

Ventilation and Refrigeration Project for the Deepened Section of Turffontein Shaft

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SYNOPSIS

This paper describes a ventilation and refrigeration system design case study for the deepening of the existing Turffontein Shaft of Rustenburg Platinum Mines Limited (Rustenburg Section) and how the deepest large diameter raise borehole was planned to solve the problem.

BACKGROUND

The mine is situated in the Bushveld Complex about 20-km east of Rustenburg in the North West Province. Production stems from the Merensky reef, which is currently being mined between 18 and 30 Levels some 630m to 1 147 metres below surface, with a virgin rock temperature ranging from 35°C to 46°C.

An incline cluster system is planned from 20 to 36 Levels, between 1 105 - 1 450m below surface to provide the lower longwalls as the upper longwalls are depleted. The area has a virgin rock temperature from 45°C to 53°C.

Optimisation simulations indicated that 350kg of air should continue to downcast through the existing Turffontein Vertical Shaft and an additional 300kg/s must enter through a new shaft to 29 Level. The use of a raise-bore to develop the ventilation shaft was found to be the best economic option but would require detailed planning as this would be the deepest hole (1 105m) of this size (4,4mØ) ever drilled.

The raise-bore shaft will not be equipped. Special high pressure "Mannesman" type steel pipes will be suspended from the surface to 29 Level. This will be another first in the mining industry.

INTRODUCTION

The deepest raise-bored shaft in the world was completed on the 22 December 1994.

This paper discusses the factors leading to the decision to raisebore the shaft, the difficulties experienced during the raiseboring, and how the shaft will be utilised.

CURRENT INFRASTRUCTURE

The existing mine ventilation system at Turffontein Shaft comprises the following:

The existing Turffontein Shaft is an 8,53m diameter vertical shaft down to 29 Level. A centralized return airway incline system in the footwall, from 29 Level to 20 Level, is connected to the bottom of a 6,15m diameter up-cast-shaft.

These return airways will eventually be extended from 29 Level down to 35 Level as mining progresses.

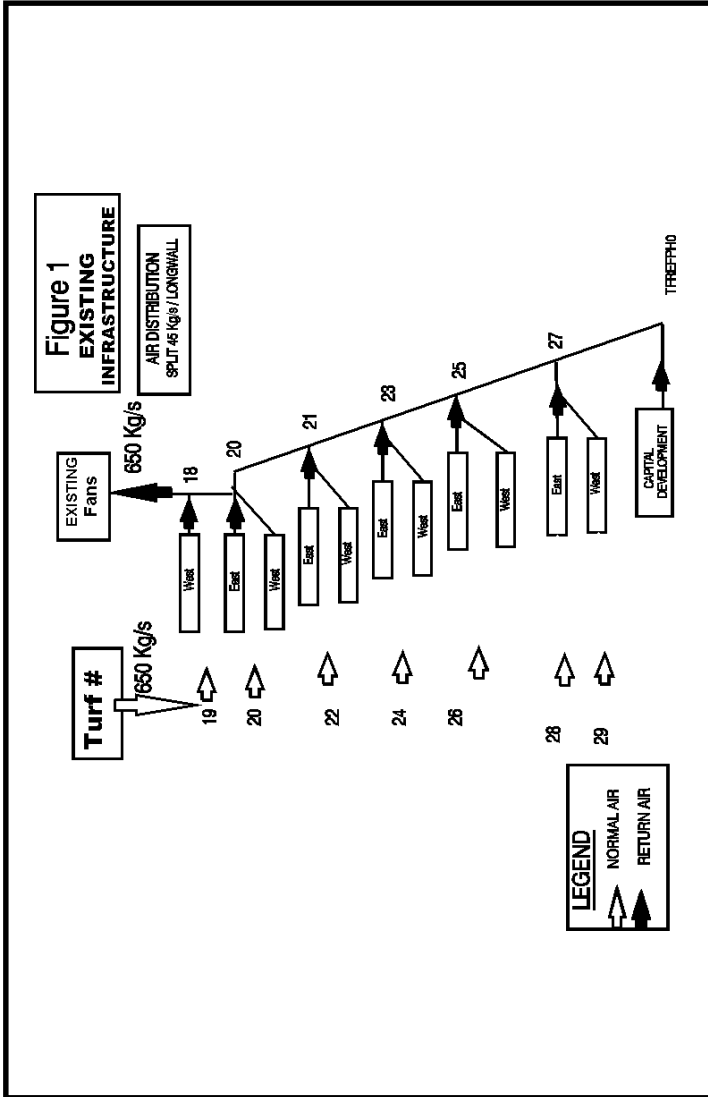


Figure 1
Existing Ventilation & Mining Infrastructure

Mining currently consists of semi-longwall and scattered mining between 18 and 30 Levels.

