Workplace Safety North™

RECOMMENDED BEST PRACTICE FOR DUST CONTROL USING A WATER CURTAIN SYSTEM DURING SHOTCRETE APPLICATION

Workplace Safety North™

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RECOMMENDED BEST PRACTICE FOR DUST CONTROL USING A WATER CURTAIN SYSTEM DURING SHOTCRETE APPLICATION

The purpose of the technical document is not to dictate or restrict standards but only to suggest ways and means to establish a documented procedure to protect workers from the hazards associated with the exposure to dust during shotcrete application. In this document, the use of the words “must” and “shall” mean mandatory.

This document is designed to help/educate ventilation technicians, industrial hygienists, engineers or other technical specialists. It can also be beneficial to shotcrete personnel.

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Workplace Safety North (WSN) is the health and safety association serving underground and surface mines, tunneling, smelters, refineries and related sectors in Ontario. We provide auditing and consulting services, training and information to help our member companies meet our shared vision of an industry where every worker comes home safe and healthy, every day.

Version 1.0

ACKNOWLEDGEMENTS

Workplace Safety North wants to acknowledge the contribution of the Workplace Environment Technical Advisory Committee, as well as all of the companies that submitted and participated in gathering information to develop this document for industry.

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1 INTRODUCTION

Sprayed concrete (otherwise known as shotcrete) is now becoming a common area support for ground control in underground mines as a stand-alone or in combination with other support systems such as bolts and screens. An important area of shotcrete application in underground mining is in the support of 'permanent' openings such as ramps, haulages, shaft stations and crusher chambers. Increasing numbers of underground excavations are being shotcreted immediately after excavation. Shotcrete application uses high-powered hydraulic, pneumatic or electric plant to apply concrete by projecting it through the air, generating large amounts of dust. If control technologies are inadequate, hazardous levels of inhalable and respirable dust may be liberated into the work environment, potentially exposing workers. Accordingly, provincial regulations are in place to limit the respirable dust exposure of mine workers. Risk assessments are also performed at the operational level to ensure proper control practices are in place to limit worker exposure.

Methods of Shotcrete Application

Shotcrete is the generic name for cement, sand and fine aggregate concretes which are applied pneumatically and compacted dynamically under high velocity.

Dry-mix shotcrete

The dry-mix method involves placing the pre-blended dry or damp (to reduce dust generation) shotcrete materials into a hopper with continuous agitation. Compressed air is introduced through a rotating barrel or feed bowl to convey the materials in a continuous stream at high velocity through the delivery hose to the nozzle, where water is added. The water and the dry mixture is completed as the mixture hits the receiving surface. Material is consolidated on the receiving surface by the high-impact velocity. **Figure 1** illustrates a typical dry-mix shotcrete system.

The dry-mix system tends to be lower capacity and uses smaller and more compact equipment, which can be moved around relatively easily in an underground mine environment.

Wet-mix shotcrete

Wet-mix shotcrete involves thoroughly mixing all ingredients, including water, and delivering the mix hydraulically to the nozzle where air is added to project the material onto the rock surface. **Figure 2** illustrates a typical wet-mix shotcrete system.

The wet-mix system is ideal for high production applications and where access allows the application equipment and delivery trucks to operate on a more or less continuous basis.

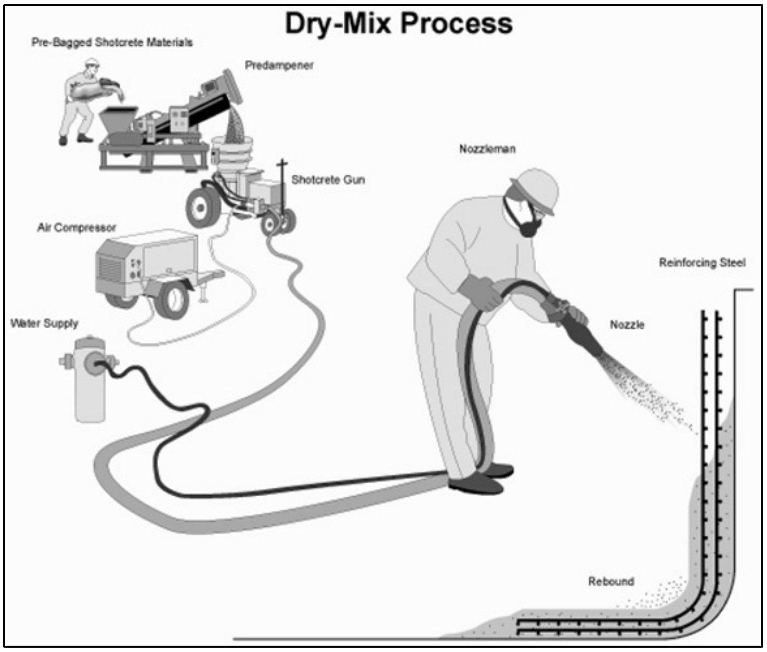


Figure 1 – Simplified sketch of a typical dry-mix shotcrete system (American Shotcrete Association www.shotcrete.org).

