Optimization of the Ventilation Circuit under Ventsim Software 4.8.6.1: Application to the Kinsenda Underground Mine

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Abstract: ***The study includes the estimation of the need for fresh air, the determination of the optimal design, the numerical simulation of the ventilation parameters of the project. The first step, the air requirement estimate, was based on data on the category of gear used in the mine. Using the Turgis mining consultant standard, this estimate gave a flow rate of 325 m3 / s. The second step consisted of a strategic analysis on the one hand and an optimization of the ventilation circuit on the other hand, in order to detect a technically feasible and faster strategy for carrying out this optimization. As a result, the numerical method of optimization selected airway graph optimization has been adopted. This method not only optimizes the ventilation circuit, but also gives a graph that represents the point of intersection of the different ventilation costs (cost of acquisition of fan, cost of consumption of electrical energy as well as operating costs) based on the airflow required by the Kinsenda mine. An optimal diameter of 5 meters is then obtained after optimization of the new well. Finally, the study focused on the simulation of ventilation parameters using the Ventsim 4.8.6.1 software, after which the dynamic simulation showed us that after 32 minutes when we assume that all the size fronts were mined at same time; stale air is diluted and no longer poses a toxic threat to personnel.***

Keywords: estimation, ventilation, flow, simulation, design

1. Introduction

An underground mine is a confined (closed) place where the ambient air is tainted by the activities which take place there, in particular by the blasting of explosives (gas, dust, etc.), the nature of the ore (presence of free silica , radon, release of methane, etc.), backfill products (ammonia, etc.), the presence of thermal stresses in deep mines and the widespread use in modern underground mines of motorized equipment, Diesel powered vehicles and vehicles that release carbon and nitride pollutants into the atmosphere, some of which are known to be carcinogenic [1]; including carbon monoxide, carbon dioxide, hydrogen sulphide, nitrogen oxides, sulfur dioxide and especially diesel particulate matter [2]. The control of these pollutants must be carried out as far as possible at the source, in particular by examining the operation of diesel engine machines: efficiency of engines and exhaust (filters, sensors, catalysts, etc.). Nevertheless, harmful gases of various kinds, whether they be irritating, toxic or asphyxiating, emerge hence the need to reduce their level of concentration in the air under exposure thresholds set by the standards in force. Dilution and evacuation of the pollutants present can then be carried out only by a ventilation of the mine (ventilation) sufficient from the point of view of the flow rate and the speed of the air which circulates in the various excavations of a underground mine (recipes, galleries, felling sites, fixtures, etc.) in accordance with the standards set by the law and the regulations in force or, failing that, the rules of art; the Regulation respecting occupational health and safety in mines (MSSR) requires every mining company to keep a record of certain measures of airflow and air quality, particularly in view of the emissions of contaminants produced by engines diesel used in underground mines [3]. Required airflows vary widely depending on the method of operation, the extent of underground structures and the type of equipment used. Airing strongly interacts with production. It is also a very energy-intensive item (around 100 GWh / year) that can absorb 50% of the total energy consumption of the mine. [4] By their productivity and flexibility in operation, diesel equipment has enabled mining operators to minimize production costs and increase ore reserves. [5] Despite these advantages, these machines are the main source of air pollution in underground mines. For more than two years, the Kinsenda underground mine has been experiencing a very difficult ventilation situation; this situation is caused by the cessation of the exploitation of the deposit since 2003 and following the collapse of the inclined UOZ (Upper Ore Zone) and MOZ (Medium Ore Zone) which served as fresh air in the mine. Following the reopening of the mine in 2010, whose main activity was exclusively the evacuation of water, the mine was equipped with three fans with a theoretical capacity of 75 m3 / s. Given that the Kinsenda mine has resumed operation since 2017, and that the planning provides for a monthly production of 50,000 tonnes of copper, this flow becomes insufficient through the use of a large range of engines driven by engines. diesel, therefore the ventilation circuit has presented a lot of difficulties compared to the need of air which the mine requires and this does not allow the rapid dilution of the gases. Faced with this problem, the employer has planned the sinking of a new ventilation shaft that will support the Bigman 10 (only return air pit) to improve thermal comfort within the mine. Hence the search for an optimization of the ventilation circuit of the Kinsenda undergrounds mine. As a result, there are two main issues: how to optimize the Kinsenda mine's ventilation system; and based on planning at the Kinsenda mine, how to determine the optimal design considering all categories of gear used in the mine.

2. Goal

The general objective of this ventilation optimization study is that after ventilation systems (network, equipment), ventilation and collection at the source can evacuate, dilute and maintain the various pollutants present in the Kinsenda underground mine within the required maximum standards and concentrations. Achieving this goal will further ensure a healthy work environment for the mine worker, both in terms of quality and quantity of air in the workplace.

3. Material and method

We will use as a method of analysis, the numerical method that will use the computer tool Ventsim 4.8.6.1 which is an underground ventilation simulation software. We will start with the preparation and encoding of data on Ventsim. The data we have is that of all levels of exploitation of the Kinsenda underground mine. They are made using the software Surpac to obtain a string file consisting of Ventsim-compatible centerline which will serve as a model base in our study. Afterwards, it will be a question of importing this file into Ventsim to begin the process of optimization and simulation of the different types of gas. To achieve the optimization of the Kinsenda underground mine ventilation system, we will begin with an estimate of the air flow required in the mine. Knowing that the estimation of the air flow required in an underground mine remains the most empirical aspect in the planning of modern ventilation. There are several empirical relationships, admittedly mostly based on the experience of older mines far less industrialized and mechanized than modern ones, to estimate the required airflow. On this, the necessary air flow can be determined according to: personnel at the bottom of the mine; the production of the mine; the power of diesel engines; the consumption of explosives; the amount of gas released in 24 hours; fuel consumption. Based on the categorization of diesel equipment used in the Kinsenda mine, and according to the cumulative capacity by category of this equipment (see Table 1); this breakdown shows us that the proportion of each category of equipment in relation to all the equipment inventoried is 38% for the loading category, 27% for the transport category and 23% for the other category; while the proportion of total installed power gives, 39% for loading, 50% for transport, 6% for drilling and 5% for others. From this observation, it is clear that the estimate of air requirement is much more influenced by the diesel engine equipment intended for the transport of materials. Thus we will have to calculate the required airflow according to diesel equipment using the standard proposed by Turgis mining consultants (South African Standard) which is based on the degree of mechanization of a mine, the calculation of the air requirement is done on the power of each diesel equipment used in the mine. In practice, 0.075 m3 / s / kW was allowed, with a specific duty factor given by the mine under study. For secondary ventilation planning, this standard is as follows: for single vehicles: the quantity of air in m3 / s to be delivered at the point of use equals KW * 0.075 m3 / s; for multiple vehicles operating at the same location: Q = [(the largest kW) + (the second highest kW * 75%) + (the third largest kW * 50%) * 0.075 m3 / s].