Mining activities are planned to extend down to 36 Level, where the deepened section of the Mine will be served with an incline cluster system from 29 Level. This will consist of a material, chairlift and belt incline, serving conventional longwall mining operations.

The upcast-shaft is equipped with three ventilation fans, two operational and one on stand-by. The two operating fans are currently operating at 650 m³/s at 5800 Pa.

THERMAL GRADIENT

The mine exploits the Merensky Reef in a geological structure known as the Bushveld Complex, comprising mainly Norite and various types of Anorthosite. These structures have relatively low thermal conductivity and correspondingly high geothermal gradient.

Observations down to 1 147m below surface indicate a virgin rock temperature to depth correlation, formula as below.

$VRT\text{ }^{\circ}\text{C} = 0,02195 * D + 20,8374$ (where D is in metres below surface.)

This formula implies a 2,2 °C increases per 100 metres vertical depth.

With mining activities extending to greater depths, 36 Level is expected to be a VRT of 52°C, resulting in unacceptable working conditions, with associated adverse effects on production.

PRODUCTION

Currently Merensky Platinum ore is being mined from six longwall production areas at a planned maximum production target of 174 kilo tonne/month between 18 and 30 Levels, between 630m - 1 147m

below surface, with a virgin rock temperature ranging from 35°C to 46°C.

The planned production target on average is about 30 000 tons per longwall area per month (Reef and Waste) with two longwalls per longwall area.

In order to maintain the production rate at 174 kilo tonne/month replacement longwalls are planned from 30 down to 36 Level.

VENTILATION

Numerous heat flow and ventilation simulations were carried out. Modelling of ventilation leakage, heat transfer related to VRT, auto compression, shaft station areas, mechanical equipment such as electrical sub stations, fans, pumps, etc. using the ENVIRON2 computer simulation package confirmed the best option.

Initially, most of this unrefrigerated air will be used to serve the upper levels, whilst the remaining air will be mixed with the cooled air from the raisebore shaft. This mixture of air will be further cooled down at the entrance to the longwalls, using a closed circuit pipe coil cooling car system. As the 34 and 36 Level longwalls are planned only to be in production by the year 2002 and 2005 respectively, it was decided to divide the refrigeration into two phases.

Initially a 9,6 MW Ammonia refrigeration plant is installed on surface to serve the Bulk Air Cooler on surface. During Phase II this plant will also provide chilled water to underground spot coolers. For Phase III a second identical 9,6 MW refrigeration will be installed to provide chilled water for the underground spot cooler through a dedicated raisebore shaft.

During Phase I, 300 kg/s of the existing 650 kg/s of air circulating through the mine will be cooled to 9°C saturated, using a 9,6 MW ammonia refrigeration plant and bulk air cooler situated on surface. The remaining 350 kg/s of air will continue to downcast at the existing

Turffontein shaft.

RAISEBORE OPERATION

Although South Africa is the world leader in conventional shaft sinking operations, the advantages of raise-boring the 4,4m diameter unequipped, unlined, vertical ventilation shaft, outstripped conventional shaft sinking in all respects.

- **SAFETY:** a total of 6 408 underground shifts and 14 443 surface shifts were completed. Two shifts were lost due to a slip and fall related injury on surface.
- **COST:** Raise-boring the shaft amounted to R13,3 million, as opposed to R50 million for conventional shaft sinking.
- **Rapid advance rate.**

DETAIL OF EQUIPMENT USED

The Machine

A Wirth HG 330 SDII machine was used. The HG330 is an all-hydraulic machine designed to drill shafts of up to 6 metres diameter, to depths of more than a 1 000 metres in hard rock formation.

Technical data of the WIRTH HG 330 SP machine:

Installed power	:	440 kW
Operating torque	:	540 kN/m
Breakout torque	:	648 kN/m
Reaming pull	:	1 000 kN
Rotation speed	:	0-48 rpm
Derrick height/mass	:	6,85/75 tonnes
Drill string diameter	:	330 mm: 260 mm
Raise diameter	:	4,44m

Raise length : 1 105m

Drill string

Special 330-mm diameter drill rods were used, each 1,52 metre long with a mass of 685kg. The total mass of the 1 105-metre drill string equaled 498 tonnes. Torque and tension on the drill string were limited by setting pressure relief valves on the machine.

Reaming Head

Sandvik Rock Tools, South Africa, supplied the reaming head and cutters on a contract basis. A CRH 10E type head was employed.

Types of cutters used were:

- 6 x Sandvik Part No 7008-4141-76-4 Row
- 6 x Sandvik Part No 7008-4241-76-4 Row
- 6 x Sandvik Part No 7008-4152-76-3 Row
- 6 x Sandvik Part No 7008-4252-76-6 Row

Pilot Drilling

A 340-mm pilot hole had to be drilled to a total depth of 1 105m. Directional drilling of the pilot hole was not required.

