Modelling Underground Ventilation Networks and Radon Flow for Radiological Protection Using VUMA

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Abstract. In uranium mines radon (^{222}Rn) is of major concern for occupational health and the concentration has to be maintained within allowable limits. It is necessary to ensure safe working conditions and occupational health in advance by predicting the expected radon concentrations throughout the underground network and to provide evidence of this in licensing procedures (SSK 1997; IAEA 2004).

This can be achieved by numerical modelling of the ventilation network as well as the contaminant transport. All flow modelling efforts require the geometrical setup of an underground network and validation. The resulting model of the network can then be used for the development of ventilation strategies with regard to contaminant transport.

This study presents the modelling of radon flow in a ventilation network of a hypothetical uranium mine using VUMA. The ventilation is modelled using the "fixed flow" option. The radon concentrations are computed using non-site-specific but realistic radon sources. Sensitivity is studied by varying the locations and exhalation rates of radon. The results are evaluated in terms of radon concentrations and compared to allowable limits.

The results of this study using VUMA show its applicability for modelling radon flows. VUMA may be used to assess the requirements for ventilation strategies to comply with regulations for occupational radiation protection. Additional conclu-

sions can also be drawn for effective energy management as well as safe working conditions in mines.

Description of VUMA

VUMA is a Windows-based software package for simulating atmospheric and environmental conditions in underground mines (Marx et al. 2001).

VUMA allows a mine network to be built up by linking underground elements such as tunnels, shafts, fans, control elements including air coolers and regulators. In such a network the fluid and heat flow, temperature, humidity as well as dust and contaminant/gas concentration distribution can be numerically modelled. The "steady-state" simulation of the flow allows evaluating the aerodynamic, thermodynamic and contaminant dynamics effects for all network components simultaneously accounting for natural ventilation effects and density changes.

The set-up of a geometrical model of an underground mine and its verification by using actual ventilation data permits the use of this "calibrated" network to monitor the details of the ventilation operation and to plan the necessary changes for new ventilation strategies. The contaminant transport is modelled in VUMA as tracer in the air flow throughout the network. Gas or dust sources can be introduced in each network component and the transport can be monitored for selected/expected flow conditions. In addition radon exhalation as well as its transport taking the decay into account is allowed to be simulated. The radon exhalation rate should be entered into the network components and the steady-state radon concentration distribution can be calculated as function of the aerodynamic conditions.

The big advantage of VUMA is that the geometric view in 3-D is based on real co-ordinates. A diagrammatic view introduces an artificial level spacing to enhance visibility of levels.

When networks are viewed, results are displayed graphically by colouring nodes and/or branches in correspondence with a colour bar graph. The colour bar graph indicates the full range of values from minimum to maximum of the parameter being displayed at that stage.

The network model

A ventilation network is created for a hypothetical uranium mine. The network consists of approx. 225 ventilation components, mainly tunnels and two main shafts in four horizons, at 165 m depth, 206 m depth, 250 m depth and 275 m depth. The north-south extension of the network reaches approximately 2000 m, and east-west extension up to 1000 m (see Fig. 1). The geometry of the tunnels is

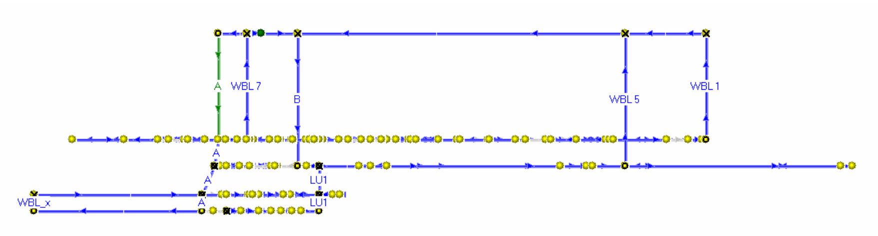

Fig. 1. Strike view of the network model.

held constant namely as regular quadratic in shape with dimensions of 3x3 m. The shafts are introduced as regular circular in shape with a diameter of 4 m.

Ventilation of the network

Realistic ventilation parameters of real mines are used. The distribution of the incoming fresh air throughout the network is performed by using the “fixed-flow” option for some main tunnels and shafts to allow a simple and a robust ventilation design. The main modelling purpose is modelling of the radon concentration. The friction factor is constant for all tunnels. The flow rate in the tunnels of the network is shown in Fig. 2.

Fresh air is provided from two shafts with a total flow rate of approximately 110 m^3/s. The air is discharged from the four venting shafts from the upper two levels at 165 m and 206 m depth. As can be concluded from Fig. 2 most tunnels are ventilated with air flow smaller than 10 m^3/s. A linear color scale ranging from zero (dark blue) to maximum value (red) is applied to all figures in the following.

