Life-of-mine ventilation and refrigeration planning for Resolution Copper Mine

by S. Bluhm*, R. Moreby†, F. von Glehn*, and C. Pascoe‡

Synopsis

Resolution Copper Mine is planned to be a 2000 m deep panel cave mine with virgin rock temperatures above 80°C in rock with a high crystalline silica content. The planned run-of-mine production rate is 120 kt/day.

The project is in prefeasibility evaluation. This paper discusses features of the ventilation system design, which include multiple ventilation shafts with total flow of about 3000 m^3/s and both surface and underground refrigeration systems with more than 140 MW total capacity. This will be a very challenging mine to ventilate, but this work has demonstrated that it will be technically achievable with the application of existing technology.

Keywords

mine ventilation, mine refrigeration, dust management, heat load, modelling.

Introduction

The Resolution Copper project is located 110 km southeast of Phoenix, Arizona and is run by Resolution Copper Mining (RCM), which is owned by Rio Tinto and BHP Billiton. The orebody is a large, deep, high-grade porphyry copper deposit located close to the historic Magma Vein (Pascoe, Oddie, and Edgar, 2008). The mine is planned to be a large block cave operation and is currently at the prefeasibility stage. Assessment for the life-of-mine and ventilation studies has been done to establish ventilation distribution layouts, and ventilation and refrigeration needs and strategies.

Although the mine development phases are hugely important to the project feasibility, this paper concentrates more on the ventilation designs for the fully established life-of-mine scenarios. Furthermore, while refrigeration will be important to the project, this paper discusses the ventilation issues in more detail than those of refrigeration.

The run-of-mine production rate will be 120 kt/day and the mining method will be an advance undercut panel cave operation using single panels. The mine will employ three hoisting and service shafts and three upcast shafts. Electrical loaders will be used for production, but diesel equipment will be used for development and undercutting. There will be an electrical rail haulage system reporting to the crushers, from which a belt conveyor will report to the hoisting shaft(s) loading facilities. There will be midshaft skip discharge, and from there another conveyor system will transport ore to the surface plant.

The orebody has a high silica content that will create serious challenges for dust control. Furthermore, the mine will be deep, with high virgin rock temperatures. Thus dust and thermal issues dominate the design evaluations and, obviously, diesel particulate matter (DPM) management will also play an important role.

Design criteria

Silica/quartzite levels

The main mining activity will be in rock with an average quartz content of 37 per cent and – depending on how crystal boundaries break – it is possible that the respirable dust fraction will have a free crystalline silica content up to 45 per cent. This high silica content will create serious challenges for dust control; however, with the highly mechanized operation most workers will not be in dusty areas for significant periods. Thus the maximum free crystalline silica limit was taken as 0.1 mg/m^3 (40-hour time-weighted average) with a short-term exposure limit of 0.3 mg/m^3. The control of respirable dust will be a very significant issue and the best practice in terms of dust control measures will be applied.

---

* *BBE Consulting.*

† *Morevent Mining.*

‡ *Mine Consulting, Rio Tinto.*

ISSN 2225-6253. This is an abridged version of the 2014 Best Paper Prize, originally presented at The Australian Mine Ventilation Conference 2013. A full version of the paper is available via the AusIMM website at www.ausimm.com.au/shop.

Temperature issues

The general geothermal gradient is 2.7°C per 100 m and the virgin rock temperatures on the crusher-to-conveyor level at 2180 m depth will be 83°C. The thermal conductivity will also be relatively high-particularly in quartz rich areas (4.8-6.6 W/m² °C).

Figure 1 presents surface design ambient temperature data. After detailed statistical evaluation, the design conditions were taken as 21/37°Cwb/db (wet bulb/dry bulb) at 88 kPa barometric pressure.

The refrigeration required depends on the design temperatures and balancing of the heat stress management needs with the cost of refrigeration. The design reject temperatures have been taken as 27.5/37.5°Cwb/db in development faces where personnel could be outside air-conditioned cabins, and 30/40°Cwb/db in production crosscuts where equipment is operated remotely. Heat stress management systems will be set up to determine different levels of operational control for rapid decision-making with various heat-related interventions.