Flushing of the pilot hole was achieved through circulating clear water at a rate of 70 litres/second, at a minimum pressure of 10 Bar.

Pilot drilling commenced in November 1993 and was completed in February 1994.

Collaring of the hole was carried out at a rate of 0,62 meters per hour. On completion of collaring, the bit force was increased gradually to 20 tonnes and the speed of rotation was increased to 24 rpm. An instantaneous rate of penetration of 0,83 metres per hour was achieved.

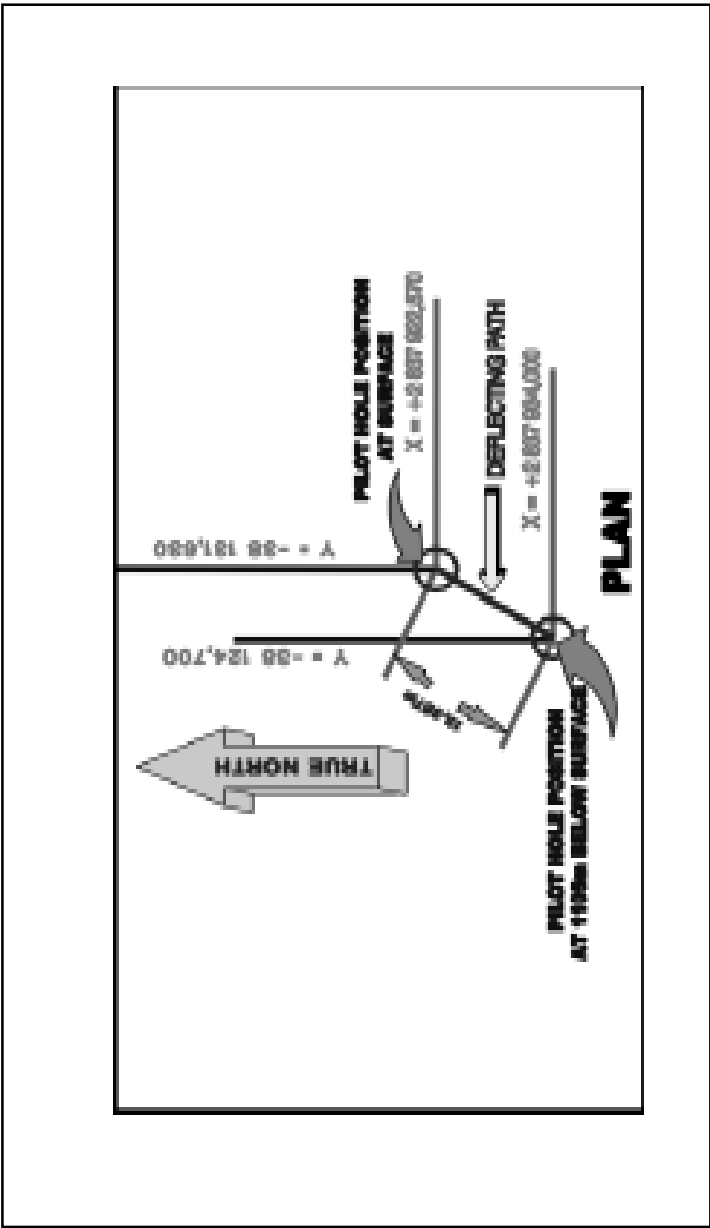


Figure 2
Diagrammatic Sketch Of Pilot Hole Deflection

The average life of a drill bit was 180 metres. On completion, the pilot hole showed a deflection of 13,367 metres from the vertical.

REAMING

Reaming operations commenced on 23 February 1994. After the reamer was collared, it was lowered again and all bolted connections were checked.

The combined mass of the drill string and reamer was 538 tonnes. After completing 40 metres, fractured ground conditions were encountered and three sets of cutters were destroyed over the next 40 meters. The decision was taken to reduce the raise-bore hole diameter to 4,1 metres and to proceed at this reduced diameter to 26 Level. The destruction of the cutters caused a 3-month delay in the project.

Simultaneously, a crosscut was developed on 26 Level for a distance of 184 metres to intersect the raise-bore hole during July 1994.

After intersection, a steel grid platform, constructed from rolled steel beams was installed in the hole below the reamer on 26 Level. The reamer was then lowered and spacers inserted to increase the reaming diameter back to the original of 4,4 metres diameter.

Prior to the 26 Level intersection, the advance was approximately 50 month/month, which increased to approximately 200 month/month, with a best daily advance of 12 metres.

The duration of cutter changes, during the project was substantially reduced, as a result of the 26 Level intersection, as these changes were done on 26 Level instead of 29 Level.