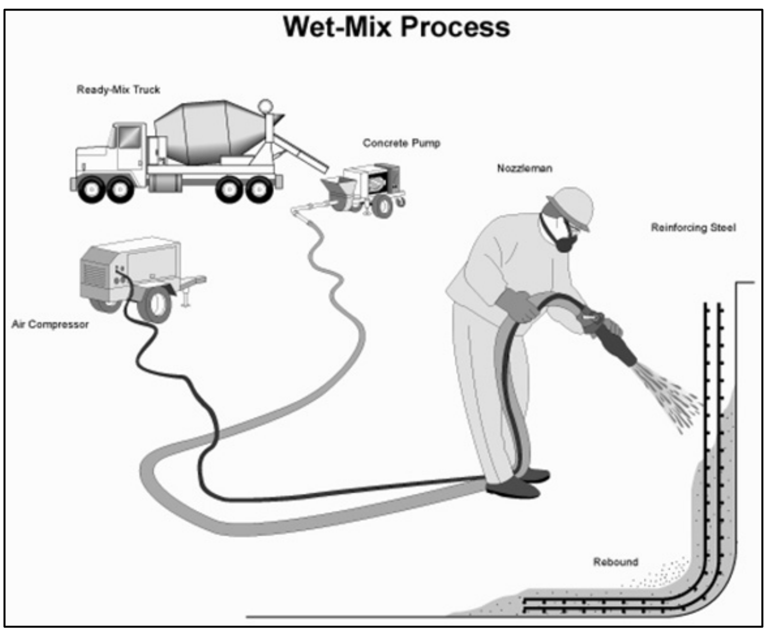


Figure 2 – Simplified sketch of a typical wet-mix shotcrete system (American Shotcrete Association www.shotcrete.org).

2 SUGGESTED POLICY

Policy

All workings where shotcrete application is conducted in underground mines must conduct risk assessments and develop a standard operating procedure (SOP) to ensure adequate water spray system for dust control techniques are installed and operable to avoid hazardous levels of respirable dust to be liberated into the work environment, potentially exposing workers.

Objective

The objective is to limit the respirable dust exposure of mine workers, which may contain one or any combination of shotcrete (cement) composition listed below, and comply with provincial regulations and company policies that are in place.

- Silica, total quartz
- Silica fume
- Portland cement – composed of oxides and cement minerals. Table 1 summarized the oxide composition of a Portland cement.

The oxide composition summarized in Table 1 may differ from product to product and from the sources of the components used to manufacture the shotcrete or concrete. Users are encouraged to refer to the shotcrete Material Safety Data Sheet (MSDS) or Safety Data Sheet (SDS) for the appropriate information. Additional analysis information may need to be obtained from the manufacturer or supplier to determine the accurate oxide count of the product. This will provide important information to help determine the appropriate substance or substances where air sampling will be performed.

Table 1 – Oxide composition of a Portland cement (Cement and Concrete Research Laboratory [CCRL] at National Institute of Standard and Testing [NIST], 2000).

Oxides	Range (wt%)	Cement #135 (wt%)
Calcium oxide (CaO)	60.2 – 66.3	63.81
Silicon dioxide (SiO_2)	18.6 – 23.4	21.45
Aluminum oxide (Al_2O_3)	2.4 – 6.3	4.45
Iron oxide (Fe_2O_3)	1.3 – 6.1	3.07
Magnesium oxide (MgO)	0.6 – 4.8	2.42
Phosphorous pentoxide (P_2O_5)	--	0.11
Titanium dioxide (TiO_2)	--	0.22
Sodium oxide (Na_2O)	0.05 – 1.20 (Na_2O equiv)	0.20
Potassium oxide (K_2O)		0.83
Sulfur trioxide (SO_3)	1.7 – 4.6	2.46
Loss on ignition	--	0.81
Insoluble residue	--	0.16
Free Calcium oxide (CaO)	--	0.64

Responsibilities

Management – Ensure risk assessments are conducted that outline required controls for hazards and activities. Management is also required to develop appropriate policies and procedures. Management is also required to ensure that all relevant personnel are trained in, understand and comply with company policies and procedures.

Front-line supervisors – Ensure that any dust control practices during shotcrete application in the workplace under their jurisdiction are adequate, operable and maintained, and meets the company's policy and procedures. Ensure that workers are aware that hazardous levels of respirable dust may be liberated into the work environment during shotcrete application. These levels may be potentially exposing workers, if control technologies are inadequate, inoperable or not properly maintained.

Workers – Once informed, workers must comply with the standards and procedures as outlined and correct/guard/report any hazards they encounter to their supervisor.