Diesel particulate matter exposure management

In addition to the dust and heat, DPM management will be an important design issue (NIOSH, 2011). Controlling employee DPM exposure to less than the current tolerance level values and potential future values will be addressed by management plans, including:

- ➤ Underground diesel vehicles with tier-3 or tier-4 engines using high-quality, low-sulphur fuel
- ➤ Exhaust conditioning over and above that provided normally on engines will be applied
- ➤ Operators to be in air-conditioned cabins with filtered intake where possible
- ➤ Series ventilation will be minimized or avoided altogether due to heat considerations
- ➤ Diesel vehicles will be operated according to a site-specific, risk-assessed DPM control plan.

Features of the fully established mine

The critical design year snapshot in the life-of-mine (Figure 2) was selected for sizing the ultimate ventilation and refrigeration needs, and this is the basis of the detailed VUMA modelling.

At this phase, the basic underground vehicle complement and equipment will be:

- ➤ Diesel auxiliary and service vehicles 8.0 MW
- ➤ Diesel loaders and diesel rockbreakers 4.2 MW
- ➤ Electrical loaders on the extraction level 4.6 MW
- ➤ Drill rigs (blind borers, raise borers) 4.1 MW

The following general 'infrastructure' zones were accounted for in the modelling: workshops, warehouses, batch plant, pump stations, refrigeration plant chamber, conveyor belt system to hoisting shaft facilities, crusher station, electrical substations, etc. In these zones the ventilation requirements will relate to the equipment/activities such as diesel vehicles, welding, pumps, compressors, vibratory feeders, belt conveyors, dust collection, fans, transformers, belts, fans, lights, etc.

Heat from broken rock

The broken rock flow rate will be large and the rock will be hot, thus creating a significant heat load. Hypothetically, the 'worst case' would be if all rock enters the draw points at the virgin rock temperature and leaves the mine at the ambient underground temperature.

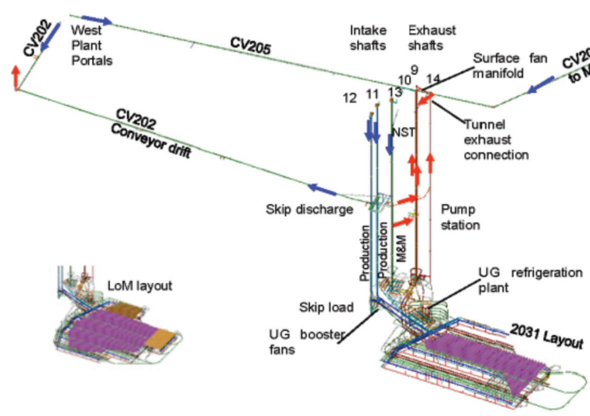

Figure 2—Snapshot at critical design condition

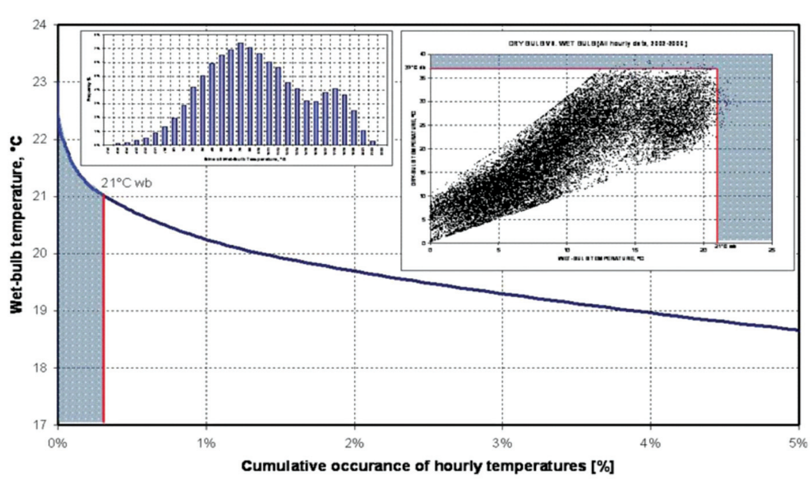

Figure 1—Surface ambient temperature data

Assuming basic parameters, this 'worst case' hypothetical potential heat flow will be of the order of 60 MW. This is large but it presents potential mitigation opportunities by reduced residence times in intake airways or separation of haulage route and crusher ventilation circuits from other intake airways.