Reamer lowering and raising time during cutter changes was reduced by approximately 5 days, considering the elevation difference between 29 and 26 Levels, (132 metres) and lowering or raising speed of 10 hour/hour. Four cutter changes were done between 26 Level and breakthrough on the surface.

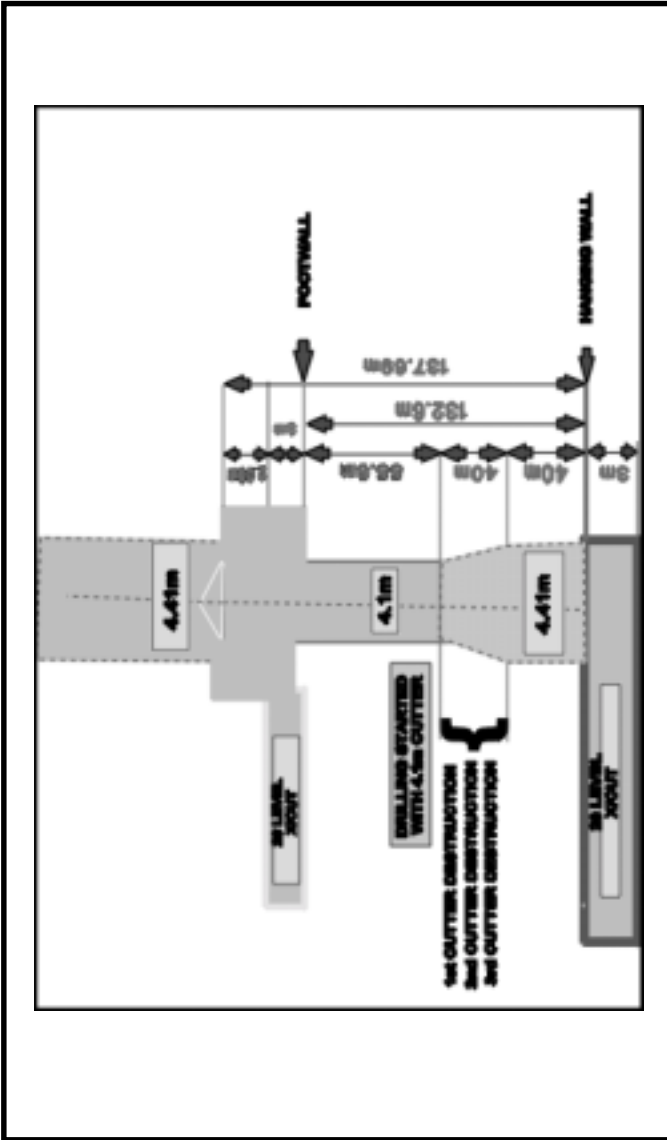


Figure 3
Plan showing reaming between 29 & 26 levels

MUCK REMOVAL ON 29 LEVEL

Unlike other projects where, delays occurred during cutter changes. Due to a build-up of muck at the shaft bottom making the reamer head inaccessible during a cutter change, no delays were experienced in this project.

This was due to the access on 26 Level, where cutter changes could be done independently of the muck pile on 29 Level.

Muck was produced at a rate of 46 tonnes per metre reamed. Removal of the muck timeously was necessary to prevent a build-up in the shaft to such proportions that a blockage would eventually form.

Underground personnel were confronted with a variety of problems, namely: -

- How should the muck be removed from the raise-bore hole?

Initially, a crosscut, with a boxhole into the shaft, was planned. The obvious danger of a blockage forming in the orepass and shaft bottom led to the implementation of muck loading with two Eimco 250 load/haul dumpers, in conjunction with a 10 tonne Goodman battery powered locomotive and 10 RC Power bottom discharge hoppers.

How to cope with the ever increasing production of ore/waste from this as well as the normal morning shift operation.

How to handle the extra 420 tonnes of muck produced from raiseboring, without increasing rolling stock on 29 Level?

The tramming distance between the main shaft and the raise-bored shaft is 1,4km, with 1 800 tones of reef and waste to be removed on a daily basis.

The muck removal took precedence over any other tramming or transporting operations.

The No 1 haulage of the twin haulage system was used only for the tramming of raise-bored muck, whilst the No. 2 haulage was used for normal tramming and material transportation. This caused minimum interference with the muck removal operation.

Scheduled high quality maintenance on all equipment resulted in the negligible downtime due to breakdowns.

The project was completed without any injury or incident relating to truck and tramming operations.

Muck build-ups were experienced when advances of between 9 and 12 day/day were obtained and build-up reached between 1 000 tonnes and 2 500 tonnes at times (50 to 60 metres of the shaft bottom filled with muck).

No blockages occurred due to continuous loading, which kept the muck moving. All built-up muck was cleared during cutter changes.

- How to maintain a 24-hour loading cycle without breaking regulation requirements with regard to hours of work?