3 PERTINENT LEGISLATION

Occupational Health and Safety Act

Responsibilities under the Occupational Health and Safety Act
Under the Occupational Health and Safety Act, employers, supervisors and workers have legal responsibilities relating to the control of safety and health hazards in the workplace. These, and other duties set out in the Act apply to silica and to toxic substances in the workplace.

Worker exposures related to the presence, production, processing, use, handling or storage of silica are subject to the Designated Substances Regulation 490/09 made under the Occupational Health and Safety Act. Control processes of contaminants in an underground mine workplace are set out in the Mines and Mining Plants Regulation 854 made under the Act. Contaminants include biological, chemical or physical agent or combination of such agents that are used, intended to be used or produced and present in the workplace.

Regulations pertaining to dust control in workplaces including underground mines are available in Appendix A.

4 HEALTH EFFECTS OF OVEREXPOSURE TO DUST DURING SHOTCRETE APPLICATION

Silica

Silica is a compound resulting from the combination of the two most common minerals in the earth's crust, silicon and oxygen, and has the general formula SiO_2. It exists in several forms, and crystalline silica is of the most concern. The recognized and most abundant type of crystalline silica is quartz, which is a basic component of soil, sand, and rocks. The crystalline-free silica is the primary cause of silica-related diseases. Other forms of silica are cristobalite, tridymite, and tripoli, which are not common. Concrete products contain silica sand and rock containing silica. These products are primary materials used for shotcreting and workers may be exposed to respirable crystalline silica during shotcreting activities. Worker exposure to crystalline-free silica is of particular concern because silica is one of the primary components of the cement as stated in Section 2.

Occupational exposure and inhalation of airborne crystalline silica can cause silicosis, a disabling, dust-related disease of the lungs. Even materials containing small amounts of crystalline silica may be hazardous if they are used in ways that produce high dust concentrations. Depending on the length of exposure, silicosis is a progressive and many times a fatal disease that accounts for approximately twenty-eight deaths in Ontario's mining industry, or 17% of all fatal occupational disease claims registered between 2005 - 2015 (Source: WSIB, enterprise information warehouse, as of July, 2015). In addition, exposure to silica as the principle agent resulted in an additional 15 death's in Ontario's mining industry between 2005-2015, represented by a variety of diseases (Source: WSIB, enterprise information warehouse, as of July, 2015).

Portland Cement

Portland cement dust may cause acute health effects such as irritation of the eyes, nose and skin. It may also cause chronic health effects such as irritation to the eyes, nose ulcers and skin rashes. Some individuals may also experience allergic skin reactions. Repeated exposures over a long period of time has produced x-ray changes of the lungs and an increase amount of shortness of breath, wheezing, and cough with sputum (Occupational Health Guideline for Portland Cement, U.S Department of Labor, Occupational Safety and Health Administration, 1978).

Others

Depending on the type of shotcrete used, each product has its own unique features which may require evaluation. Some shotcrete products may include: steel fiber, synthetic fiber, additives, etc. Please consult with your manufacturer's Safety Data Sheet (SDS or MSDS) for further information.

5 CONTROLLING DUST DURING SHOTCRETE APPLICATION

Primary Methods

Primary methods for controlling shotcrete dust include engineering controls which eliminate dust generation at the source during shotcrete application. This would be considered the highest level of control.

If such a method is not possible, a water curtain option is an effective control that can reduce the workers exposure to airborne dust below the occupational exposure limit, if executed properly. The water curtain can be utilized to capture dust once it has become airborne to protect those in the work area. However, there are various aspects to consider when utilizing a water curtain.

Appendix A outlines the flowchart for establishing a new water curtain or evaluating an existing process. The premise behind this is to evaluate the control to ensure its effectiveness.

Advantages of a water curtain system:

1. Relatively easy to transport and install.
2. Very effective at reducing the dust levels, when installed properly.
3. Allows other workers in the area to be able to work downwind from shotcrete operations (if curtain effectiveness has been verified). This allows mine operations to function as normal.
4. Flexibility in the type, design and set-up required to achieve the desired results of reducing the dust levels.
5. Most practical method to employ in the underground environment when other methods such as local exhaust ventilation are not practical.

Disadvantages of a water curtain system:

1. Does not provide any benefit to the workers actually applying shotcrete. Therefore the control at the source is not achieved, utilizing this control strategy.
2. Depending on the design, installation of the water curtain can be done incorrectly. As a result the water curtain can become less effective. Largely an administrative control.
3. Installation and set-up can sometimes be difficult for the workers. This may be due to physical limitations of the workplace or lack of mine services in the desired area.
4. Adds additional set-up time.

Other Methods

There are various levels of control which can be utilized to control exposure to shotcrete dust. These controls are explained in full detail published in the "Dust Control Handbook for Industrial Minerals Mining and Processing, NIOSH January 2012". Some examples include:

Dust collector systems
Local exhaust system captures dust at the source via ductwork to a dust collection filtration device.

Ventilation systems
Ventilation systems utilize clean fresh air to dilute the contaminants to a safe level.