The estimation of the heat load from the broken rock involved the fundamental assessment of residence time in various sections (Figure 3), rock sizes, and transient cooling in broken rock masses. While this required simplifying assumptions, it supplied order-of-magnitude guidance and indicated that about 50 per cent (30 MW) of the 'worst case' hypothetical potential will manifest itself in the underground mine. The remaining potential heat will be in rock that leaves the mine in a 'still hot' condition.

Primary ventilation system

Primary ventilation flow rates

The overall primary ventilation distribution is 2760 kg/s (or 2345 m³/s) to the underground workings. The total flow from surface will be 3120 kg/s, with the difference being that used on the midshaft skip discharge level. During full production, the needs will be dominated by the 70-odd extraction drives with 35 regulated exhaust raises serving each pair. Some of the specific considerations included:

- Development crew allocations based on two separate active faces per crew with exhaust vent raises installed to limit force duct lengths to <500 m
- Undercut and drawbell levels involve both development and mucking of swell
- Extraction drives will have remotely controlled electric loaders only
- Potential for high dry bulb temperatures will be prevalent on the production level and liberal amounts of water will be used for controlling temperature and dust
- Ventilation for fuel/tyre bays will report directly to return airways, but other workshop ventilation will be re-used
- Dust management will be based on capture velocities of about 2.5 m/s applied to the cross-sectional area of the capture point
- Midshaft skip discharge dust control will use a return connection to No. 14 Shaft exhaust
- The underground conveyor ramp with crusher station and rock handling systems will be isolated as an independent ventilation district.

Comparison with other block cave mines

Figure 4 compares the planned ventilation requirements for RCM and those of some other block cave mines. Considering the need at RCM to manage high heat loads and to allocate relatively large flow rates for controlling dust, this comparison indicates that the planned ventilation rates are consistent with those employed at other block cave mines (assuming flows reported for the other mines are at surface density).

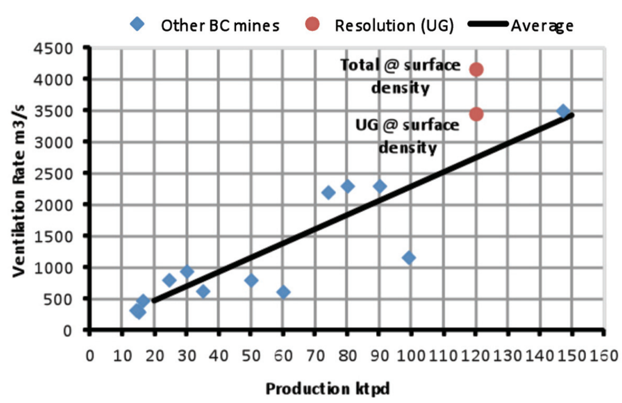

Figure 4—Resolution ventilation rate benchmarking

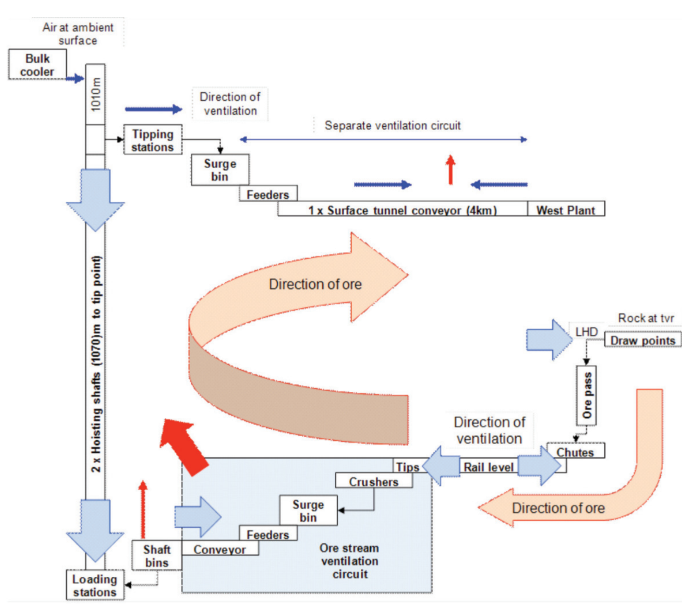

Figure 3—Ore transport flow chart

Shafts and primary ventilation infrastructure

Figure 5 shows the life-of-mine primary ventilation circuit. No. 11, No. 12, and No. 13 Shafts will downcast and No. 9, No, 10, and No. 14 Shafts will upcast together with exhaust via the conveyor drift.