Table 1: Cumulative potency by gear category (Kinsenda, 2018)

Equipements	Number of Equipment	Cumulative power (Kw)
Loading	10	2023
Transport	7	2635
Drilling	6	335
Other	3	237

After estimating the airflow required in the mine, we will go through a strategic analysis to optimize the ventilation design. In our study, we will use the selected airway graph optimization which will allow us to optimize the dimensions, the forms as well as the operating costs of the works. The data is defined in the form of tables so that they are used for the calculation of different ventilation costs with corresponding dimensions. A graph will be drawn to show the variation of these three major ventilation costs (operating costs, electricity consumption costs and fan allocation costs). Reducing these combined costs will normally be the optimal sizing point; and global financial simulation which will allow us to take into account the default data found in the software parameter to determine the costs of ventilation for the life of the mine. These costs include costs related to developments, main fans as well as electricity consumption costs. This optimization is economic if the works are smaller, that is to say, small dimensions. For the numerical optimization of the ventilation design of the mine, we will base ourselves on the distribution of air by optimizing the speed of the ventilation fans which will serve to minimize the total power consumed by the fans. This minimization is based on a model that relates the fan speed changes to the variations in air flow and actual power consumption. The optimum speed will be calculated from the air requirements of several drifts, the characteristics of the fans and their engines. To minimize the total power consumed by the fans, the regulation must provide the galleries supplying the workplaces with an air flow greater than the required flow rate, whereas the other galleries must reduce the ventilation to a minimum. The dynamic optimization model of the ventilation will be put into practice by having many advantages as the operator sees lowering of its operating costs and the mining atmosphere gains in quality by receiving exactly the quantity of air required by the 'activity. This optimization model is consistent with the evolving nature of the mine, ensuring continuous optimization of ventilation, even in the extreme conditions of the most remote sites. The optimization of the ventilation design will be done in two parts: the optimization of the main and secondary fans and the optimization of the dimensions of the ventilation works. Optimizing a fan will minimize the actual power consumed by the fan as it runs by providing the required flow. Optimizing the dimensions of the ventilation structures will make it possible to make an optimal dimensioning of the structure according to the need for air and the resistance that will have to be overcome according to the capital cost of the infrastructures. The capital cost of ventilation infrastructure is the development cost and the cost of allocating fans and accessories. Therefore, the correct choice of the dimensions of the ventilation works is of paramount importance to have reliable results. For that we will go through different numerical simulations of ventilation parameters. The main objective of this simulation is to evaluate the air flows sent underground and the concentration of certain pollutants in the atmosphere of the mine as well as to give readers a better understanding of the simulation result of the ventilation circuit from the Kinsenda mine.

4. Results and Discussions

a) Thermal comfort and estimation in need of air in Kinsenda

1) Theoretical estimate of air requirement in the Kinsenda mine

Table 2: Estimation according to diesel equipment (Kinsenda, 2018)

Equipements	Amount	Power KW	Total power KW	Dilution ratio	Effective walk rate	Effective total power	Air needs
Drilling equipment				0,075 m^3/s/kW	kW*CU*MU	kW	m^3/s
Simba S7 D	2	55	110	0,075	39,6	79,2	5,94
Boomer S1D	3	55	165	0,075	39,6	118,8	8,91
Boomer DD2710	1	60	60	0,075	43,2	43,2	3,24
Loading equipment				0,075 m^3/s/kW	kW*CU*MU	kW	m^3/s
ST1530 LHD	4	291	1164	0,075	209,52	838,08	62,856
AARD Majors	2	92	184	0,075	66,24	132,48	9,936
ST2D	1	87	87	0,075	62,64	62,64	4,698
Sandvik LH400t	2	204	408	0,075	146,88	293,76	22,032
Bell loarder L1806	1	180	180	0,075	129,6	129,6	9,72
Transport equipment				0,075 m^3/s/kW	kW*CU*MU	kW	m^3/s
MT5020	3	485	1455	0,075	349,2	1047,6	78,57
Sandvik TH430	1	310	310	0,075	223,2	223,2	16,74
Howo truck	3	290	870	0,075	208,8	626,4	46,98
Auxiliary transport equipment				0,075 m^3/s/kW	kW*CU*MU	kW	m^3/s
Scissors lift	2	79	158	0,075	56,88	113,76	8,532
Anfo truck	1	79	79	0,075	56,88	56,88	4,266
Flow rate for all equipment in m^3 / s							282,42
Leakage 15% of the flow							42,363
Total flow in m^3 / s							324,42

Thus, we will retain the flow calculated according to diesel equipment for good thermal comfort in the mine, which is 324.42 m^3 / s or 325 m^3 / s to be more precise

2) Estimated needs for air in developing sites and galleries

When multiple devices operate at the same time, the mines provide the airflow as follows: 100% of the flow rate approved for the most demanding mobile units; 75% of the approved flow rate for the second most demanding units and 50% of the approved flow rate for the other mobile units [5]. As a result, the actual flow rate provided to dilute the exhaust is less than the sum of the certified flow rates for each mobile unit. It should be noted that the flow per tonne hoisted for haulage and loading equipment contributes on average to 68% of the debit per tonne hoisted for the mines, even though on average they account for only 53% of the flow required by the regulation for the dilution of gases [7]. If we consider that in a construction site, there is equipment such as: a ST1530 LHD loader of 291 kW; a 485 kW MT5020 skip and a 55 kW S1D Boomer. The theoretical flow estimated with reference to the Turgis mining consultants standard will therefore be: Q = (485 + 291 x 0.075 + 55 x 0.5) x 0.075m3 / s = 54.80625 m3 / s. Assuming that the equipment with the greatest power is operating in the developing gallery, the flow required to dilute the gas will be Q = 485 x 0.075 m3 / s = 36.375 m3 / s. For reasons of safety, we will take 37 m3 / s. On the other hand, for a dead-end gallery, we rely on the speed of the air, which must be kept constant at all costs; it is maintained at 0.5 m / s in any dead-end gallery where staff are traveling. Knowing the size of the operating sites, the flow to be maintained will be Q = 5 m * 5 m * 0.5 m / s = 12.5 m3 / s.