Please review the "Dust Control Handbook for Industrial Minerals Mining and Processing, NIOSH January 2012" for further information.

6 REFERENCES

1. Best Practices for Dust Control in Metal/Nonmetal Mining, Department of Health and Human Services. Center for Disease Control and Prevention. National Institute for Occupational Safety and Health (NIOSH), 2010.

2. Dust Control Handbook for Industrial Minerals Mining and Processing, Department of Health and Human Services. Center for Disease Control and Prevention. National Institute for Occupational Safety and Health (NIOSH), 2012.

3. Fatal Allowed Occupational Disease Claims, Workplace Safety and Insurance Board of Ontario, Enterprise Information Warehouse, July 2015.

4. Occupational Health Guideline for Portland Cement, U.S Department of Labor, Occupational Safety and Health Administration (OSHA), 1978.

5. Oxide composition of a Portland cement. Cement and Concrete Research Laboratory [CCRL] at National Institute of Standard and Testing; NIST, 2000).

7 APPENDIX A (next two pages)

Shotcrete Water Curtain Flow Chart Control Evaluation – Control evaluation of:
a) Developing a new process

Shotcrete Water Curtain Flow Chart Control Evaluation – Control evaluation of:
b) Evaluating a current process

Figures Illustrating Shotcrete Atomizer Set-up’s

R.R.O. 1990, Regulation 854: Mines and Mining Plants

R.R.O. 1990, Regulation 833: Control of Exposure to Biological or Chemical Agents

Shotcrete Water Curtain Flow Chart Control Evaluation

Control evaluation of:

a) Developing a new process

This flowchart is designed to help/educate ventilation technicians, industrial hygienists, engineers, other technical specialists & shotcrete personnel on the methodology for developing the design of a new control strategy for the operation.

Risk Assessment & Controls
It is encouraged that a risk assessment process should be established to evaluate the task & the direction of the sampling program.

Type of shotcrete process

Dry: typically exposures are higher vs wet.

Wet: generally exposures are lower vs dry.

Determine the Quartz Silica & Portland Cement exposures of:

a) Nozzel operator
b) Mixer operator
c) Other shotcrete workers (forklift operator, etc.)
d) Pre & Post water curtain***

It is important when establishing controls for the shotcrete process (i.e. water curtain) to understand the exposures of all workers associated with the task to provide a clear picture.

It is also important to consider quantity of shotcrete applied when conducting your assessment (i.e. bags, shot per hour, etc.).

If exposures are unknown, conduct a gravimetric air sampling survey to quantify the results for groups a-d.

Once exposures are known, proceed to the next steps.

Below the Action Limit
Each company can establish their own Action Limit based upon their organizational structure. Most often, best practice for an Action Limit is 50% of the Occupational Exposure Limit.

No further action required. Current shotcrete application set-up & process appears to be exposing workers to levels that are not harmful.

Each organization may want to further reduce the exposure and may have different thresholds of acceptable risk.

1) Record results on the process, set-up & what type of equipment is being used (i.e what controls are in place); so you can re-create this time and time again for consistent results.
2) Establish a process for auditing the set-up to ensure complacency does not occur (auditing the controls).

Above the Action Limit
When exposures are measured to be above the Action Limit either consistently or some of the time, post water curtain, it may be an indicator that the design or set-up of the water curtain does not provide enough protection and additional layers of control may be required.

Risk Assessment & Controls:

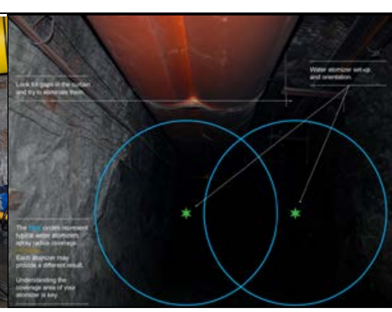
Re-look at the baseline risk assessment. Align any changes discovered from sampling.

When attempting to assess the water curtain design and set-up, evaluating the controls based on the hierarchy of controls may be a good exercise.

Water curtain design and set-up evaluation:

Selecting nozzle type:	Water curtain set-up:	Air to water ratio for supplying the nozzels & air/water pressures:	Direction of nozzle:
As outlined in the NIOSH document "Best Practices for Dust Control in Metal/Nonmetal Mining, Chapter 4 Controlling respirable silica dust in mineral processing operations" each type of nozzle offers different advantages and disadvantages. Each operation should review the options and determine which type of nozzle is best for their application. Examples of nozzle types include: Full cone, Hollow cone, Flat spray, Air Atomizing & others. Rule of thumb: in most cases, when deciding nozzle type, selecting a nozzle which matches the particle size of the shotcrete dust is ideal. As explained in "NIOSH's Dust Control Handbook for Industrial Minerals Mining and Processing, Chapter 2, pg. 63". In general, selecting a nozzle which provides the smallest water droplet size possible, is ideal for most cases.	The most common issue resulting in elevated exposures post water curtain involve gaps in the water curtain, therefore decreasing the likelihood of dust suppression. a) Conduct an evaluation of the proposed design. This would include sketching or drawing the water curtain with the intent of identifying gaps and eliminating them. b) Re-evaluate the gaps in the curtain during the first field trial. This would include a visual evaluation of the curtain. c) Once the curtain has been established, the long term goals are to determine how often it is inspected, to ensure it is being consistently installed to company standard regarding orientation, location and quantity of atomizers.	Determine a best practice for the air and/or water pressures. For air atomizing nozzels, establish a proper ratio of air & water. It is important to note that optimizing the performance of the atomizer requires certain pressures & ratios for the air and/or water. In some instances, experimenting with varying pressures in combination with air sampling can help an organization determine this. Manufacturer's may also have recommended guidelines which you can reference	When shotcrete workers install a water curtain, care must be taken to ensure the nozzles face the proper direction. Facing the nozzle into the ventilation promotes water droplet dust particle collision. Designing the water curtain with this aspect in mind is important. Common mistakes include installing nozzels perpendicular to the ventilation or in the direction of the ventilation. Refer to Figure 3 for illustration.

Understanding the nozzel you selected will help you understand the coverage area of the water spray. This will help you understand where any potential gaps may be and will help you in developing a plan to avoid this.



Verify the control is effective:

Conduct a sampling program which includes personal exposure samples of the workers involved as well as fixed station samples for:
- before & after the curtain
- Various incremental distances post water curtain (100ft, 200ft, etc.)

If control is ineffective, re-evaluate the design and/or installation.

Establish the process & audit:

Record results on how the curtain is set-up & what type of equipment is used.

Establish a process for auditing the set-up to ensure complacency does not occur.

Disclaimer: a water curtain is one type of control that can be utilized to protect those downwind from a shotcrete process. This best practice does not indicate it is the best or only control option available. This best practice is designed simply to help those implementing it as a new control, execute the design and installation process properly.

Shotcrete Water Curtain Flow Chart Control Evaluation

Control evaluation of:

b) Evaluating a current process

This flowchart is designed to help/educate ventilation technicians, industrial hygienists, engineers, other technical specialists & shotcrete personnel on the methodology for evaluating the design of a current control strategy for the operation.

Risk Assessment & Controls
It is encouraged that a risk assessment process should be reviewed to evaluate the task and the direction of the sampling program.

Type of shotcrete process

Dry: typically exposures are higher vs wet.

Wet: generally exposures are lower vs dry.

Determine the Quartz Silica & Portland Cement exposures of:

a) Nozzel operator
b) Mixer operator
c) Other shotcrete workers (forklift operator, etc.)
d) Pre & Post water curtain***

It is important when establishing controls for the shotcrete process (i.e. water curtain) to understand the exposures of all workers associated with the task to provide a clear picture.

It is also important to consider quantity of shotcrete applied when conducting your assessment (i.e. bags, shot per hour, etc.).

If exposures are unknown, conduct a gravimetric air sampling survey to quantify the results for groups a-d.

Once exposures are known, proceed to the next steps.

Below the Action Limit
Each company can establish their own Action Limit based upon their organizational structure. Most often, best practice for an Action Limit is 50% of the Occupational Exposure Limit.

No further action required. Current water curtain set-up appears to be sufficiently reducing exposure to those workers who may be working post water curtain.

Each organization may want to further reduce the exposure and may have different thresholds of acceptable risk.

1) Record results on how the curtain is set-up & what type of equipment is being used (i.e what controls are in place); so you can re-create this time and time again for consistent results.
2) Establish a process for auditing the set-up to ensure complacency does not occur (auditing the controls).

Above the Action Limit
When exposures are measured to be above the Action Limit either consistently or some of the time, post water curtain, it may be an indicator that the design or set-up of the water curtain does not provide enough protection and a re-design may be required.

Risk Assessment & Controls:

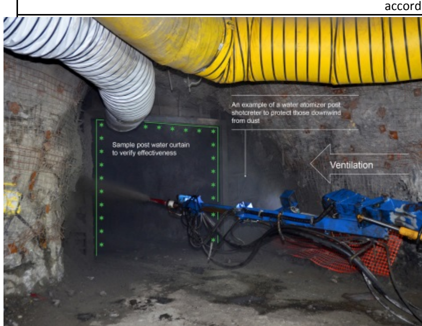
Re-look at the baseline risk assessment. Align any changes discovered from sampling.

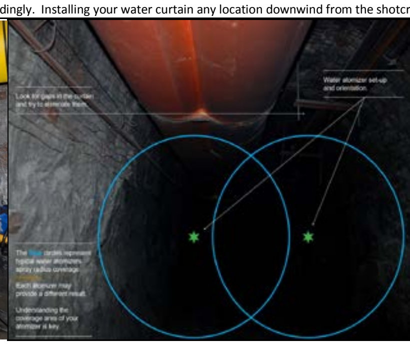
When attempting to assess the water curtain design and set-up, evaluating the controls based on the heirarchy of controls may be a good exercise.