Provision is made for a return connection between the skip discharge zone and midshaft pump station to the exhaust shafts and conveyor tunnel to surface. The ventilation distribution in each airway, with the exception of the conveyor and regulated returns, is based on free splitting out of the shafts and through the workings. The return ventilation from the mining block will join the return air from the ore handling system and flow in the main return system to the upcast shafts. The underground return airways will operate at near-limiting air velocities for occasional vehicle or pedestrian access. The main fan stations will be installed on surface and will operate in exhaust mode. To allow for phased increase in ventilation capacity, available surface space during sinking, and long-term security of production, it is planned to connect all exhaust shafts together in a manifold configuration (all fans connected to all shafts).

High-speed intake airways with booster fans

The primary intake infrastructure will include two large airways (each >60 m²) that will be used as high-speed dedicated intakes. These airways will be no-go zones and will be operated at air speeds >11 m/s, and they will carry more than 60 per cent of all underground ventilation (below skip discharge level). Booster fans will be installed in each of the airways with the objective of optimizing the carrying capacity of these large airways as well as controlling air velocity in other trafficable airways. Each of these fan stations will have four fan motor sets (each 250 kW) installed in parallel.

Undercut levels

There will be two undercut levels (spaced at 20 m) in order to achieve the required wide inclined undercut for cave initiation. The undercut levels are generally challenging from the ventilation perspective, and they were examined in particular detail with stand-alone VUMA models. In the models, provision was made for dead-end swell mucking, rim tunnel and crosscut development, and cubbies for swell muck dump every 200 m.

Production level

Once steady production has been achieved, there will be up to 70 open, 150 m long production crosscuts. Of these, 35 production crosscuts will be active (35 electric loaders will be mucking) and 35 production crosscuts will be available for operation. The production crosscut allocation alone is 840 kg/s. The air will be distributed to open production crosscuts by regulators or secondary fans in the return raises, controlled from a central control station. This is a relatively low air allocation and the ventilation distribution control will be challenging. This specific VUMA model was scrutinized in detail (Figure 6).

Dust management

The management of respirable dust will be very important because of the high levels of silica. The dust will have to be suppressed, captured, or report to return airways. The main strategy will be to direct contaminated air to return airways and for this, significant ventilation capacity has been allocated. With respect to control of respirable dust, provision will be made for industry best-practice dust controls such as:

- Dedicated exhaust ventilation systems with large flows. In total, there will be 755 kg/s (25 per cent of the entire primary ventilation) allocated to dust control direct to return
- Remote loading of extraction level with operator location on the intake side
- Extensive use of water sprays (which will also help control high dry bulb temperature) at draw points and loading/transfer points, thus wetting broken rock to at least 2 per cent moisture
- Road base maintenance and dust suppression with water suppression sprays in all roadways for routine and controlled wetting
- Limited access to return airways
- Overall layout design will minimize the need for filtration and re-use of contaminated air. However,