3) Choice of ventilation columns

This choice is focused on the dimensions of the gallery and the gauge of the machine. In the Kinsenda mine, the maximum height of the bucket is 3.4 meters empty and 3.9 meters when loaded and the theoretical height of the drifts is 6m. The difference of these two heights gives us the margin of safety and this difference gives us an idea about the choice of the diameter of the ventilation column. The height difference is 2.1 m. We choose our flexible columns of 1,015 meters in diameter and 0,8 meters for the front of size gates (site), because answering the requirements of the dimensions of the galleries and leaving us a margin of 2,1 m -1,015 m = 1.085 m and 2.1 m - 0.8 m = 1.3 m when moving the bucket in the works without worrying the column. Figures 1, 2 and 3 below show the characteristics of the secondary fans, type of columns chosen according to whether one is in development or in front of size.

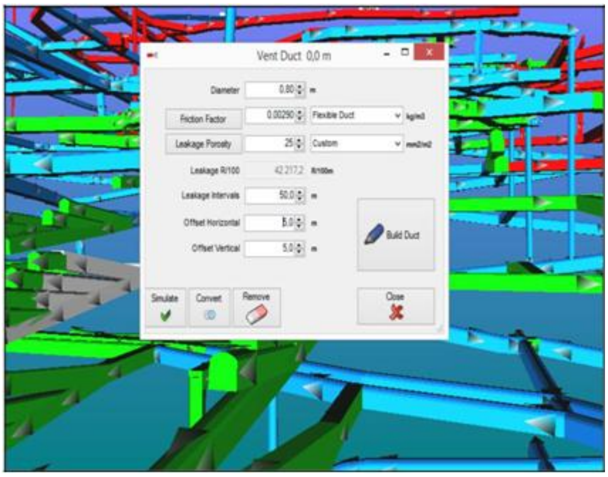


Figure 2: Type of column placed at the forehead

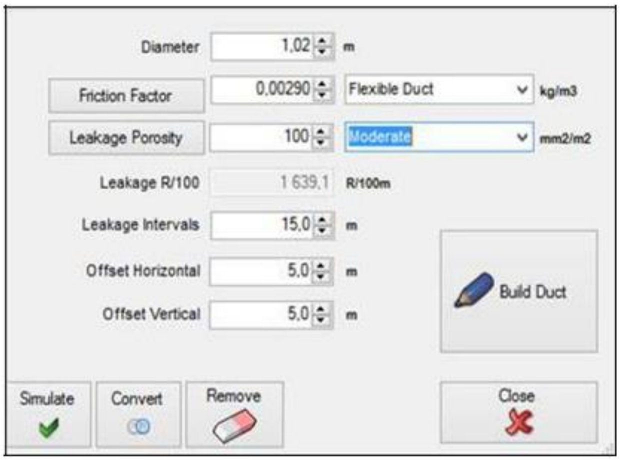


Figure 3: Column type placed during development

4) Choice of the fan

The choice of fan depends on the flow required by the installation, reassuring of a good performance of the fan for stable operation. For our simulation, the main features of the fan are shown in Figures 4 and 5 below.

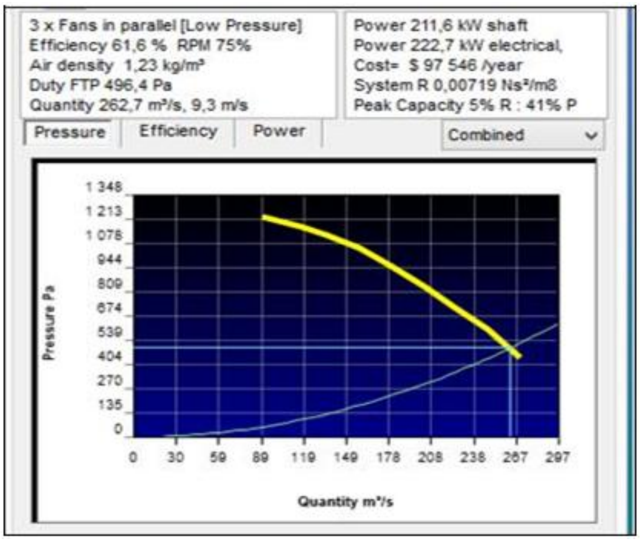


Figure 1: Courbe caractéristique des ventilateurs installés au BM 10

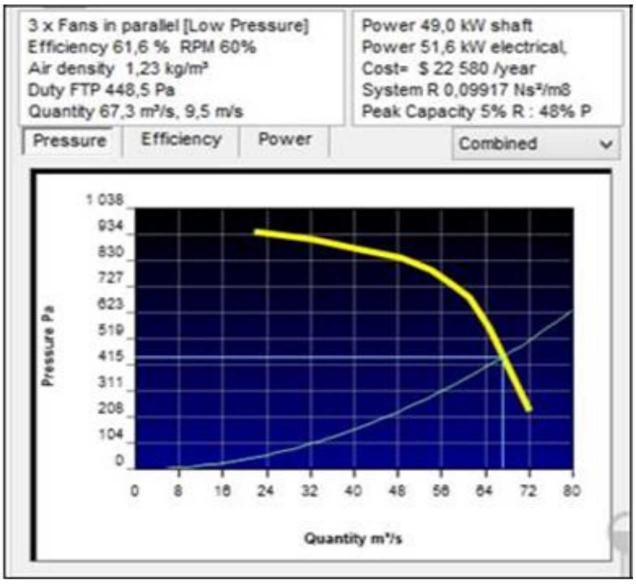


Figure 5: Characteristic curve of the fans installed at the new well

b) Strategic analysis and optimization of ventilation design

1) Optimization of the new well

The objective of well optimization is to minimize the consumption of electrical energy while having the necessary and sufficient air flow at the mine. In our case, the big challenge is to find the optimum diameter of the well to be dug according to the air requirements of the mine. Indeed, after using the selected airway graph optimization, we obtained a 5 m diameter well which represents the point of intersection of the different ventilation costs (cost of fan allocation, cost of electricity consumption and the operating cost) based on the airflow required by the Kinsenda mine. This diameter then represents the optimal diameter of this well. Chart 1 below shows the result of the optimization of the new well by the selected airway graph optimization method while Figure 6 illustrates the different gains obtained with respect to the choice of the dimensions of the well.