Water curtain design and set-up evaluation:

Selecting nozzle type:	Water curtain set-up:	Air to water ratio for supplying the nozzles & air/water pressures:	Direction of nozzle:
As outlined in the NIOSH document "Best Practices for Dust Control in Metal/Nonmetal Mining, Chapter 4 Controlling respirable silica dust in mineral processing operations" each type of nozzel offers different advantages and disadvantages. Each operation should review the options and determine if they are satisfied with their current nozzel. Examples of nozzel types include: Full cone, Hollow cone, Flat spray, Air atomizing & others. Rule of thumb: in most cases, when evaluating nozzel type, utilizing a nozzel which matches the particle size of the shotcrete dust is ideal, as explained in "NIOSH's Dust Control Handbook for Industrial Minerals Mining and Processing, Chapter 2, pg. 63". In general, the nozzel currently being used ideally should provide the smallest water droplet size possible.	The most common issue resulting in elevated exposures post water curtain involve gaps in the water curtain, therefore decreasing the likelihood of dust suppression. a) Have you ever conducted an evaluation of the design. This would include visually inspecting the water curtain in the field during use with the intent of identifying gaps and eliminating them. b) If gaps are found, consider the curtain design to eliminate these gaps. c) The long term goals should include proper training for workers & supervisors. The curtain should be inspected periodically, to ensure it is being consistently installed to company standard. The inspection would include orientation of the water curtain, location in the drift in relation to shotcrete operations and quantity of atomizers.	Have you established a best practice for the air and/or water pressures? For air atomizing nozzels, have you establish a proper ratio of air & water? It is important to note that optimizing the performance of the atomizer requires certain pressures & ratios for the air and/or water. In some instances, experimenting with varying pressures in combination with air sampling can help an organization determine this. Manufacturer's may also have recommended guidelines which you can reference.	When shotcrete workers install a water curtain, do they ensure care is taken so the nozzles face the proper direction? Facing the nozzel into the ventilation promotes water droplet dust particle collision. Designing the water curtain with this aspect in mind is important. Common mistakes include installing nozzels perpendicular to the ventilation or in the direction of the ventilation. Refer to Figure 3 for illustration.

Understanding your current nozzel will help you understand the coverage area of the water spray. Understanding your nozzels & curtain design will help you to identify where any potential gaps may be. You can then develop a plan accordingly. Installing your water curtain any location downwind from the shotcrete operations is sufficient.





Verify the control is effective:

Have you conducted sampling to verify the effectiveness of the control?

- personal exposure samples
- before & after the curtain
- Various incremental distances post water curtain (100 ft., 200 ft., etc.)

If control is ineffective, re-evaluate the design and/or installation.

Establish the process & audit:

Have you recorded the results on how the curtain is set-up & what type of equipment is used?

Establish a process for auditing the set-up to ensure complacency does not occur.

Disclaimer: a water curtain is one type of control that can be utilized to protect those downwind from a shotcrete process. This best practice does not indicate it is the best or only control option available. This best practice is designed simply to help those evaluating the control ensure it is an effective with regards to its design and installation.

