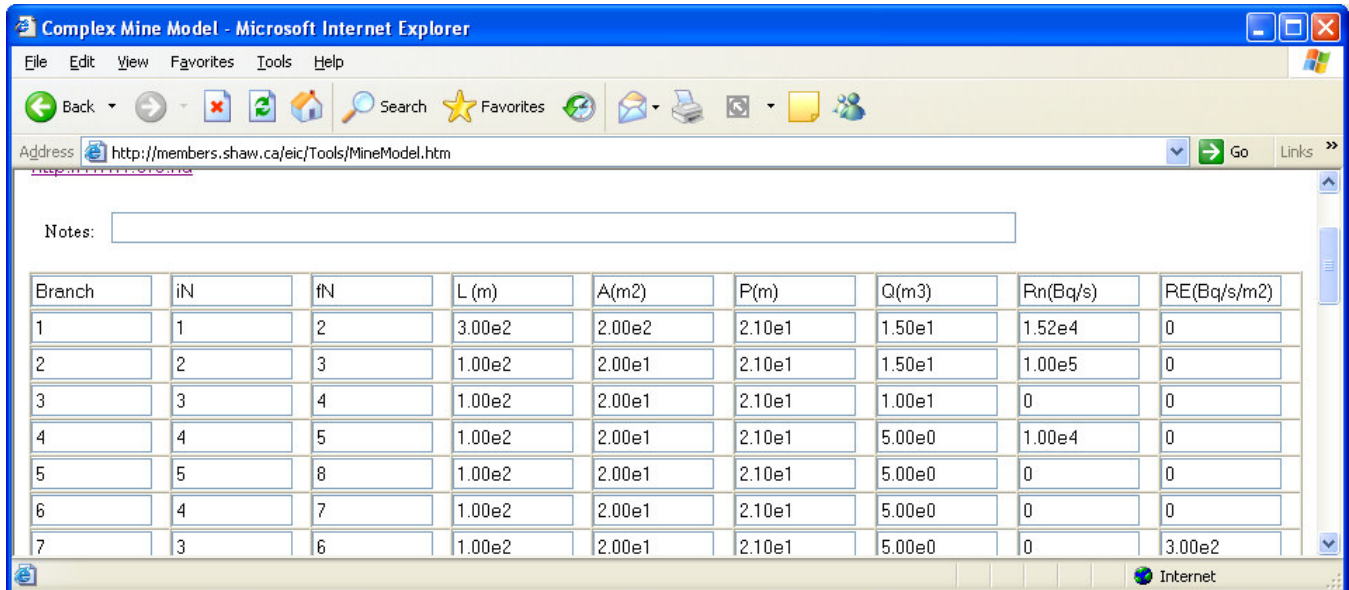
Notes:

Branch	iN	fN	Rn222(Bq/m3)	Po218(Bq/m3)	Pb214(Bq/m3)	Bi214(Bq/m3)	WL	F
1	1	2	9.99e2	7.83e2	7.92e1	6.32e0	3.37e-2	1.25e-1
2	2	3	7.66e3	3.53e3	2.03e2	1.52e1	1.29e-1	6.26e-2
3	3	4	7.66e3	5.74e3	5.83e2	5.42e1	2.48e-1	1.20e-1
4	4	5	9.65e3	8.81e3	1.71e3	2.73e2	5.13e-1	1.97e-1
5	5	8	9.64e3	9.47e3	2.91e3	6.88e2	7.40e-1	2.84e-1
6	4	7	7.65e3	7.24e3	1.55e3	2.60e2	4.46e-1	2.16e-1
7	3	6	1.34e5	6.82e4	4.83e3	3.53e2	2.63e0	7.30e-2

Internet

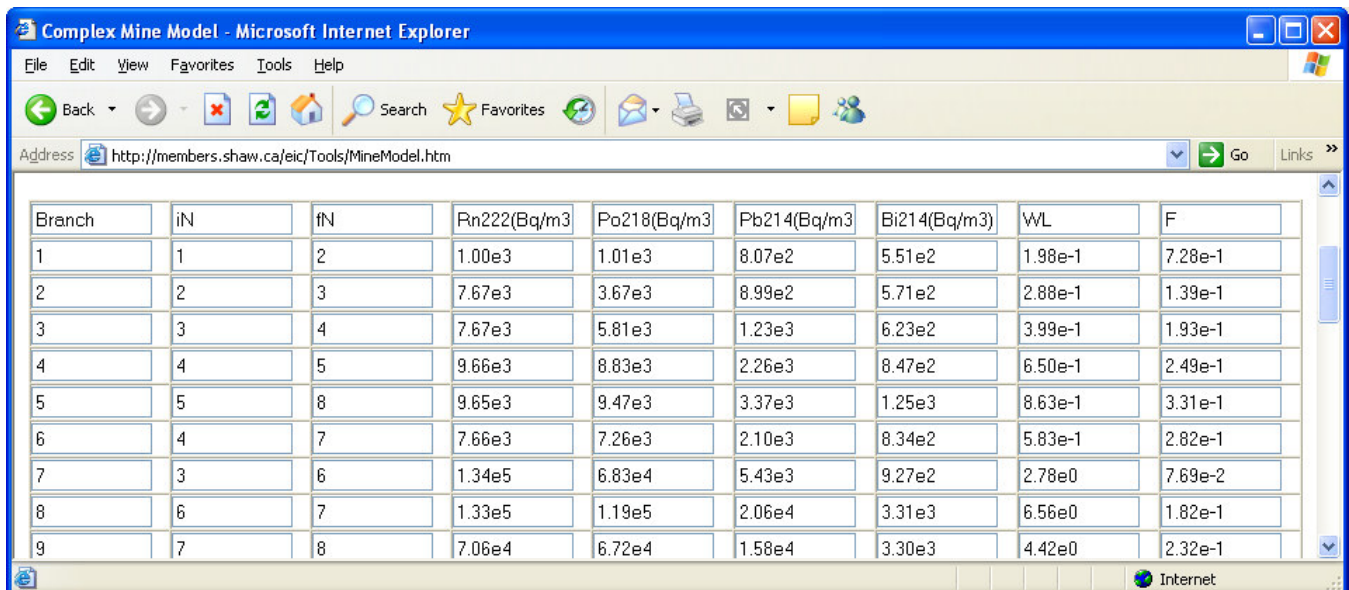
So, we have to increase the decay time from node 1 to 2, in order to increase the radon progeny concentration. We can do this by either increasing the length or area of branch 1. (We can't change the flow rate, because we want the flows to remain balanced.)