Four mucking teams were established. A Team consisted of:

1 x Load/Haul dumper driver
1 x Locomotive driver
1 x Locomotive guard
1 x Team Supervisor

A system of 4 days work and 1 days rest was employed with a team getting a weekend off every fortnight. Constant motivation and a display of interest by all supervisors involved, ensured an injury free project, completed one month behind original program date.

REFRIGERATION SYSTEM

A "three"-phase refrigeration approach is planned to cater for the initial and future mining areas.

Phase 1

A single 9,6MW (R) refrigeration plant with the associated hot and cold storage dams, condenser towers, etc., operating on a surface bulk air cooler provides 300 kg/s air at 9°C saturated to the ventilation raise-bore shaft.

A further 60 kg/s of air is provided from the existing infrastructure for the 26 to 31 Level longwall.

Phase 11

The refrigeration strategy is similar to phase 1, except that a total of 150 kg/s of air is provided from the existing infrastructure for the 26 to 31 Level production areas as the workings move further away from the shaft.

During this phase some 50 l/s of chilled water is piped down the raise-bore shaft to cool the air with underground pipe coil cooling cars at the entrance to the 29 and 31 Level longwall.

Phase III

When the upper longwalls mine out, some 300 kg/s of air is provided from the existing infrastructure for the 26 Level to the 36 Level longwall production areas.

Air is mixed with the cooled air from the raise-bore shaft and a second 9,6 MW (Rated) surface refrigeration plant installed to provide 250 l / s of chilled water at about 1.5° C, for the underground cooling cars. The water exiting the coils is piped back to surface via a closed loop.

VENTILATION AND REFRIGERATION PRINCIPLES

Several options of ventilation and cooling were investigated, based on the current infrastructure and mining operations, which are moving further away from the main shaft system at an increasing depth, down the inclines. It was decided to opt for a dedicated ventilation downcast shaft from surface to 26 and 29 levels as well as a refrigeration plant with an associated Bulk Air Cooler on surface. WHY?

To meet the immediate requirements of the mine it was decided to place a 4,4-metre diameter shaft in close proximity to the incline connected to 26 and 29 levels.

VENTILATION AND REFRIGERATION STRATEGY

With the introduction of refrigeration to Turffontein Shaft the workings are divided in to two distinct areas namely: -

- UPPER SECTION - 24 longwall and above.
- LOWER SECTION - All workings below 24 level

The area above 24 level is ventilated via the existing infrastructure without refrigeration, whilst the bottom area below 24 level is ventilated with refrigeration air from the raise-bore shaft. The raise-bore shaft downcasts 300 kg/s of refrigeration air through the surface Bulk Air Cooler to 26 and 29 levels, serving the lower section.

Similar to the refrigeration development program the ventilation and refrigeration strategy is divided into three phases, as the refrigeration process is upgraded to cater for the initial and future mining areas.

Phase I

To serve the mining operations in the production areas from the 26 Level to 31 Level longwall. (Required 1995)