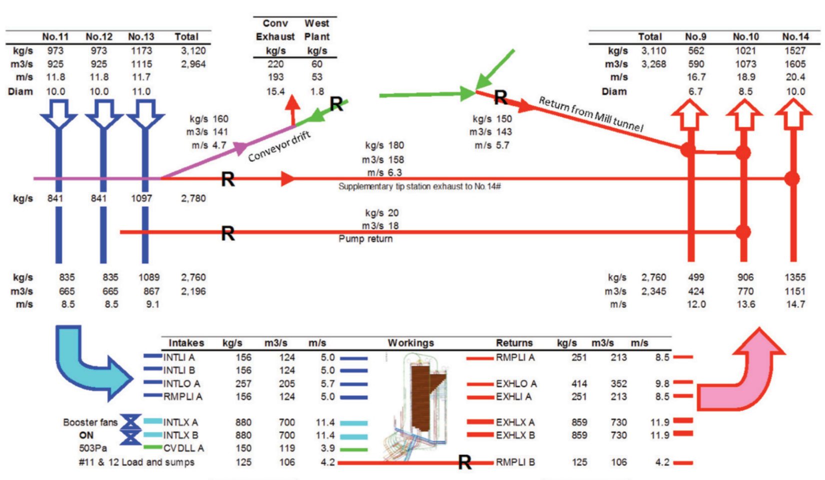

Figure 5—Distribution of ventilation

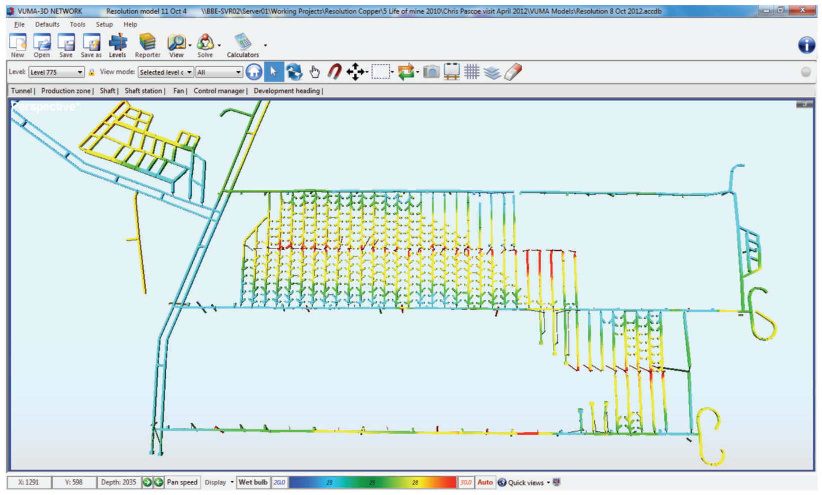

Figure 6—Production level temperatures (blue = 20°Cwb; red = 30°Cwb)

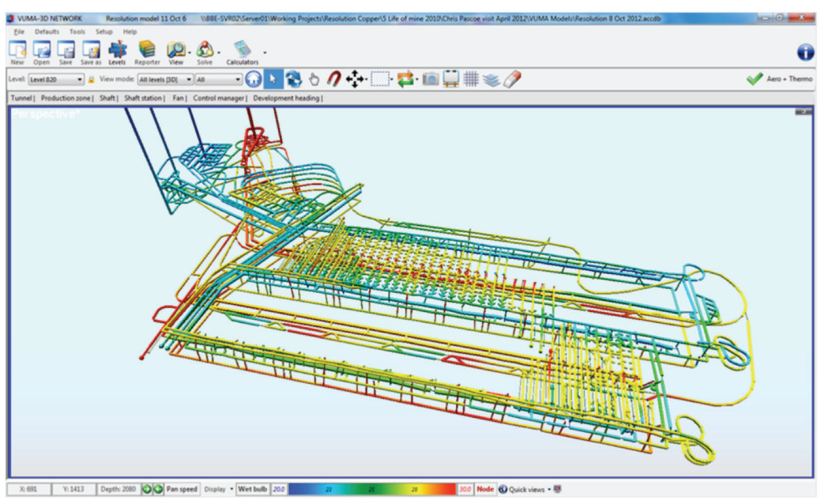

Figure 7—Ultimate VUMA model (blue = 20°Cwb; red = 30°Cwb)

some filtration may be needed in areas remote from return airways such as main conveyor transfer points and secondary belts

- Extensive use to be made of PPE and personnel will be trained in the control of exposure to respirable dust
- Respirable dust sampling regime will be set-up to monitor employee exposure and samples will be analysed for composition, including respirable free silica in its various forms.

The following dust generation and ore transfer points have been accounted for: extraction level loader transport and tipping; rail loading level; rail tip to belt feeders (rail tip level, crusher level, transfer conveyor feeders); skip loading; skip discharge, shaft-to-surface conveyor drift.