Figure 3 – Shotcrete Atomizer Set-up Illustration

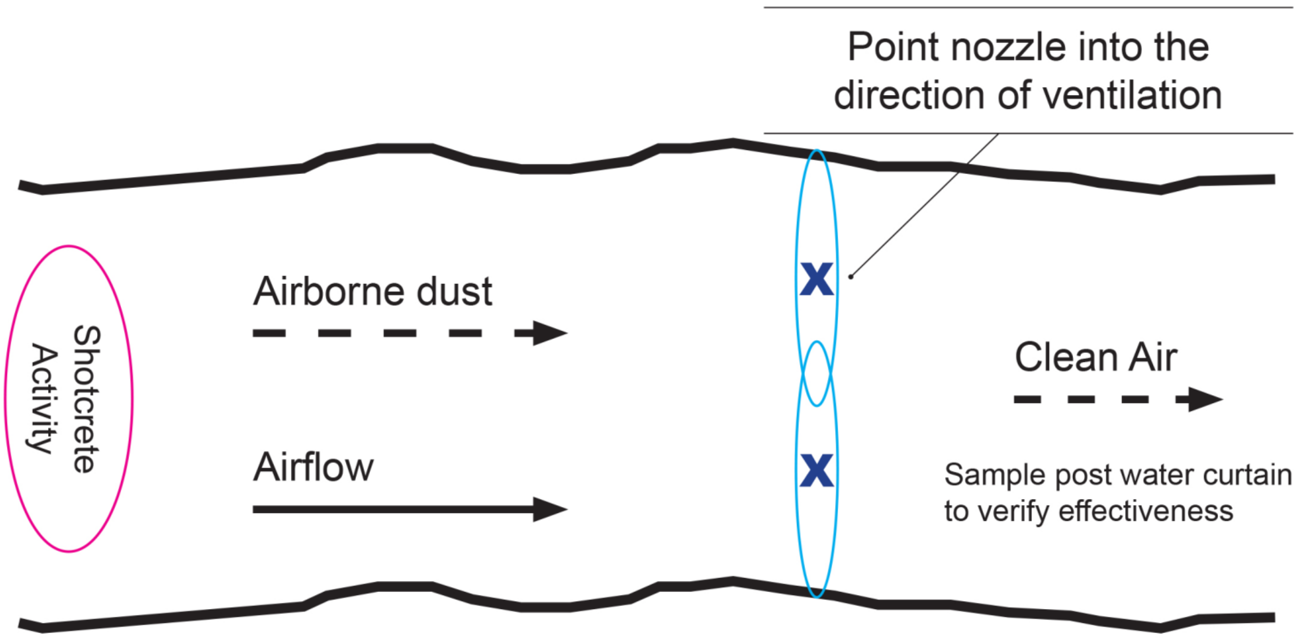


Figure 5 – Shotcrete Atomizer Set-up Example

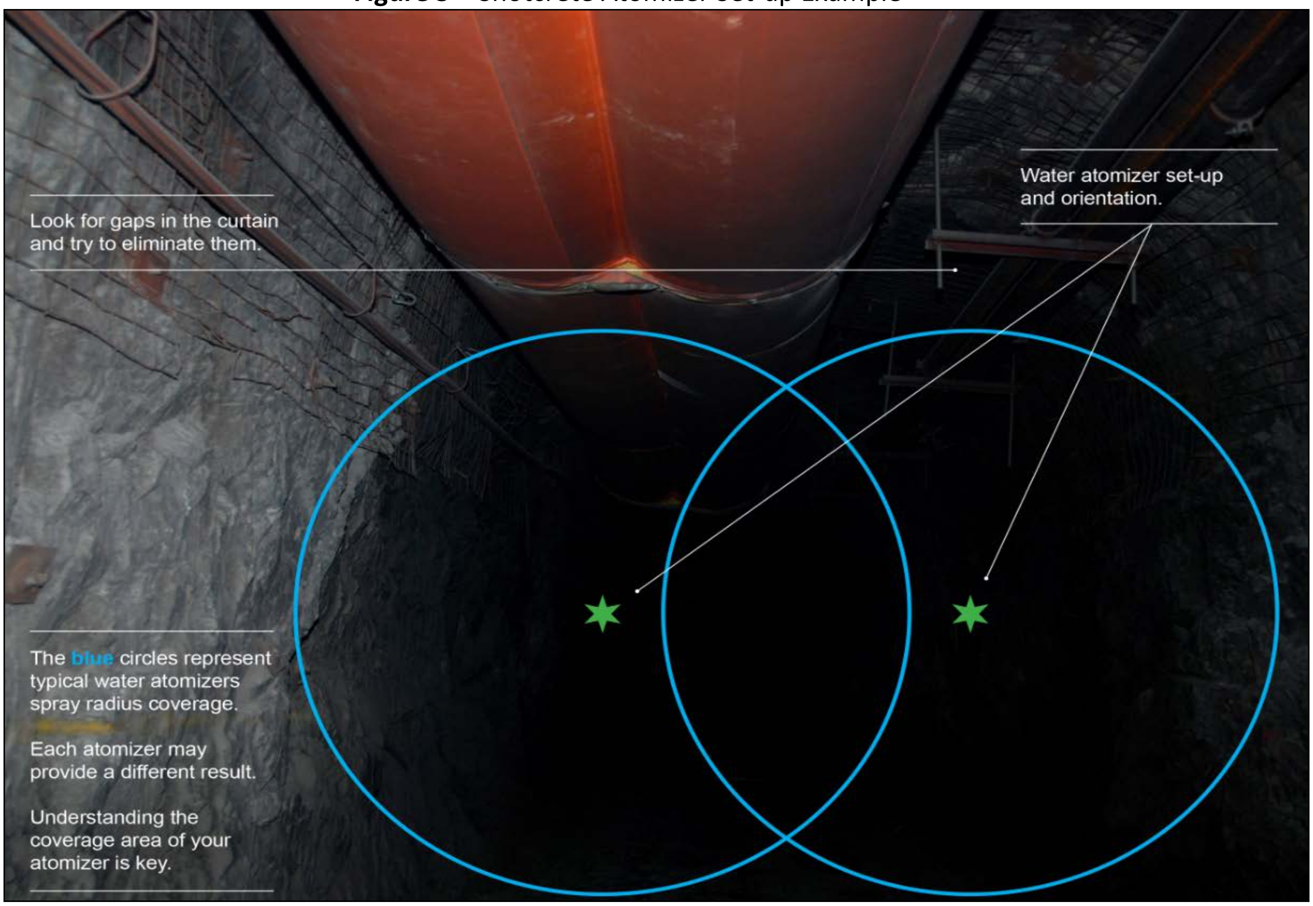
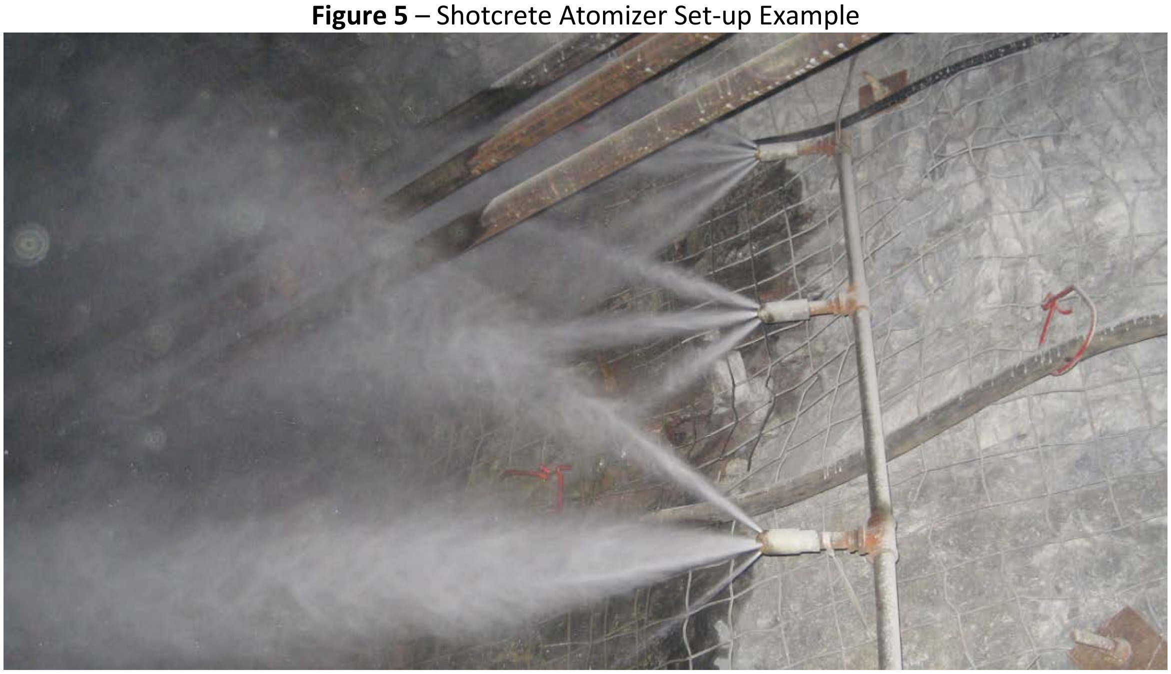