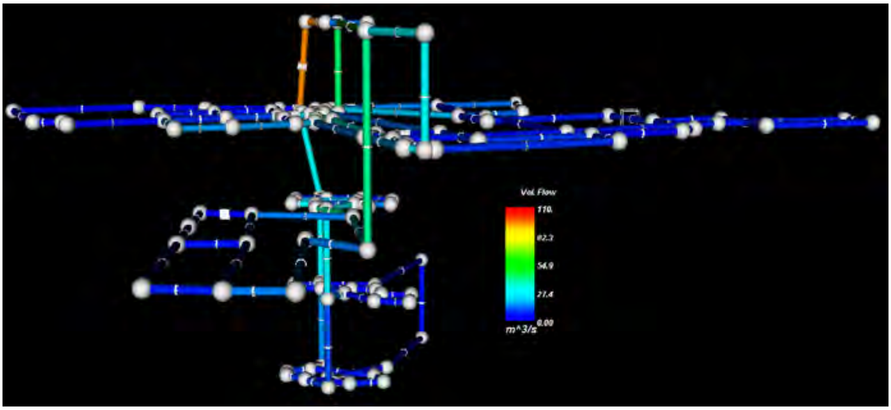

Fig. 2. Flow rates in the network.

Calculation of Radon concentration

Basic scenario

The radon exhalation is set at a uniform rate of 2 Bq/(m^2.s) in all tunnels. This is within an expected range for uranium mines. The result is depicted in Fig. 3.

The total ^{222}Rn discharge is 348 kBq/s rsp. 11 TBq/a. The highest radon concentration at a venting shaft is 8 kBq/m^3, whereas a high radon concentration of 2600 kBq/m^3 is observed in a tunnel at the level 165 m. Most radon concentration are below 250 kBq/m^3 (blue).

Additional scenarios

Some demonstrative changes to the basic parameters are made in order to study the effects on the radon concentration.

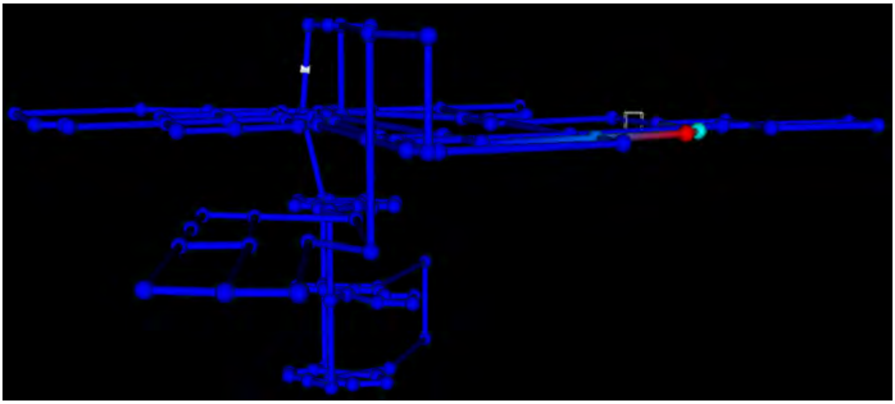

Fig. 3. Radon concentration using a uniform exhalation rate.

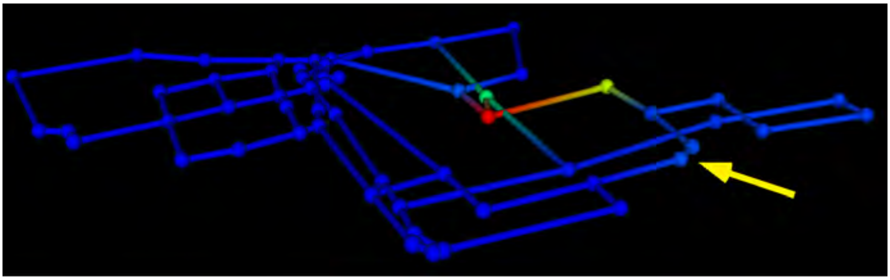

Fig. 4. Radon concentration of level 165 m after redirection of flow.

Redirected or increased ventilation rates

Redirecting the air flow can lower high radon concentrations. The low flow rate of the tunnel with a high radon concentration in Fig. 3 was increased to 8 m^3/s using the fixed flow option (yellow arrow, Fig. 4.). The resulting distribution of ^{222}Rn concentrations is shown in Fig. 4. The maximum radon concentration is relocated and reduced to 1400 kBq/m^3. Subsequent testing will improve the ventilation network to comply with occupational radiation protections limits.