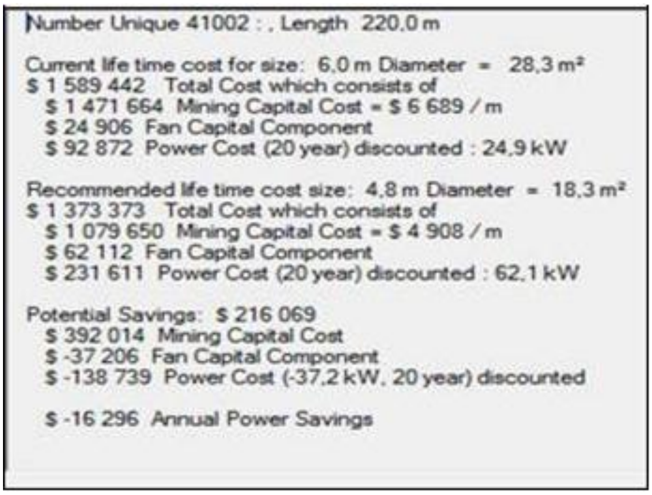


Figure 6: Optimization of the new well by the Global Financial simulation method

Referring to the results of the global Financial simulation method, we opt for the 5-meter diameter well since, taking into account the updated flows over the 20 years of the project, we will notice that the gains obtained on the operating cost, which is 392,014 USD are far higher than when we update future electricity consumption losses (expenditures) over a period of 20 years. These future discounted losses are calculated using the discounted cash flow formula: Current loss = loss (1+ interest rate) number of years. This is equivalent to saying that future losses will be: Losses = 16,296 USD (1 + 0,10) 20 = 109,631.34 USD. By comparing the value of current gains with the value of future losses, we can only choose from a well 5 meters in diameter. We can see it on the next graph 2 that it is the well that gives us an optimal flow of 232.5 m3 / s.

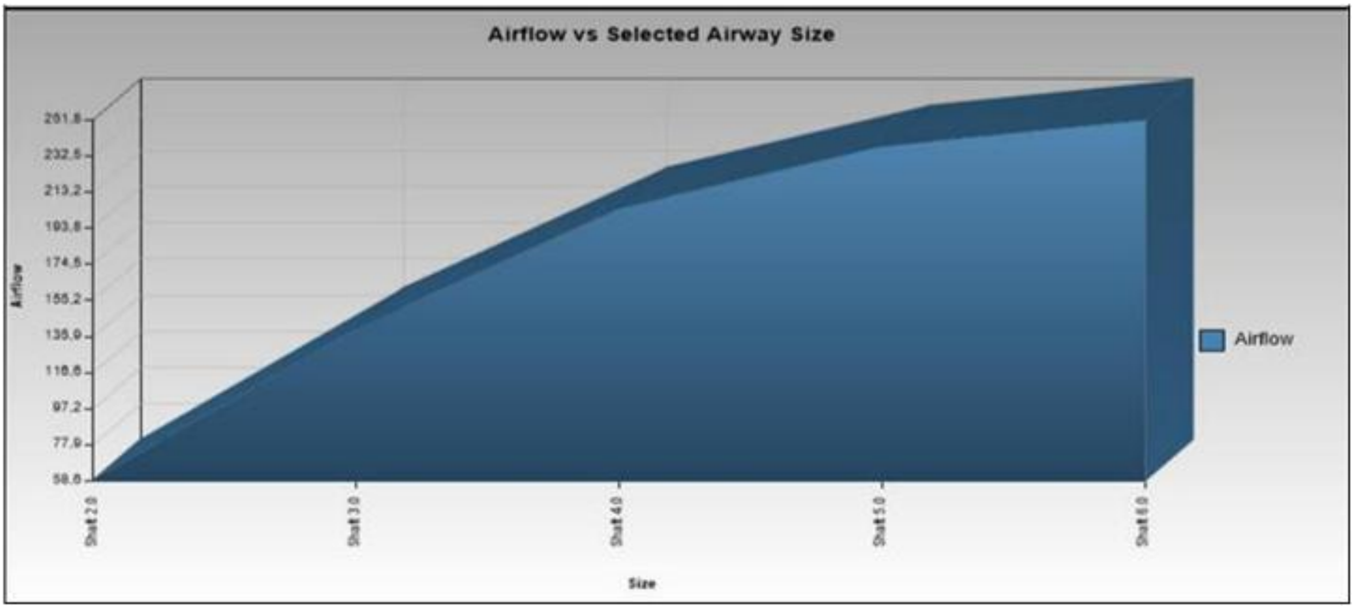


Chart 2: Variation of the required flow according to the dimensions of the structures

2) Optimization of the overall design

The optimization of the new well gave us an idea of the dimensions (optimal diameter) as well as the various ventilation costs. Nevertheless, to have an optimal design of our ventilation circuit, we used the global financial simulation option. Figure 7 below shows the various gains obtained after a financial optimization of the ventilation design of the Kinsenda mine. We note in the figure that when we optimized all the ventilation design of the Kinsenda mine, only 5 galleries were found and the total cost to be won was $ 24,235.

Figure 7: Optimization of the ventilation design of the Kinsenda mine

c) Numerical simulation of ventilation parameters

On the basis of the theory mentioned, we will be talking here about carrying out the various simulations in order to evaluate the flow of air sent underground and the concentration of certain pollutants in the atmosphere of the mine.

1) Flow simulation

After calculating the flow rate that the mine needs, the found values were inserted into the Ventsim model to get an idea of the flow distribution on the whole. The distribution of flows on fresh air intake and exhaust air outlets is as follows: we have a volume flow of 15.1 m3 / s at the entrance of BM (Bigman) 2 and 3; a volume flow at the inlet of the LOZ (Lower Ore Zone) inclined at 121.3 m3 / s; an air flow at the entrance to well 1 of 64.9 m3 / s; a volume flow of fresh air at the entrance of the incline MOZ (Medium Ore Zone) of 5 m3 / s; a volume flow of 116 m3 / s at the entrance to the West ramp; a volume flow of fresh air at the entrance of the UOZ (Upper Ore Zone) inclined at 10 m3 / s; a volume flow of stale air at the outlet of BM (Bigman) of 67.1 m3 / s and a volume flow of stale air at the outlet of the new well of 262.7 m3 / s.