Figure 4 – Shotcrete Atomizer Set-up Example

Figure 5 – Shotcrete Atomizer Set-up Example



R.R.O. 1990, Regulation 854: Mines and Mining Plants

257. In an underground mine, clean water under pressure shall be made available for dust control purposes in a workplace where rock or ore is drilled, blasted, loaded or transported. R.R.O. 1990, Reg. 854, s. 257.

258. In an underground mine, broken rock or ore shall be thoroughly wetted by water,

(a) during blasting operations or immediately thereafter; and
(b) when the ore or rock is being loaded or scraped. R.R.O. 1990, Reg. 854, s. 258.

266. Where dust or other material is likely to cause a hazard by becoming airborne, the dust, or other material, shall be removed with a minimum of delay by,

(a) vacuuming;
(b) wet sweeping;
(c) wet shovelling; or
(d) other suitable means. R.R.O. 1990, Reg. 854, s. 266.

R.R.O. 1990, Regulation 833: Control of Exposure to Biological or Chemical Agents

3. (1) Every employer shall take all measures reasonably necessary in the circumstances to protect workers from exposure to a hazardous biological or chemical agent because of the storage, handling, processing or use of such agent in the workplace. R.R.O. 1990, Reg. 833, s. 3 (1).

4. Without limiting the generality of section 3, every employer shall take the measures required by that section to limit the exposure of workers to a hazardous biological or chemical agent in accordance with the following rules:

(1) If the agent is listed in the Ontario Table, exposure shall not exceed the TWA, STEL, or C set out in the Ontario Table.

Listing	French Listing Equivalent	Agent [CAS No.]	Time-Weighted Average Limit (TWA)	Short-Term Exposure Limit (STEL) or Ceiling Limit (C)	Notations
-	-	Portland Cement [65997-15-1]	1 mg/m^3 (E, R)	-	-
84a.	91a.	*Silica, Crystalline – Quartz/Tripoli [14808-60-7; 1317-95-9]	0.10 mg/m^3 (R)	-	-

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