After a couple of tries (hit 'Display input parameters' after each calculation, so you don't have to re-type everything) we find that



Branch	iN	fN	L (m)	A(m2)	P(m)	Q(m3)	Rn(Bq/s)	RE(Bq/s/m2)
1	1	2	3.00e2	2.00e2	2.10e1	1.50e1	1.52e4	0
2	2	3	1.00e2	2.00e1	2.10e1	1.50e1	1.00e5	0
3	3	4	1.00e2	2.00e1	2.10e1	1.00e1	0	0
4	4	5	1.00e2	2.00e1	2.10e1	5.00e0	1.00e4	0
5	5	8	1.00e2	2.00e1	2.10e1	5.00e0	0	0
6	4	7	1.00e2	2.00e1	2.10e1	5.00e0	0	0
7	3	6	1.00e2	2.00e1	2.10e1	5.00e0	0	3.00e2

gives returns pretty close to the desired results at node 2.:



Branch	iN	fN	Rn222(Bq/m3)	Po218(Bq/m3)	Pb214(Bq/m3)	Bi214(Bq/m3)	WL	F
1	1	2	1.00e3	1.01e3	8.07e2	5.51e2	1.98e-1	7.28e-1
2	2	3	7.67e3	3.67e3	8.99e2	5.71e2	2.88e-1	1.39e-1
3	3	4	7.67e3	5.81e3	1.23e3	6.23e2	3.99e-1	1.93e-1
4	4	5	9.66e3	8.83e3	2.26e3	8.47e2	6.50e-1	2.49e-1
5	5	8	9.65e3	9.47e3	3.37e3	1.25e3	8.63e-1	3.31e-1
6	4	7	7.66e3	7.26e3	2.10e3	8.34e2	5.83e-1	2.82e-1
7	3	6	1.34e5	6.83e4	5.43e3	9.27e2	2.78e0	7.69e-2
8	6	7	1.33e5	1.19e5	2.06e4	3.31e3	6.56e0	1.82e-1
9	7	8	7.06e4	6.72e4	1.58e4	3.30e3	4.42e0	2.32e-1

**15. What if I need more than 20 branches?**



In the future, this functionality will be supported. For now, you either have to simplify your layout or look at the mine in sections of 20 branches each and model these individually.

## Appendix: Theory of Radon Decay and Progeny Growth

This program is a model that follows radon through the mine and keeps track of the individual radon progeny. It does not use rule of thumb approximations like 'WL = k\*Rn\*t<sup>0.86</sup>', which are used in some programs. The reader is assumed to be familiar with the Bateman equations for radioactive decay.

We consider a unit volume of air as it moves through the mine. The change in the amount of radon per unit time is given by:

$$dNR_n / dt = S - l_{Rn} NR_n$$

where:

$NR_n$  = the number of radon-222 atoms.

$S$  = the rate at which radon-222 atoms are being added.

$l_{Rn}$  = the decay constant of radon.

The change in the amount of **radon progeny** per unit time is given by:

$$dNP_i / dt = l_{i-1} NP_{i-1} - l_i NP_i$$

where:

$NP_i$  = the number of atoms of the  $i^{th}$  progeny. ( $i=0,1,2,3$  corresponds to Rn-222, Po-218, Pb-214, Bi-214 respectively) .

$l_i$  = the decay constant of the  $i^{th}$  progeny.

We solve these equations by stepping through them in increments of  $TI$  seconds. As long as  $TI$  is much smaller than the half-life of the shortest lived radon progeny, the results will be accurate. As long as  $TI < 15$  seconds the results will be accurate to within a few percent.

$$NR_n = NR_{n0} + S TI - l_{Rn} NR_{n0} TI$$

For the progeny calculations, we use the average concentration of the parent  $NP_{i-1a}$  as the input. For  $i=1$ ,

$$NP_{i-1a} = (NR_n + NR_{n0})/2$$

And for all other  $i$ :

$$NP_i = NP_{i0} + l_{i-1} NP_{i-1a} TI - l_i NP_{i0} TI$$

The total amount of time  $TT$  that is required for the air to traverse the tunnel is the total volume of the tunnel  $VT$  divided by the airflow  $Q$ .

$$T_T = V_T / Q$$

We choose  $T_I$  to be less than 15 seconds:

$$T_I = T_T / (\text{int}(T_T / 15\text{s}) + 1)$$

where  $\text{int}()$  is the truncation operator.