2) Simulation of contaminants

This simulation makes it possible to see the distribution and the content of the different types of gas according to the type of gear at a given moment in the mine. This simulation requires the introduction of certain pollutants at a specific location to allow the field of propagation of these pollutants to be seen in the air at this location of the mine. These pollutants must be moved to different areas of the mine to give a good analysis of the entire ventilation system. Figures 8 and 9 below show the extent of air pollution from diesel engine engined vehicles in the mine. We can well note on the legend that there are potential sources of pollution, but they are permissible if we refer to gas standards. Considering that the work is done on all fronts of the mine, we note that there is excessive accumulation of pollutants in the mine. Figure 10 illustrates the spread of contaminants placed in all size-sizing fronts after simulation.

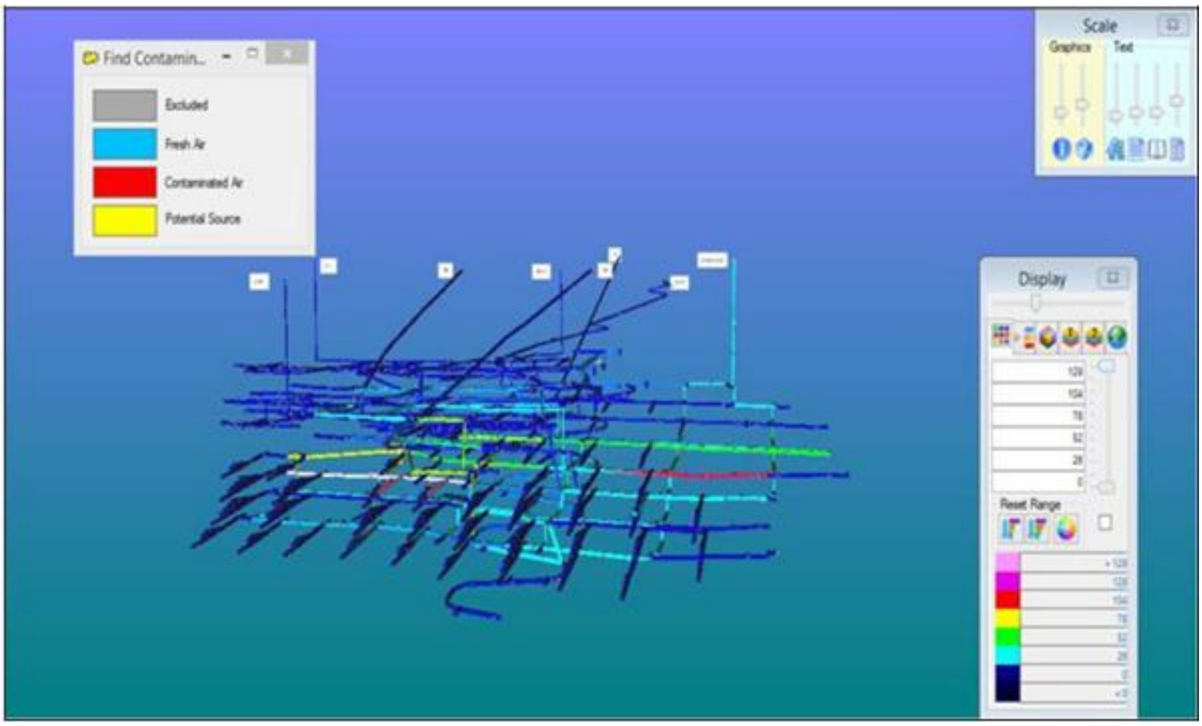


Figure 8: Contaminant placed on one of the taxiways after simulation

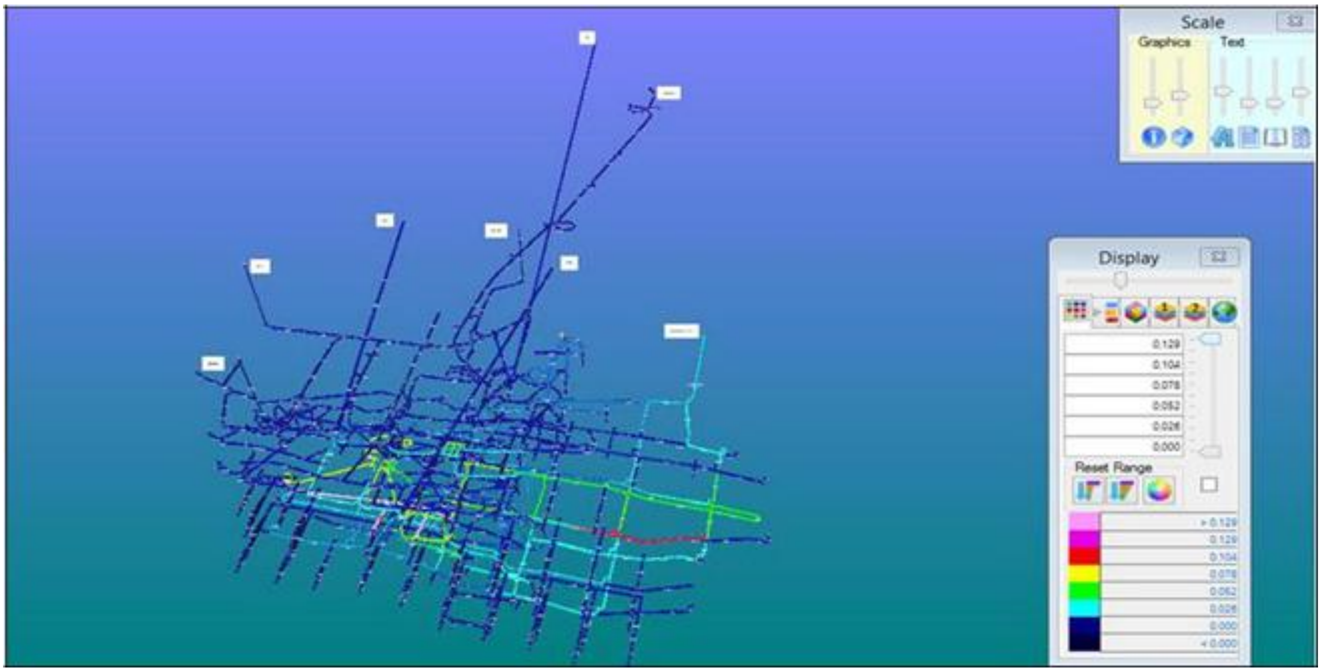


Figure 9: Plan View of Pollutants in Mining Areas

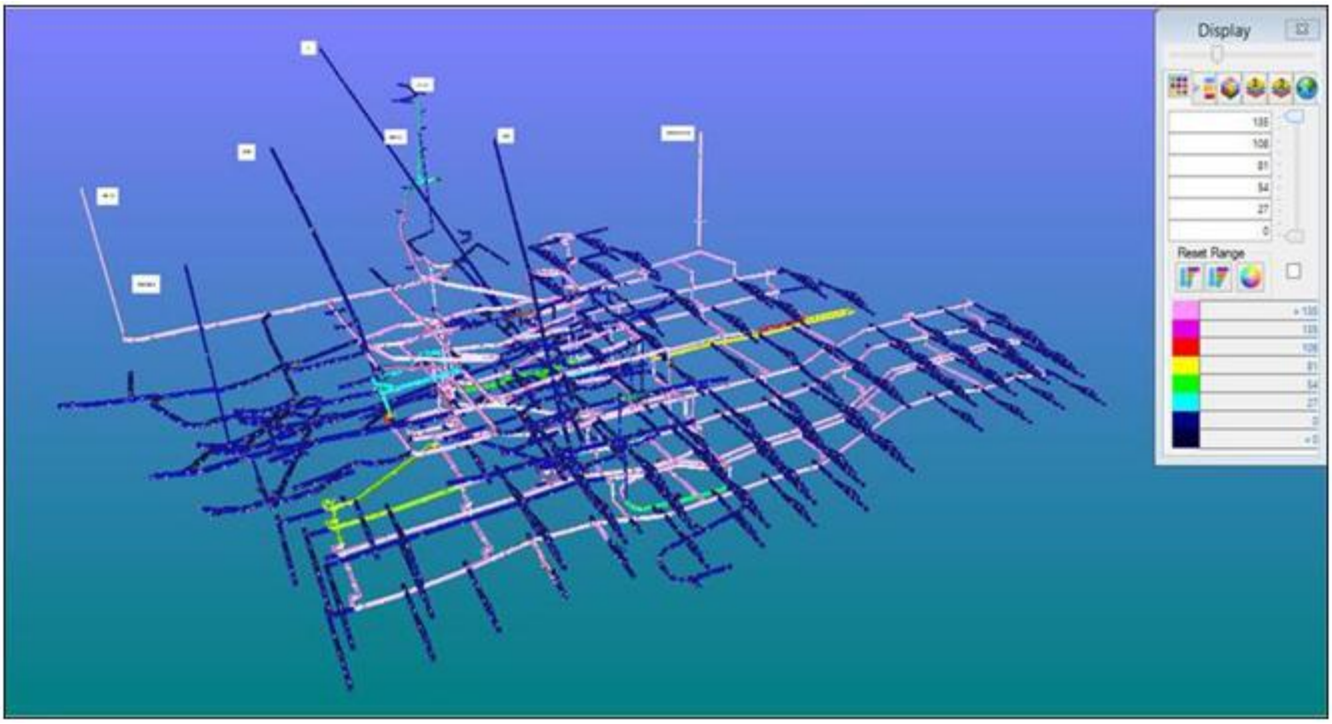


Figure 10: Propagation of contaminants placed in all pruning fronts after simulation

d) Static simulation of gases

This simulation consists in giving the concentration of the different types of gas at a point during an emission by diesel engines, by the mining or by self-compression of the underground rock mass. In our study we only deal with air pollution from diesel engines. To do this, it is better to make simulations of the main known contaminants in an underground mine among which we could mention: diesel particulate matter (PMD), nitrogen oxides (NOx), heat, gas (including the humidity) and dust. Figures 11, 12, 13 and 14 below illustrate each source of pollution placed at the waistlines with its corresponding concentration.