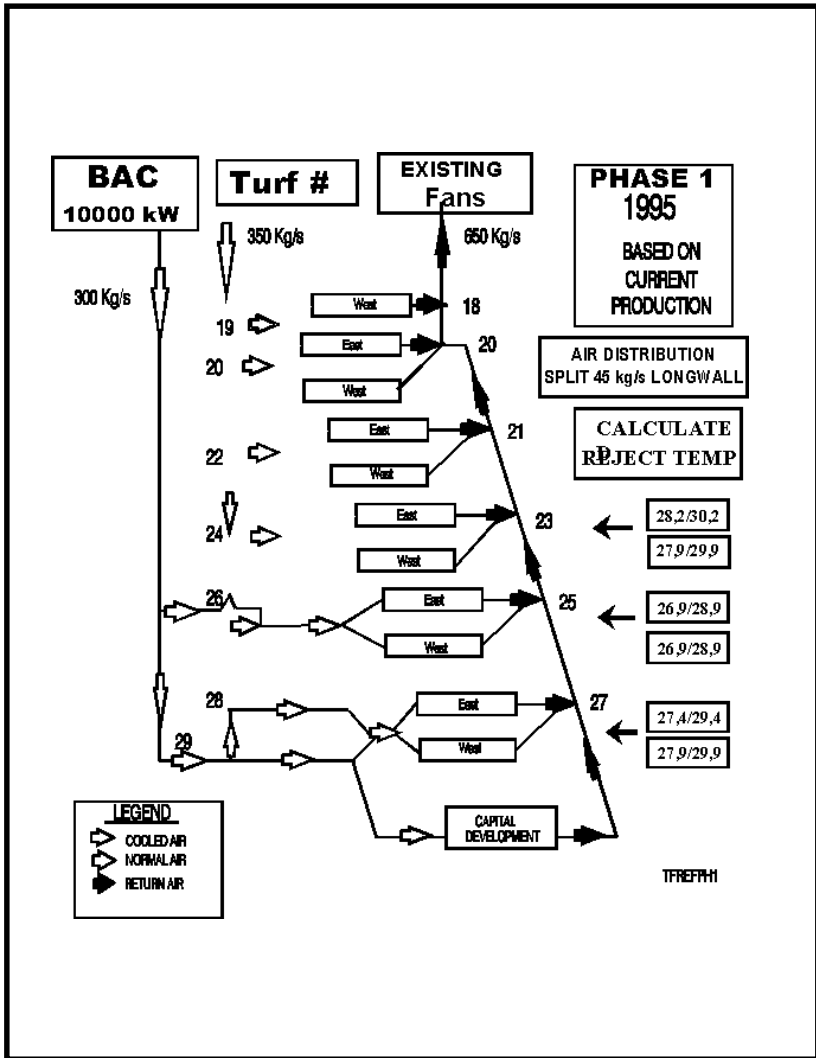


Figure 4

Phase 1 - Ventilation and Refrigeration Strategy

During Phase 1, the upper section is ventilated with 350kg/s of air from the main Turffontein Shaft. The lower section is served with 300kg/s of refrigerated air from the raise-bore shaft.

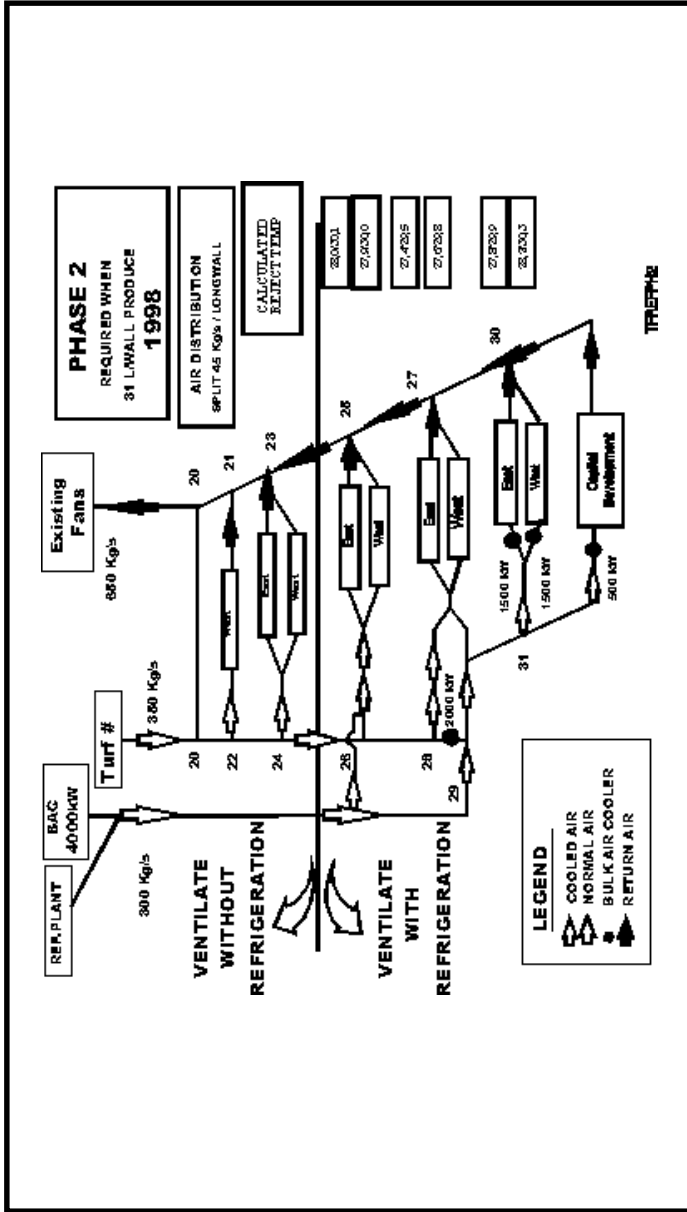


Figure 5

Phase II - Ventilation and Refrigeration Strategy

Chilled water is introduced to serve the cooling cars at the entrance of the 29 and 31 level longwalls.