VUMA heat load and energy balance modelling

The design snapshot scenario (Figure 2) was selected as the critical design year for sizing the ultimate ventilation and refrigeration needs. VUMA software was used to model the full mine layout and to simulate the different ventilation strategies. This includes the full interactive simulation of the heat flow, ventilation, and cooling systems to determine the air temperatures, flow rates, heat loads, and cooling requirements (Figure 7). The simulations take full account of the block cave mining details, and this software is unique in that it deals with the important effects of broken rock and advancing rock faces.

This design snapshot relates to the period when the first panel is approaching completion and the second panel is starting production. Other scenarios towards the end of life-of-mine as well as the development phases were modelled separately (but are not discussed here).

The heat load due to all the mobile equipment and static equipment facilities was input at the relevant nodes and branches, as was the heat flow from the broken rock discussed above. The models indicated that the mine heat loads will be satisfied with the following ventilation resources:

- Chilled ventilation downcast ex from surface 3120 kg/s at 10.5°Cwb

- Surface bulk air cooler duty 105 MW
- Chilled service water 50 L/s at 4°C
- Underground secondary air coolers 35 MW

The global energy balance can be satisfied by different combinations of higher air flow rates with cool air or lower air flows with colder air. The optimum is dictated by issues such as available downcast capacities, overall costs of the ventilation and cooling systems, standard equipment capacities, and phase-in needs.

Following a number of iterations that included the shaft(s) sizing, sensitivity studies (more/less underground refrigeration, use of ice, etc.), the above mix of flow rate and refrigeration capacity is considered to be close to optimum. Trade-off studies were conducted with different splits between surface and underground refrigeration and the manner in which the cooling is distributed.

In summary, a significant refrigeration capacity will be on surface. However, the underground refrigeration will be extremely important during the development phases and will provide the essential high positional efficiency air coolers directly in the workings during production phases.

Description of refrigeration system

Surface refrigeration system

The surface refrigeration system will comprise:

- Central surface refrigeration plant room and refrigeration machines (and thermal store)
- Surface bulk air coolers at each downcast shaft
- Service water refrigeration system to provide chilled surface water to underground.

From the central plant room, chilled water will be served to surface bulk air coolers at each of the downcast shafts. In addition, there will be a supplementary surface refrigeration system that will provide general chilled service water to underground.

The primary refrigeration system will comprise main base load machines prechilling water flow from the bulk air coolers. From these plants, chilled water will then flow to the thermal storage dam containing tube banks through which subzero glycol is circulated. Ice will be formed on the outside of the tubes during the colder part of the day and then melted by the circulating water during the warm part of the day. The chilled water will leave the thermal storage dam at temperatures close to 0°C. The thermal storage will allow peak load damping and optimal energy management.

The combined plant and ice store system will provide 109 MW nominal refrigeration capacity.

There will be a number of large refrigeration machine modules chilling water and glycol. All the machines will be similar, with interchangeable components. The refrigeration machine modules will be factory-assembled and packaged plants with R134a centrifugal compressors and shell-and-tube evaporators/condensers. Each plant will have differing process conditions that will depend on final equipment selection. However, for example, the lead water chilling plants will have a refrigeration duty of 22 MW.

Each of the downcast shafts will be served by bulk air coolers in the form of horizontal spray heat exchangers in which the air is forced through an intense spray of chilled water in a horizontal concrete tunnel (Bluhm *et al.*, 2001). Within the sprays, heat exchange will occur directly across the large surface area of the spray drops. Where the cool air emerges from the chamber, mist eliminators will be installed to ensure that no water is carried out. For example, the No. 13 Shaft bulk air cooler will have a cooling duty of 40 MW.

Chilled service water will be a very important part of the underground cooling. The chilled service water will be used for dust control, localized cooling sprays, and mine service needs and will provide effective localized cooling wherever it is applied. Thus, on surface, in addition to the main refrigeration system, there will be a separate independent surface refrigeration system that will provide general chilled service water to all the underground workings.

Underground refrigeration system

The underground refrigeration system will comprise two main components:

- Centralized underground refrigeration plant chamber and refrigeration machines
- Suite of underground air coolers and cold water distribution system.

There will be a single central underground refrigeration plant chamber located near the mining block off the exhaust vent level. The return ventilation system will be used for heat rejection from the refrigeration plant. The refrigeration machines will provide cold water, in an insulated closed circuit network, to air coolers situated strategically throughout the workings.