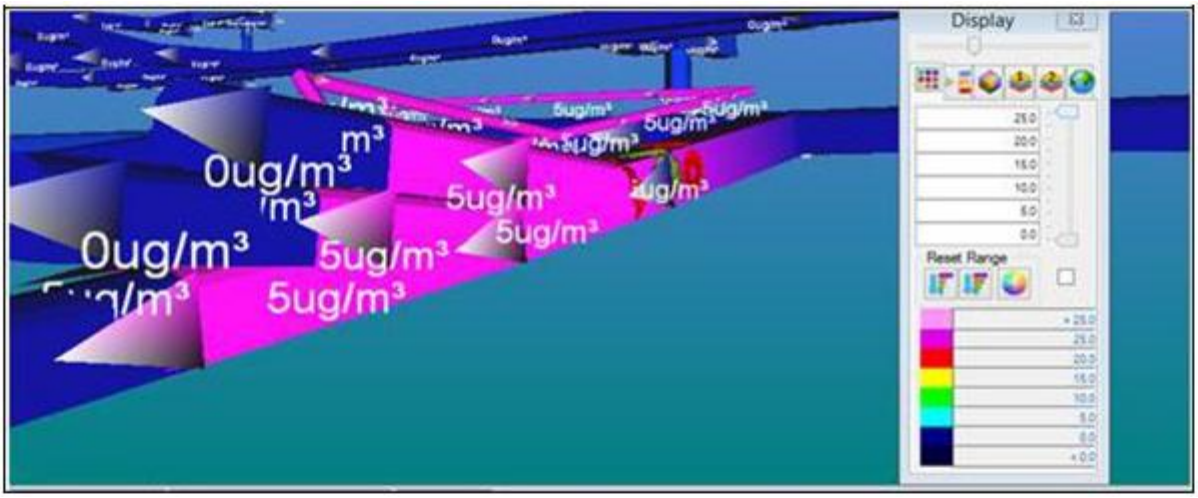


Figure 11: Concentration of MPD in an exploitation site

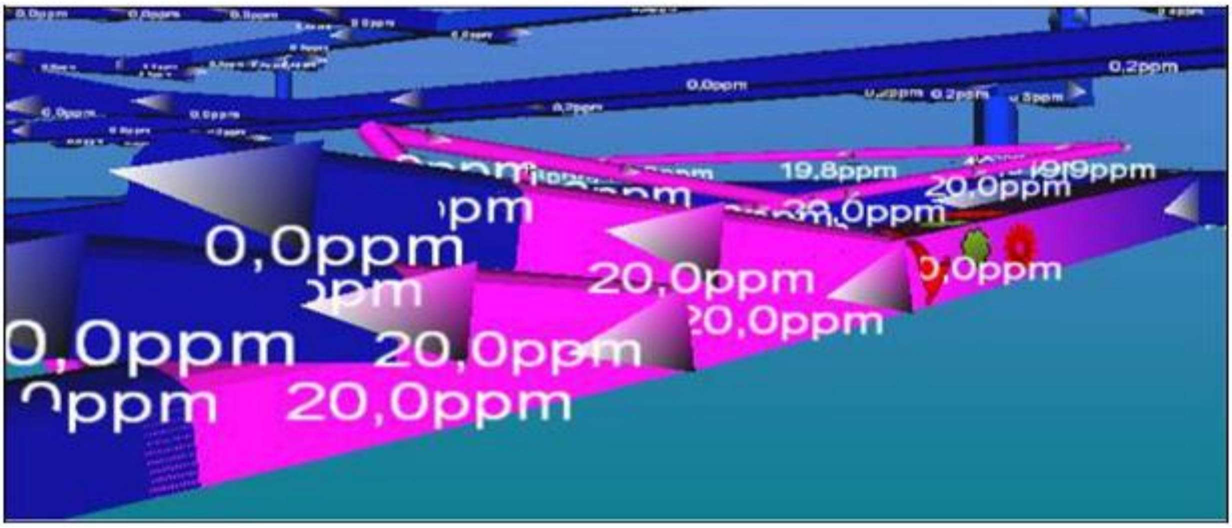


Figure 12: Concentration of NO in an operating site

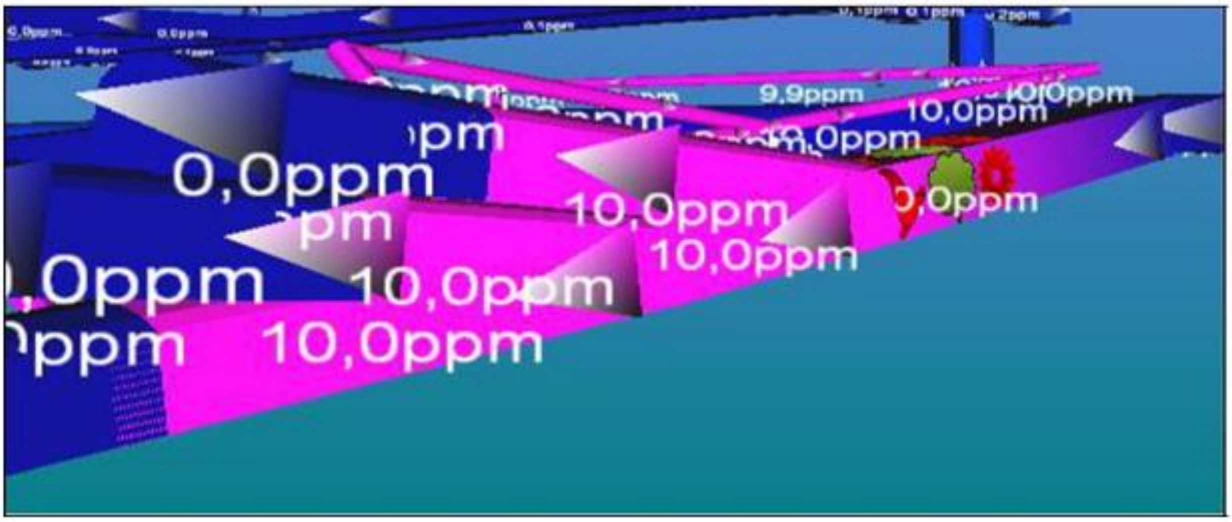


Figure 13: Concentration of NO2 in an operating site

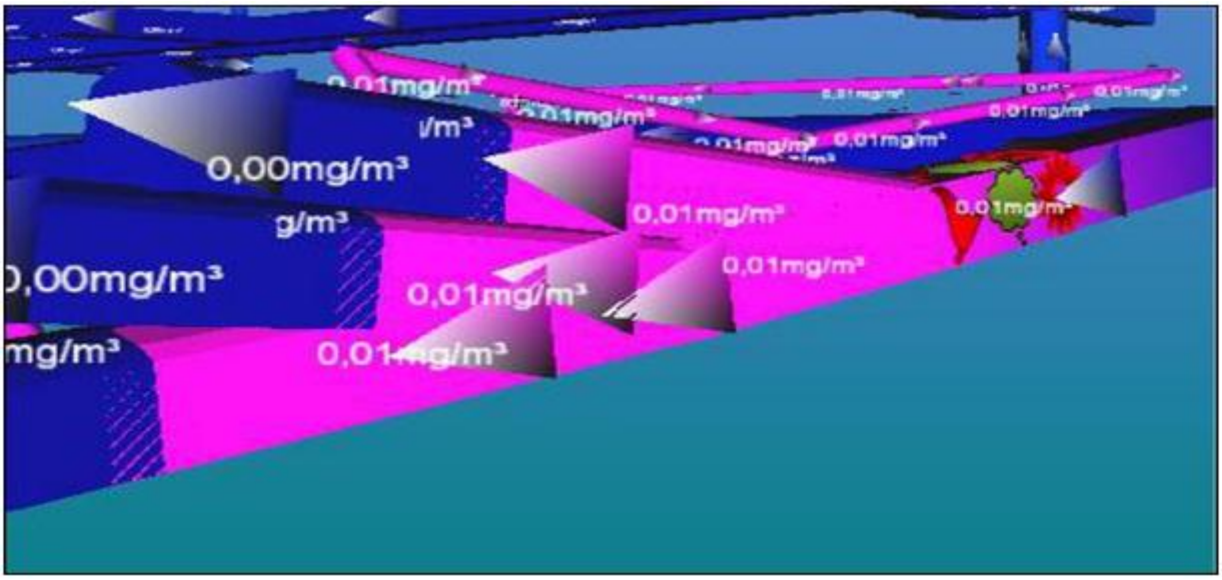


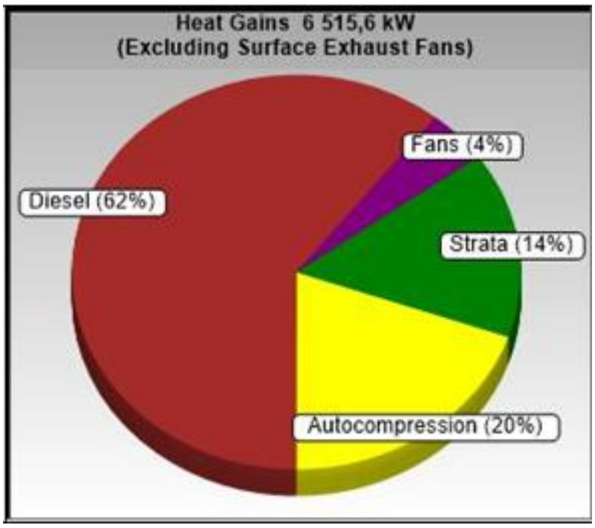
Figure 14: Concentration of dust in a construction site