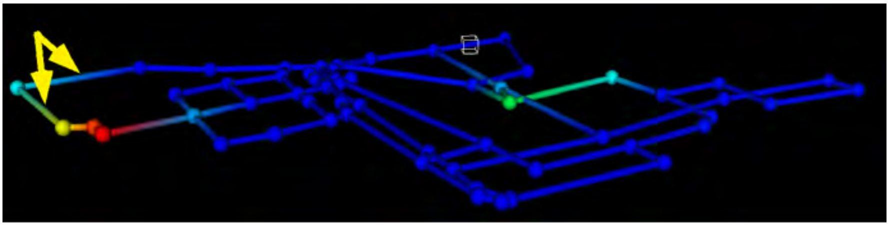

Fig. 5. Radon sources and concentration at level 165 m.

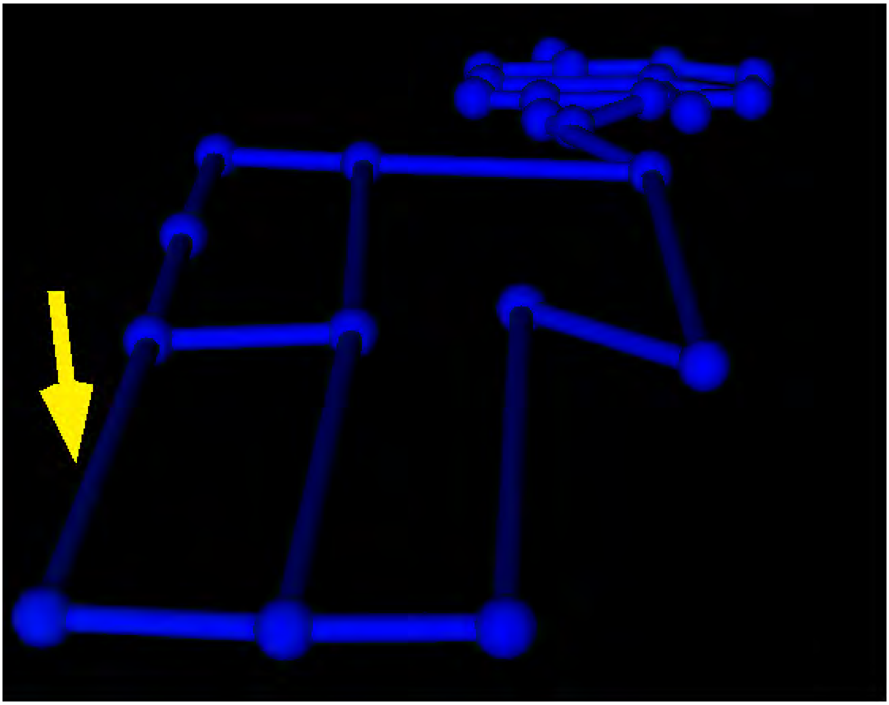

Fig. 6. Radon source and concentration at level 206 m.

Increased local radon sources

Localised radon sources are defined with increased exhalation rates of 2000 Bq/(m2.s) in two tunnels on level 165 m and one tunnel on level 206 m. The sources are indicated (yellow arrows) in Fig. 5 (level 165 m) and Fig. 6 (206 m) and the resulting radon concentration is shown. Increased 222Rn concentrations are observed for level 165 m (up to 3320 kBq/m3). Most radon concentration are below 330 kBq/m3. The tunnel at level 206 m has 132 kBq/m3 222Rn. The total 222Rn discharge is increased only slightly by 14 kBq/s to 362 kBq/s rsp. 11.4 TBq/a.

Discussion and Summary

ISTec has introduced VUMA as a new tool for modelling ventilation of underground networks with respect to radon. Setting up a network is time consuming since a large amount of network information is required for a detailed evaluation.

A comparison with other software for modelling of underground mine ventilation shows superior graphical display capabilities which allow an easy understanding of contamination pathways.

Testing on a hypothetical uranium mine network yielded reasonable results. The values calculated for radon concentration in this example have been relatively high since 1 kBq/m^3 ^{222}Rn is already close to the working limit of 40 MeV/cm^3 (depending on equilibrium factor). The average radon discharge of approx. 3 kBq/m^3 (radon discharge of 348 kBq/s, air flow 110 m^3/s) clearly shows that not all locations can comply with this limit.

VUMA also allows adjusting additional parameters such as temperature, pressure and humidity. These options are not discussed with the work presented here.

If a reasonable database (underground network, validated set of parameters and flows) is provided this tool is able to model the radon concentration and to assess the compliance with occupational radiation protection limits. In addition it would allow to assess further details, such as energy costs, and to figure out an efficient ventilation strategy.

Conclusion

The results of our study show the applicability of VUMA for modelling radon concentration in underground networks of uranium mines. VUMA may be used to assess the requirements for ventilation strategies to comply with regulations for occupational radiation protection. Additional conclusions can also be drawn for effective energy management as well as safe working conditions in mines.

References

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