The required secondary air cooler overall duty will be 35 MW and the underground refrigeration plant will provide 40 MW capacity to overcome losses.

The refrigeration installation will ultimately have five 8 MW machines operating (plus one standby). The machines will operate in parallel and this arrangement will allow the system to adjust to changes in demand. The machines will use refrigerant R134a and will include high-speed, multistage, centrifugal compressors. The refrigeration machines will be identical packaged units with compressor motor sets and shell and tube evaporators/condensers.

The plant room layout includes two machine rooms with the chilled water pumps and condenser water pumps grouped in common pump chambers adjacent to their respective dams. Rejected heat will be in cooling towers in the form of spray filled vertical excavations rejecting heat into the return ventilation. The refrigeration plant will be adjacent to two large main return airways and a large part of the return flow will be directed to the cooling towers.

For the ultimate life-of-mine scenarios, there will be numerous underground secondary air coolers with duties ranging from 0.5-3 MW, with a total duty of 35 MW. These secondary air coolers will be in the form of closed-circuit cooling coils. The main chilled water piping will comprise a 500 mm insulated system near the plants, reducing as the network splits up to ultimately 150 mm insulated pipe sections.

Conclusion

Resolution will be a deep, hot, block cave operation with 120 kt/day production. The rock will have a high silica content and the mine will be deep in hot virgin rock temperature. Thus dust issues and thermal issues dominate the design evaluations.

The mine will employ three hoisting and service shafts and three upcast shafts, and the total primary ventilation capacity will be about 3000 m³/s. The general approach to dust management will be to direct contaminated air to return, and some 25 per cent of the total primary air flow will be allocated in this manner. The primary intake system will include two large airways which will be used as high-speed dedicated intakes with booster fans. These airways will be no-go zones operating at high air speeds and will carry more than 60 per cent of all underground ventilation.

VUMA software was used to model the full mine layout and simulated different ventilation and refrigeration strategies. The simulation uses an iterative process to determine heat loads and cooling needs as well as the sizing and positioning of refrigeration system components. The large heat load components were the broken rock flow, surrounding rock conduction and mobile and static equipment facilities. The refrigeration systems will include 105 MW surface bulk air cooler duty and 35 MW underground secondary air cooler duty.

This will be a very challenging mine to ventilate and cool, but this work has demonstrated that it will be technically achievable with the application of existing technology.

Acknowledgement

Permission from Rio Tinto RCM to present this paper is gratefully acknowledged.

Refsernces

BLUHM, S., FUNNELL, R., and SMIT, H. 2001. Horizontal spray chambers for surface bulk air cooling. *Proceedings of the Seventh International Mine Ventilation Congress*, Cracow, Poland.

ISO. 2004. Standard 7933, Ergonomics of the thermal environment – analytical determination and interpretation of heat stress using calculation of the predicted heat strain. 2nd edn. Geneva.

NATIONAL INSTITUTE OF OCCUPATIONAL SAFETY AND HEALTH (NIOSH). 2002. NIOSH Hazard Review, Health effects of Occupational Exposure to Respirable Crystalline Silica. Atlanta, GA.

NATIONAL INSTITUTE OF OCCUPATIONAL SAFETY AND HEALTH (NIOSH), 2011. Diesel Aerosols and Gases in Underground Mines: Guideto Exposure Assessment and Control. (eds.) Bugarski, A.D., Janisko, S.J., Cauda, E.G., Noll, J.D., and, Mischler, S.E. Report of Investigations 9687. Atlanta, GA.

NATIONAL TOXICOLOGY PROGRAM (NTP). 2003. Silica Crystaline (Respirable Size), US National Toxicology Program. US Department of Health and Human Services, Research Triangle Park, NC.

PASCOE, C., ODDIE, M., and EDGAR, I. 2008. Panel caving at the Resolutioncopper project. *Proceedings of the Fifth International Conference and Exhibition on Mass Mining*, Lulea, Sweden. ◆

AusIMM President Geoff Sharrock FAusIMM(CP) presenting the 2014 AusIMM Best Paper prize to Steven Bluhm in Cape Town