e) Dynamic simulation of gases

This simulation not only allows to see the dispersion of the contaminants during a given moment but also gives an idea on the performance of the ventilation circuit. Some contaminants are to be introduced on operating sites, taxiways to see the distribution of these contaminants on the field of study. The computer tool used by this dynamic simulation also gives us the opportunity to predict an event that may occur in the future to bring out appropriate solutions. The simulations are given as follows: The values are placed on a front and on a taxiway to the east of the mine, the following result is obtained: a change in the distribution of contaminants after 5 minutes and 54 seconds simulation. After 13 minutes, the contaminants are almost discharged to the surface via the new return air shaft. After 19 minutes of simulation, we notice that the stale air has been totally diluted. So, to get an idea of the performance of this ventilation system, we had to place contaminants on four fronts of size according to the requirements of the mining planning at each workstation. After 32 minutes of simulation, when we assume that all size fronts were mined at the same time, the stale air is diluted and no longer poses a toxic threat to the personnel. This leads us to say that our ventilation system is well dimensioned since the exhaust air after mining in different operating sites is diluted after only 32 minutes, this is what is recommended by the standards for toxic gases. It has also been found that the concentration of gases, in particular carbon monoxide which reached the maximum of 1394 ppm and only after 7 minutes, it decreased substantially until reaching 0 ppm and kept its consistency after 9 minutes of simulation. . The dust concentration is almost zero after only 12 minutes. The wet temperature is increasing to 24.2 degrees. This is due to the start up of the diesel equipment but unfortunately, it does not represent a lot of danger because the value reached is admissible.

f) Thermodynamic simulation of gases

In this simulation, we see more heat and humidity that come from several sources. It should be noted that heat has a negative effect on personnel in the mine as it increases. The sources of heat in underground mines are numerous among which we can mention: stratigraphy; self-compression; equipment powered by diesel engines; electrical equipment; mining and oxidation. Figure 3 below shows the proportion of different sources of heat after taking into account all the contaminants placed in the Kinsenda mine. We note on the graph that the heat is much more influenced by the use of diesel equipment which represents 62% of the total.



Graph 3: Proportion de chaque source de chaleur

5. Conclusion

We define the optimization of a ventilation circuit as the action of supplying the required quantities of underground air by choosing a solution as economical as possible to the problem of a sufficient flow of fresh air. So, starting from the planning done at Kinsenda's underground mine, how can we determine the optimal design taking into account all the categories of gear used? The objective of this study is to optimize the ventilation circuit of Kinsenda's underground mine in order to ensure good ventilation in an economical way and, if necessary, to make simulations of the different gases so that at the end to have an efficient ventilation design. . To achieve this, we made use of a numerical method of optimization using the Ventsim 4.8.6.1 software which has been of great importance to us. Based on the power of equipment used, we arrived at determining the required underground flow rate of 325 m3 / s using the standard of Turgis mining consultants. Indeed, after using the selected airway graph optimization, we obtained a 5 m diameter well which represents the point of intersection of the different ventilation costs (cost of allocation of the fan, cost of consumption of electrical energy as well as the operating cost) as a function of the airflow required by the Kinsenda mine. This diameter is optimal. Referring to the results of the global Financial simulation, we confirm that the diameter of 5 meters is optimal since taking into account the discounted flows over a period of 20 years, we noticed that the gains obtained on the operating cost of 392 USD 014 is far higher than when we discount future electricity consumption losses (expenditures) over a 20-year period of US $ 109,631.34. By comparing the value of current gains with the value of future losses, we made our choice on a well 5 meters in diameter that will have to be excavated. We noticed that after 32 minutes of dynamic simulation when we assume that all size fronts were mined at the same time, the stale air is diluted and no longer poses a toxic threat to the personnel. This dynamic simulation was very important since it allowed us to say that respecting the theoretical flow rate above, the ventilation circuit of the Kinsenda mine will be efficient.

References

[1] CSST, The Belmine Newspaper, Issue 20, November 2005, page 5.
[2] Metz E. A., 2001: Diesel particulate matter- what's the big deal? [Conference] // A mining odyssey-EMS Annual meeting, Denver Colorado: SME- vol. V. 7.0 / 300 dpi.
[3] CSST, Dumps and Diesel Engines in Underground Mines, 2005, page1.
[4] Lundth M., Nyqvit J., Malander M., 2013: Good Air Underground, ABB review, page 36.
[5] Mafuta K., 2013, Impact of mechanization on ventilation in Québec's underground mines, Master's thesis; Faculty of Mining Engineering, University of Laval. Page 1 ; 60; 61.
[6] Maamri R., 2014, Modeling and experimentation of combustion engines operating with different alternative fuels and mixtures, thesis, Université de Québec.
[7] Lacroix R. Identifications of Energy Savings Opportunities in Ventilation Systems in Québec's Underground Mines [Report]. - Ottawa: MMSL-CANMET Report 07-060 (RC), 2008.
[8] McPherson, M. J. Subsurface ventilation and environmental engineering [Book]. - Blacksburg, Virginia: Chapman & Hall, 1993.
[9] RSSTM Regulation respecting the health and safety at work in Québec mines [Online] // www2.publicationsduquebec.gouv.qc.ca. - Québec Official Publisher, June 1, 2013. - C. S-2.1, r. 14. - June 8, 2013. - www2.publications quebec.gouv.qc.ca/dynamicsearch/telecharge.php.
[10] Diesel engines and air pollution in confined space, ND 1704, INRS, Paris 1988.