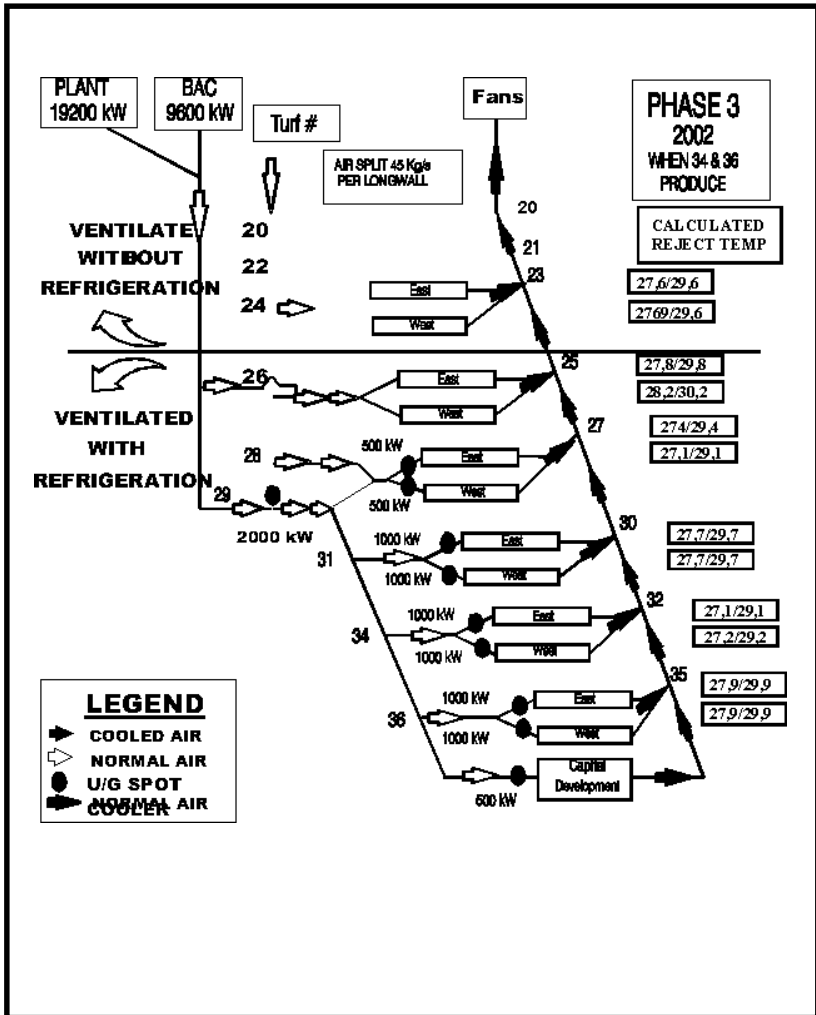


Figure 6

Phase III - Ventilation and Refrigeration Strategy

During this phase, as mining in the upper section, above 24 level is completed, all mining operations are concentrated below 24 level.

Phase II

To serve mining operations in the production areas from 26 to 31 longwall as the workings move away from the shaft. (Required 1998).

Phase III

To serve mining operation in the production areas from 26 to 36 longwall. (Required 2002.)

During Phase I the upper section is ventilated with 350 m³/s of air from the main Turffontein Shaft whilst the lower section is served with 300 m³/s of refrigeration air from the raise-bore shaft.

Phase II serves the main mining operations as they advance further away from the shaft. When the upper longwalls, 20 West and 22 East, are mined out the 31 level longwalls will be in full production.

During phase II, 300 m³/s refrigeration air will mix with 120 m³/s of air from the existing infrastructure on 29 level serving the lower section.

The 120 m³/s from Turffontein Shaft is cooled with 150 l/s chilled water in pipe coil cooling cars, on 29 level before it mixes with the cool air from the new raise-bore shaft to serve the 29 and 31 longwalls, the capital development and the incline cluster system.

Phase III provides refrigeration for mining when the 34 and 36 longwall areas come into production. A second 9,6 MW refrigeration plant will be installed on surface to provide chilled service water for the pipe coil cooling cars at the entrance to the longwalls.

During this phase, mining in the upper section, above 24 Level will be completed and all mining operations will be concentrated in the lower section below 24 Level.

The air downcasting at Turffontein Shaft will, during this phase, be used to ventilate the workings in the lower section. Part of this air is cooled down on 29 Level before it mixes with the cooled air

down casting at the raise-bore shaft.

To serve mining operations in the production areas from 26 to 36 Level longwalls a second 9,6 MW refrigeration plant will be installed on surface to provide 250 l/s of chilled service water for the pipe coil cooling cars at the entrance to the stopes. Water for the underground pipe coil cooling cars will be supplied by the second refrigeration unit as well as off-shift cooling and storage of water from the first refrigeration plant as described above for phase II.

The air serving the 29, 31, 36 Level longwall areas will be further cooled down at pipe coil cooling cars in the respective intake airways at the entrance to the longwalls.

UNDERGROUND SPOT COOLERS

In order to save on development, pumping and water treatment costs, the operation makes use of closed system pipe coil cooling cars underground rather than open spray chambers.

With traditional open spray chambers, the air velocity through the spray chamber is limited to 4 m/s, with the result that large excavations (approximately 800 m²) are required where 45 m²/s, is to be cooled for each side of a longwall.

Excavations required for closed circuit spot coolers is about one tenth of the excavations required for an open spray chamber, the previous crosscut or mini sub station excavations may be used.

Pumping of water and treatment costs for a closed system will also be much less than for three-stage open spray chambers.

The closed circuit pipe coil cooling cars will operate at 14000 kPa with a rated pressure of 30000 kPa, which will allow the option of using the system without a pressure reducing station.

COSTS

Phase I

Mining including Raise-bore	R 14 242 438.00
Civil works	R 9 518 621.00
Structural	R 1 336 551.00
Mechanical	R 8 909 011.00
Piping	R 3 798 806.00
Electrical	R 4 576 461.00
Instrumentation	<u>R 1 022 205.00</u>
TOTAL (EXCLUDING Eng. Fees)	<u>R 43 404 093.00</u>

Phase II

Estimated cost R 17,5 Million

Phase III

Estimated cost R 20,0 Million

Total estimated project cost R 80,9 Million

CONCLUSION

From a safety point of view, raise-boring is vastly superior compared with conventional shaft sinking techniques, and this project was completed without a single underground lost time injury being reported.

Although the shaft was completed one month after the original program date, completion was much more rapid and safer than would have been the case if conventional shaft sinking methods were applied.

Due to the project being a non-labour intensive operation, with winders, concrete lining and other conventional materials not needed, it proved to be extremely cost affective.

The success of any raise-bore operation hinges on the rate of muck removal and this particular aspect must feature very high on the planning agenda of any future raise bore shaft in order to achieve the desired and timeous result.

At the time, it was the deepest shaft ever raise- bored in the world. Another first is the 400 mm NB Mannesman twin chilled water pipe columns hanging free in the shaft and suspended only from two steel beams resting on the shaft collar. The combined mass of the twin column filled with chilled water is 860 tonne.

ACKNOWLEDGEMENTS

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REFERENCES

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2. SHAFT SINKERS Pty. Ltd.

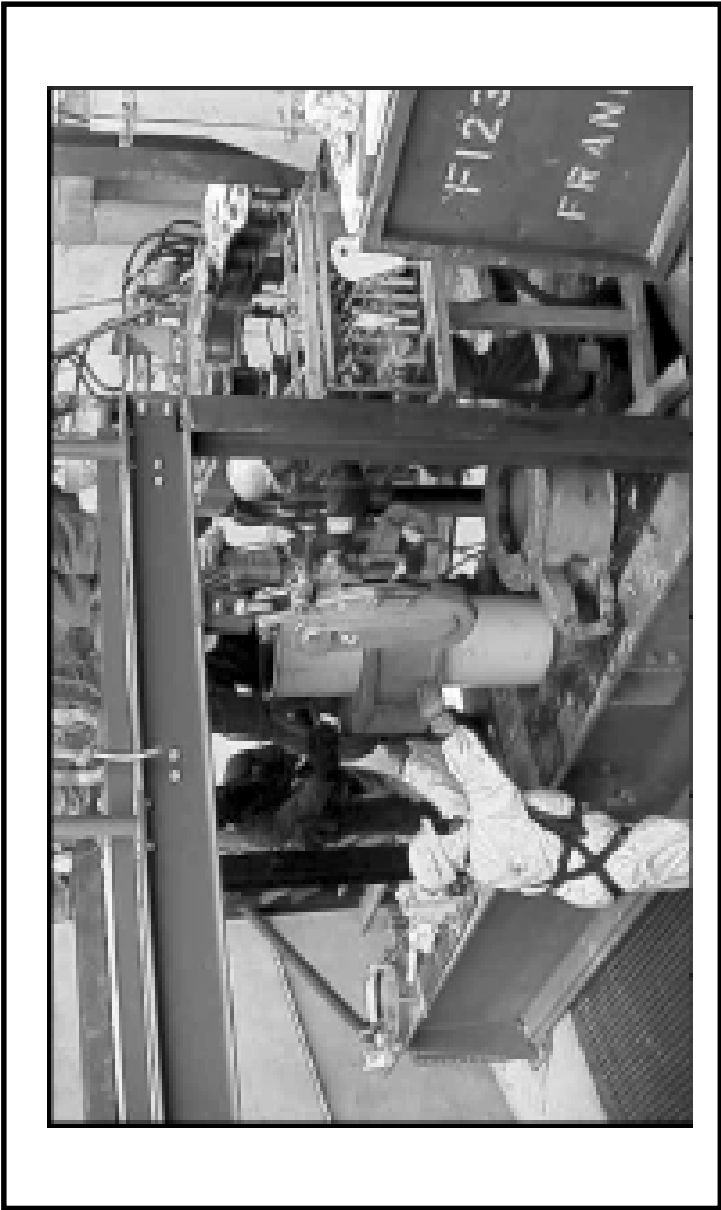


Photo 1:



Photo 2:



Photo 3: