REMEDIATION GUIDELINES FOR
ABANDONED MINE OPENINGS
IN NORTHERN CANADA
(JUNE 29, 2011)

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

1. INTRODUCTION

Mineral resources have been developed in northern Canada since the early 20th Century. Historic practices allowed for production to continue to resource exhaustion or until the commodity prices rendered the mine uneconomic to operate, at which point companies would generally abandon sites for new prospects. Where post-abandonment remediation has not occurred, mines may remain with potentially unsecured, often hazardous, openings to the underground mine workings. These mine openings pose potential hazards to both humans and wildlife and need to be addressed in closure. Remediation of abandoned mine openings in remote northern locations offers unique challenges that often require different approaches and considerations, which may be less applicable to southern locations.

The Indian and Northern Affairs Canada (INAC), Northern Contaminated Sites Program (NCSP) is responsible for a number of abandoned mine sites in northern Canada. Due to the desire to develop a consistent approach to selecting appropriate remediation measures for abandoned mine openings, INAC commissioned the Remediation Guidelines for Abandoned Mine Openings in Northern Canada (the Guidelines).

The intent of these Guidelines is to provide INAC staff with a document that conveys the various considerations required in the selection, construction and monitoring of remediation measures for abandoned mine openings in northern Canada. Specifically, the Guidelines review the following topics:

- A summary of the current standard of practice for the remediation of mine openings including:
  - A summary of the legislative requirements with Canada's three northern territories, as well as a summary of legislative requirements and regional guidelines in other southern jurisdictions within Canada and abroad.
  - A list of available methodologies that have been used to remediate abandoned mine openings, with references specifically to locations in northern Canada.
- A list of specific considerations for sites located within northern Canada.
- Guidance in the selection of remediation measures.
- A summary of cost considerations, including a summary of published costs associated with the remediation of mine openings in various jurisdictions.
- Considerations for post-closure performance monitoring.

It should be noted that the Guidelines are not intended to provide a prescriptive methodology for how to remediate mine openings. Each northern site and each abandoned mine opening is unique and requires site specific assessment prior to selection of the most appropriate remediation measure.

The Guidelines are not intended to be applied to new or operating mines. These mines are generally required to have closure plans in place prior to and during operations that addresses the sealing and abandonment of the underground mine workings and surface openings.

The Guidelines are not intended to specifically address the remediation of crown pillars, although they are acknowledged throughout the Guidelines as a related element. The long term stability of Crown Pillars, whether associated with mine openings or just near surface areas of the underground mine workings, requires special consideration and design efforts to be properly assessed and remediated.

2. HAZARDS ASSOCIATED WITH ABANDONED MINE OPENINGS

Abandoned mine sites often contain a number of different types of unsecured mine openings, such as:

- Shafts – primary vertical or inclined openings, which provide access to the underground workings.
- Raises – vertical or near vertical openings developed upward, connecting levels at different elevations, possibly extending to the surface.
- Winze – steeply inclined shaft driven to connect one mine level to a lower level.
- Adits – horizontal or near-horizontal tunnels into the mine from surface.
- Portals – openings or entrances into adits or inclined shafts.
- Declines – tunnels developed from surface at a shallow angle to connect underground levels at various elevations.
- Stopes – underground excavations developed above or below a given mining level, which may connect various levels to each other or to surface.
- Test pits – surface excavations, generally square or rectangular in plan areal extent, made to examine sub-surface conditions.
- Exploration trenches – elongate pits excavated at surface for the purpose of delineating sub-surface conditions (i.e. mineralization and structure).
- Caving features – formed by the collapse or infilling of underground workings by rock from the ceiling or sides of openings, which extended to surface.
- Subsidence features – formed through surface settlement of rock and overburden as a result of deformations or the caving of underground openings.

These openings may extend to great depths, be blocked with random debris or ice plugs, or the adjacent mine workings may be flooded. Injury or death can result to anyone venturing into or near one of these hazards by falling, drowning in flooded workings or by being buried by the collapse of the mine workings.

Besides the noted mine openings, underground mines at shallow depths can create crown pillars which are relatively thin ground covers above underground stopes. Crown pillars are not themselves "open", but they are related to underground openings and hence, are included herein for completeness.

In addition to the physical and stability related hazards, further hazards associated with mine openings can include dangerous mine gases, dilapidated buildings and structures, mine drainage and seepage, mechanical and electrical equipment and explosives. All may pose significant hazards to humans and wildlife.

Unsecured mine openings may present some of the greatest physical hazards regarding abandoned mine sites. Mine openings at abandoned mine sites were generally not designed to remain stable post closure. Mine openings can fail for a variety of reasons if not remediated properly for closure. The various failure modes include the following:

- Supports and roof spans weaken and deteriorate, and can fall without warning.

- The rock adjacent to vertical or horizontal mine openings can become unstable or weakened with weathering or frost action and water seepage.
- Timber, steel or shotcrete supports around and over shafts can deteriorate and weaken.
- Strapping, dowels and anchors on portals may weather, rust and fail over time, leading to progressive failures of exposed rock and soil masses.
- Underground workings mined close to surface can cave and collapse resulting in sinkholes or surface subsidence.
- Temporary plugs placed in the opening upon abandonment (often comprised of random debris from the mine site) can fail, re-establishing access to the underground workings.
- In permafrost regions, degradation of the permafrost can lead to loss of strength of the rock mass in the underground workings, leading to failure and potentially creating an opening to the underground mine workings.
- Given the context of mining, crown pillars may have been constructed with marginal Factors of Safety. This means deformations are possible, as are failures that daylight at surface.
- Flowing or seeping water into or through underground openings has the potential to create instability in the ground, as well.

Other, less visible hazards associated with unsecured mine openings include the following:

- The presence of additional vertical openings (raises and winzes) in close proximity to the main mine opening.
- The presence of toxic gases, mold or poor air quality (oxygen deficiency).
- Unstable explosives.
- Unused chemicals or other hazardous materials improperly disposed of by previous operators.

Additionally, any water draining from mine openings may be of poor quality and could pose potential health hazards should humans and wildlife come into contact with or ingest contaminated mine water.

3. STANDARD OF PRACTICE

3.1. Legislative Requirements – Northern Territories

Northwest Territories and Nunavut

The Mine Health and Safety Act of the Northwest Territories, and the Mine Health and Safety Act of Nunavut address the securing of surface openings. Section 17.03 in each document is particularly relevant, as it contains regulations for closure of mine openings:

> *(1) Where work at a mine or exploration site is stopped for a period exceeding 30 days, the owner or managers shall cause the entrances to the mine or exploration site and all other pits and openings that are dangerous by reason of their depth or otherwise, to be suitably protected against inadvertent access within the time limit specified by the chief inspector.*
>
> *(2) Before permanently closing a mine, the owner or manager shall ensure that all shafts, raises, stope openings, adits or drifts opening to the surface are either capped with a stopping of reinforced concrete or filled with material so that subsidence of the material will not pose a future hazard.*
>
> *(3) In the case of shafts or raises, the owner or manager shall, unless exempted by the chief inspector, ensure that the stopping is*
>
> > *a) secured to solid rock or to a concrete collar secured to solid rock; and*
> > *b) capable of supporting uniformly distributed load of 12 KPa or a concentrated load of 24 kN, whichever is the greater load.*
>
> *(4) Where the chief inspector is of the opinion that an opening referred to in subsection (2) presents no greater hazard than the local natural topographic features, the chief inspector may, in writing, exempt the mine from the application of subsection (2).*

Yukon Territory

Part 15 of the Occupational Health and Safety Act of the Yukon Territory addresses Surface and Underground Mines or Projects. Item 15.08 provides the following specific instructions with respect to the closure of mine openings:

> *(a) written notice shall be given to the director at least 14 days prior to closing a mine and shall ensure that*
> *(b) prior to the mine closing operation closing permanently, all shafts or raise openings shall be*
>
> > *i. capped with a stopping of reinforced concrete, or*
> > *ii. filled and kept filled with material so that any substance of the material will not endanger any person, and*
>
> *(c) the stopping prescribed in subsection (b)(i) shall be*
>
> > *i. secured to solid rock or to a concrete collar secured to solid rock, and*
> > *i. capable of supporting a uniformly distributed load of 12 kPa (1.7 psi), or a concentrated load of 24 kN (5,395 lbs.), whichever is greater.*

3.2. Legal Requirements

Section 263 of the Canadian Criminal Code deals with offences related to the Duty to Safeguard Openings in Ice and Excavations on Land. The section imposes legal duties in connection with openings in ice and excavations on land and describes the circumstances under which criminal liability may be incurred for failure to perform either duty.

> Subsection (2) of Section 263, states that:
>
> “Everyone who leaves an excavation on land that he owns or of which he has charge or supervision is under legal duty to guard it in a manner that is adequate to prevent persons from falling in by accident and is adequate to warn them that the excavation exists.”
>
> Subsection (3) states that:
>
> “Everyone who fails to perform a duty imposed by subsection (2) is guilty of
>
> (a) Manslaughter, if the death of any person results therefrom;
>
> (b) An offence under section 269 (unlawfully causing bodily harm), if bodily harm to any person results therefrom; or
>
> (c) An offence punishable on summary conviction.”

3.3. Regulatory Requirements

Land Use Permits and / or Water Licenses are often issued by regional regulatory authorities for remediation activities to be undertaken. These permits and licenses are generally issued following review and acceptance of the remediation plan for the site. Although they can be in place prior to development of the remediation plan if the site is under active care and maintenance.

4. AVAILABLE GUIDANCE DOCUMENTS

Available guidance documents pertaining to the remediation of abandoned mine openings may include the following:

- Mine Remediation Guidelines issued by regulatory bodies, Federal, Provincial / State or Territorial Governments,
- Mines Act sections of Occupation Health and Safety Regulations issued by Provincial or Territorial Governments.

A list of available guidance documents from various jurisdictions in Canada and the USA is provided below. Note that this is not a comprehensive list. Additionally, the various documents are frequently updated; for example, INAC's Mine Site Reclamation Guidelines for the Northwest Territories are currently undergoing revision. As such, the web links for each document have been provided and should be referenced prior to any use for any update to the documents. Excerpts pertaining to the remediation of mine openings from several of these documents are provided in Appendix A.

<u>Canada</u>

1. Nova Scotia Department of Natural Resources 1997. Abandoned Mine Openings Hazard and Remediation Handbook. Information Series ME23, 1997. (http://www.gov.ns.ca/natr/meb/pdf/is23.asp)
2. Indian and Northern Affairs Canada 2007. Mine Site Remediation Guidelines for the Northern Canada. (Currently undergoing revision). (http://www.ainc-inac.gc.ca/ai/scr/nt/ntr/pubs/MSR-eng.asp)
3. Yukon Government 2008. Yukon Mine Site and Remediation Closure Policy – Financial and Technical Guidelines. (http://www.emr.gov.yk.ca/mining/pdf/final_text_ft_guidelines.pdf)
4. Saskatchewan Ministry of Environment 2008. Guidelines for Northern Mine Decommissioning and Remediation. (http://www.environment.gov.sk.ca/Default.aspx?DN=52a8a117-332f-4c49-89b9-2f90d79bca5a)
5. Government of Manitoba, Ministry of Industry, Trade and Mines, Mines Branch 2006. Manitoba Mine Closure Regulation 67/99 – General Closure Plan Guidelines. (http://www.gov.mb.ca/stem/mrd/mines/acts/closureguidelines.pdf)
6. Government of Ontario 2007. Mining Act – Ontario Regulation 240/000 – Mine Development and Closure. (http://www.e-laws.gov.on.ca/html/regs/english/elaws_regs_000240_e.htm)
7. Government of Quebec, Ministry of Natural Resources 1997. Guidelines for Preparing a Mining Site Rehabilitation Plan and General Mining Site Rehabilitation Requirements. (http://www.mrnf.gouv.qc.ca/english/mines/rehabilitation/rehabilitation-guide.jsp)

8. Government of British Columbia, Ministry of Energy, Mines and Petroleum Resources, Mining and Minerals Division 2008. Health, Safety and Remediation Code for Mines in British Columbia.
(http://www.empr.gov.bc.ca/MINING/HEALTHANDSAFETY/Pages/HSRC.aspx)

USA

9. Colorado Division of Minerals and Geology 2002. Best Practices in Abandoned Mine Land Remediation: the remediation of past mining activities. Colorado, U.S.A.: State of Colorado. (http://mining.state.co.us/Abandoned%20Mines.htm)

10. State of Alaska, Department of Natural Resources, Division of Mining, Land and Water 2004. Mining Laws and Regulations.
(http://dnr.alaska.gov/mlw/mining/)

The most pertinent of these documents are the Abandoned Mine Openings Hazard and Remediation Handbook, produced by the Government of Nova Scotia and the Best Practices in Abandoned Mine Land Remediation produced by the Colorado Division of Minerals and Geology. Both of these documents refer specifically to the remediation of abandoned mine openings and both have been referenced where appropriate during the development of the Guidelines.

The Occupational Health and Safety Acts and Regulations of each jurisdiction throughout Canada can be accessed through the following website:

http://www.awcbc.org/en/occupationalhealthandsafetyactsandregulations.asp

Each site generally includes a link to the specific Mine Health and Safety Regulations for each jurisdiction. Excerpts pertaining to the remediation of mine openings from several of these provincial and territorial regulations are provided in Appendix A.

5. GENERAL NORTHERN CONSIDERATIONS

Mine remediation in northern locations (north of 60° latitude) must be designed for the unique challenges that arise from the site location, access constraints, geology and climate, along with the remoteness and short summer construction season. A thorough understanding of site-specific characteristics is essential to the success of remediation projects in design, construction and long term performance.

5.1. Remoteness

Many abandoned mine sites in Canada's northern territories are situated hundreds of kilometers from any significant population centre. Site remoteness increases the cost of mobilizing equipment, personnel and materials and prolongs construction schedules. At remote sites, work crews are typically supported by camps. Bringing in equipment to conduct site investigation and preliminary design work is both costly and time-consuming for remote sites. Site remoteness also increases costs associated with post construction performance monitoring and maintenance. As such, remediation measures that minimize post-construction performance monitoring and maintenance requirements (i.e. a "walk away" scenario) are preferred for remote locations. An on-site assessment, followed by preconstruction design prior to project mobilization, will reduce costly modifications or additional equipment, material or personnel needs. That being stated, the need for robust, yet flexible designs (that can be field modified as required), should be emphasized.

5.2. Terrain

The geomorphology across Canada's northern territories varies considerably, but the following general comments are provided:

- Soil cover is non-existent to thin across the Precambrian Shield, slowing re-vegetation and limiting the availability of top soil materials for potential construction uses.
- Frost affected bedrock often surrounds mine openings and this rock may need to be removed prior to implementation of any remediation measure.
- Frost jacking of near surface bedrock exposures can occur along fractures and joint sets within the rockmass in response to numerous freeze thaw cycles encountered at many northern locations.
- The sensitive boreal forest land surface is susceptible to damage by vehicle traffic and the re-vegetation process is imperceptible to lengthy.
- Slope stability, seismic risk, non-glaciated areas and a more dynamic hydrogeological regime west of the Slave Craton must be factored into closure plans.

5.3. Climate

Climatic conditions at many northern locations are often harsh, consisting of long cold winters with limited daylight and short summers. Climate can impact remediation activities in many ways.

- Cold, dark conditions during the winter months often limit the length of the construction season to the more amenable and warmer summer months.
- Site climactic conditions can also affect accessibility. Air and vehicle transportation often depend on frozen lakes or ice roads to bring supplies and personnel to site. These transportation links are susceptible to sudden climactic extremes, hindering transportation of personnel, equipment and supplies into or out of the site, potentially impacting the construction schedule and project costs.
- Cold air temperatures can impact the quality of construction, unless appropriately accommodated for during construction.
- Cold air temperatures may impact integrity of remediation measures including any external or internal drainage elements.
- Climate change may modify permafrost conditions affecting the long term performance of some remediation measures that are dependent upon specific climatic conditions.

5.4. Permafrost

Many of the abandoned mine sites within the Northern Contaminated Sites Program are located within the continuous or discontinuous permafrost zones. Permafrost conditions can impact the selection and performance of remediation measures by the following:

- Permafrost is susceptible to climate change. This is especially relevant for warm permafrost characteristic of sites located within the discontinuous permafrost zone which can exhibit ground temperatures within one to two degrees of 0°C.
- Cold climate and permafrost conditions at mine sites often result in the development of an ice plug within the underground workings and may complicate the construction of some remediation measures or preclude construction of others. Ice plugs are also susceptible to a warming climate and may not be considered a permanent element. Ice plugs may additionally block access to the walls of openings or restrict backfilling.
- Permafrost conditions can also affect the availability of borrow materials used during remediation. Borrow materials such as granular deposits may be frozen at depth, with only material within the seasonally thawed zone (e.g. the active layer), readily available for construction. Additionally, disturbance of borrow areas exhibiting permafrost requires appropriate remedial planning, as permafrost degradation will occur post-excavation and may result in negative surface impacts such as slope instability, soil erosion and the development of run-off water high in suspended sediments.
- The loss of permafrost conditions due to site disturbance and climate change may have impacts on the hydrogeologic regime of underground workings.

- Permafrost often enhances the strength characteristics of the rockmass surrounding mine openings due to the enhanced strength of the frozen pore water. Loss of this strength component due to permafrost degradation may impact the performance of remediation measures built on or around this rock.

5.5. Material Sourcing

Natural materials such as sand and gravel can sometimes be utilized in the construction of remedial measures for abandoned mine openings, particularly in the construction of concrete seals.

- Due to the typically thin soil cover and sporadic presence of thick granular deposits such as eskers, suitable deposits of construction materials may not be readily accessible in close proximity to many abandoned mine sites. Furthermore, the use of eskers may not be suitable due to their potential cultural significance and importance to wildlife. As such, transportation costs and extraction effort from suitable deposits may be significant. Alternatively, development of granular resources may require drilling, blasting and crushing activities, which can be very costly.
- Permits are generally required from various regulatory authorities to develop borrow sources.
- Deposits may be frozen due to permafrost conditions mentioned previously and hence may be difficult or impractical to extract.
- In some cases, granular deposits may contain massive ice rather than sand or gravel.
- Materials may not be geochemically suitable/compatible for use in concrete mixture.
- Geochemical testing of all borrow materials is required.

To address the challenges associated with material sourcing, a thorough, geographically extensive pre-remediation site assessment is necessary to support conservative cost estimates for material use and transport.

5.6. Environmental Sensitivity

Northern Canada is composed of diverse ecosystems and environmental conditions, with an estimated one-third of the Northwest Territories occupied by rivers and lakes. Environmental changes require long recovery periods.

Soil is susceptible to erosion as a result of post-glacial warming; vegetative cover is often thin with shallow root-holds. Vehicle traffic on the sensitive boreal land surface may lead to thinning or destruction of vegetation and permafrost degradation and is typically not allowed under work permits issued by regulatory authorities.

Environmental preservation in Northern Canada is very important to its inhabitants. Furthermore, the North is culturally and spiritually significant to aboriginal communities, who maintain dependency on and fervent respect for the land, its northern wildlife and vegetation. Damage to the environment has the potential to adversely affect traditional ways of life. Engagement with all regulatory bodies and stakeholders is advised when selecting potential remediation options.

6. REMEDIATION METHODS

This section provides a description of various potential remediation methods for abandoned mine openings. The methods are separated into the following categories:

- Temporary;
- Long Term; and
- Permanent.

For each method the following is provided:

- A general description of the method including the level of security offered by each method.
- Comments regarding construction practices.
- Comments regarding effective design life of each method.
- Comments regarding proven northern (north of 60° latitude) application and performance of Long Term and Permanent Measures.
- A list of advantages and disadvantages to using each method.
- A list of northern considerations specific to each method.

6.1. Remediation Objectives

Remediation objectives for abandoned mine openings can be site specific or can vary from opening to opening on the same site. Some general remediation objectives often include:

- Minimize access to underground workings from surface openings to protect humans and wildlife.
- Minimize surface water infiltration into underground mine workings.
- Maximize the stability of underground workings so that there is no surface expression of underground failure.
- Prevent collapse, stress transfer and flooding of adjacent mines.
- Minimize the potential for the underground workings to become a source of contamination to the surface environment or nearby taliks or waterbodies.
- Minimize potential for contamination from mine waters.
- Re-surface, re-slope and contour areas surrounding mine openings including portal plugs) as required to blend with surrounding topography or desired end land-use targets.

The remediation objectives for each mine opening should be incorporated into the remediation objectives for the entire site.

6.2. Temporary Remediation Measures

Temporary closure methods prevent deliberate or accidental entry into a mine opening, but do not alter the general condition of the opening. These closure methods are generally the least expensive and are applicable to openings that represent hazards, but which also have potential future economic and/or historical value (Government of Nova Scotia 1997). As temporary methods are intended to be replaced by long term or permanent methods, legislative requirements regarding strength criteria are not applicable.

Temporary measures that can be implemented to reduce the hazards associated with abandoned mine openings prior to or in conjunction with implementation of a long term strategy may include the following:

- Signage.
- Barriers (fences, wire screens, steel grates and steel plates).

6.2.1. Signage

Description of Method

Signs are used to alert unknowing parties to the presence of a mine opening. Signs are typically used as a temporary measure prior to the implementation of a longer term remediation measure. As they neither secure the opening nor deter wildlife, their use is limited to warning humans to exercise caution, and suitable only for low risk hazards.

Construction

Effective placement of a warning sign is determined by its visibility and proximity to the hazard, such that the sign will be noted by individuals in the vicinity of the opening with enough notice that a vehicle (e.g. snowmobile, ATV) may be safely stopped. Signs should be easily observable at eye level from every access direction and surround the outer limits of the hazard. Posts should be stable structures, likely to withstand harsh environmental conditions, vandalism and damage due to wildlife and storms. Galvanized fasteners and washers will reduce rusting and secure the sign to the post. Signs should be functional in all seasons and climactic extremes. A post may require two signs at different heights to accommodate seasonal ground cover and darkness. Both symbols and applicable language(s) must be used to indicate danger and hazard. Reflective lettering may be required to increase visibility during the dark winter months.

Effective Design Life

Signs are considered temporary fixtures and can only be expected to remain effective for 5-10 years. To ensure their continued functionality, frequent inspection and maintenance is required.

Advantages

- Signs are inexpensive and easily attainable.
- Sign installation is relatively simple.
- Multiple signs, in various locations, can alert people approaching from any direction.

Disadvantages

- Signs have a short effective life expectancy, as they can be removed, vandalized, obstructed or damaged suddenly by natural forces or wildlife or gradually by corrosion.
- Signs require regular inspection to ensure their continued functionality.
- Unnecessary attention can be drawn to the hazard, resulting in harm to curious individuals.
- If visitors to the site do not understand the language in which the sign is written, they may not be aware of the hazard.
- Signage does not afford protection to wildlife; furthermore, some species may damage or destroy signage.

Northern Considerations

- Regular inspection and maintenance of signs is expensive for remote locations.
- Multiple languages, reflective of local and regional dialects and symbols may be required on signs to enhance effectiveness.
- Signs may become buried in snow during winter months, reducing effectiveness.
- Limited light conditions during winter months may reduce visibility of sign and impact effectiveness.
- Harsh climactic extremes, wildlife habituation and human activities (e.g. vandalism) may necessitate more frequent inspection and maintenance.

6.2.2. <u>Barriers</u>

Barriers prevent humans and most wildlife from entering a mine opening, but do not completely eliminate the possibility of entry into a mine opening. Their use in shaft or adit closures is appropriate where future site use is anticipated or where the construction of a more permanent seal is not possible (Colorado Department of Natural Resources, 2002). Possible barrier selections include fences, wire screens, grates and steel plates.

6.2.2.1. Fencing

Description of Method

Fencing can be installed around the perimeter of a mine shaft, raise, or subsidence area; or across the portal of an adit, decline or stope to discourage access to the underground mine workings. Since no seal is placed over the opening, the possibility of entry is not eliminated. Fences, like signs, are a temporary measure and require regular inspection and maintenance to sustain effectiveness for as long as possible. Fencing may be used in combination with another barrier method (screens or grates) to provide an increased level of mitigation.

Construction

In order to be effective, fencing should be installed a sufficient distance from the perimeter of the horizontal or vertical mine opening, to enclose all areas with potential for instability, subsidence or caving. As a guideline, this distance should allow five times the largest dimension of the opening to remain between portal and the fence (Government of Nova Scotia 1997).

Galvanized chain link fences are most effective in discouraging access with the addition of barbed wire along the top of the fence to discourage climbing into the enclosed area. Galvanized metal posts and rails should be used to prevent corrosion and maintain effectiveness. The posts and chain links can either be set in concrete or drilled into competent rock. Fence heights and depths vary with hazard location, severity and species of wildlife frequenting the area.

Effective Design Life

Galvanized chain link fences are expected to last between 10-15 years. Their useful lifetime can be extended with regular inspection and maintenance. Plastic or wooden fences or those fastened to impermanent fixtures usually remain functional for less than 10 years.

Advantages

- Fencing is relatively inexpensive, safe and simple to install.
- Fencing provides a perimeter barrier and prevents accidental entry by humans and medium to large wildlife into hazardous areas.
- Disturbance to the site is minimal.

Disadvantages

- Fencing offers only temporary protection and requires regular inspection and maintenance.
- Damage to fencing can occur from falling or growing trees, subsidence of mine workings, vandalism, theft and corrosion.
- The hazard is not eliminated, as entry by determined visitors remains possible.
- Fencing is aesthetically unattractive in natural environments. Design considerations and increased maintenance will increase costs of improving fence aesthetics.
- Potential to trap or entangle wildlife inside fenced areas.
- There is no protection to small wildlife, including small winged species.
- Fencing must be accompanied by signage posted at a safe distance to mitigate vehicular impacts.

Northern Considerations

- To be effective in most northern locations, drilling into rock is likely required to install fence posts, increasing the difficulty of construction and cost of installation.
- Regular maintenance of fencing is expensive for remote locations.
- Required materials can be easily flown into remote sites.
- Fences may provide a hazard to people travelling on land, especially those travelling by snowmobile during winter months during low light conditions.
- Fences may be hazardous to all manner of wildlife.

6.2.2.2. Steel Wire Screen Closure

Description of Method

Steel wire screens, constructed from commercially available wire mesh, can be installed across an abandoned mine opening to restrict unauthorized entry. The screens can deter entry more effectively than fencing; however, the screen does not provide a permanent seal. In cases where the opening has become home to wildlife, steel wire screens can provide continued access for small wildlife. If future entry into the mine is required for mineral exploration or historical purposes, the barrier can easily be removed.

Construction

Steel wire screen barricades are suitable for various opening shapes, including both shafts and adits. Installation methods differ with opening orientation. Vertical and inclined openings require anchoring of the screen to competent bedrock or a stable concrete shaft collar. In contrast, the steel screen is installed over the entrance or inside the opening of adits, declines and stopes. Due to its inability to support anything other than nominal surface loads, wire screens may not be suitable for use in vertical openings. Material overlying the installation site, as well as any loose rock around the opening, must be removed before the steel screening can be positioned and anchored in place using rock bolts or grouted rebar pins. Where the steel screen is attached to concrete shaft collars, concrete expansion anchors can also be used. Following installation, the wire screen and any other bare steel rock bolts or pins should be covered with a zinc-rich protective paint to prevent corrosion.

Effective Design Life

Regular maintenance and repair is required if a life expectancy beyond 10-15 years is expected.

Proven Northern Application and Performance

Steel wire screens have been used at many abandoned northern mine sites as a temporary measure prior to implementation of a long term or permanent closure method.

Advantages

- Steel wire screen barricades restrict entry.
- Natural airflow and access to mine openings is possible for some wildlife.
- Screens permit water to drain from opening preventing build-up of water pressure behind the closure.
- Steel wire barricades are relatively inexpensive and can be custom fabricated offsite and transported into the field for installation.
- Wire screen barricades are easy to install.
- Placement inside the mine opening results in minimal visibility of the closure method, if desired for aesthetic purposes.
- Screens are relatively inexpensive to remove or replace if future access is necessary.

Disadvantages

- Steel wire screen barricades may be subject to earth movements, vandalism and corrosion, requiring regular maintenance and inspection.
- Chipping or trimming of rock around the entrance may be required to attach the wire screen.
- Installation generally requires a compressor to power a rock drill used to install rock bolts or rebar anchor pins, limiting installation in remote or vehicle inaccessible locations.
- Inability to support anything other than nominal surface loads may necessitate perimeter fencing and signage proximal to vertical openings, or may limit use of screening to sub-horizontal openings.
- Unlike fencing, steel wire screens do not encompass areas adjacent to the mine openings, which may be unstable.
- Steel wire screens could present an entanglement hazard to wildlife.
- Screens covering vertical openings allow surface water to flood workings.
- Placement over vertical openings presents risk to small wildlife.

Northern Considerations

- Regular maintenance of wire screen barricades is impractical and expensive for remote locations.
- Required materials and equipment necessary for installation can be easily flown into remote sites.
- Screens made of some alloys, while more costly, may require less maintenance.

6.2.2.3. Steel Grate Closure

Description of Method

Steel grate closures, like steel wire screens, restrict entry into abandoned mine openings of various shapes, while still permitting airflow, drainage and access for small wildlife. Access to the hazard is restricted; however, removal is possible if entry into the mine is required at a later date. Grate materials include angle iron, rebar or floor grating, attached to a rigid steel frame.

Construction

Installation causes minimal site disturbance. Vertical shafts, inclined shafts and raises require the firm anchoring of steel grates in competent bedrock or a stable concrete shaft collar, necessitating the removal of debris and soil around the opening. Grates are placed over the entrance or inside the opening of adits, declines and stopes once loose rock above and beside the adit entrance, roof and walls is removed, scaled down or supported.

Chipping or trimming of the rock around the installation minimizes gaps and ensures uniform contact between the steel frame and the bedrock, shaft collar, entrance or opening. Once positioned, the grate is anchored using rock bolts or grouted rebar pins. Concrete expansion anchors and pre-fabricated brackets can also be used to attach the steel grate to the top of a concrete shaft collar. Following installation, any bare steel should be covered with a zinc-rich protective paint. Alternate alloys, less susceptible to corrosion, may be considered.

Effective Design Life

The functioning life of a steel grate is longer than a wire screen or fence. The Nova Scotia Abandoned Mine Closure Handbook estimates that the grate will last between 15-20 years, while the Colorado Division of Minerals and Geology approximates their lifespan at 50 years.

Advantages

- Steel grate barriers provide a high level of security for the underground workings, restricting unauthorized and unintended entry by humans and most wildlife.
- Natural airflow and access to mine openings is possible for some small wildlife.
- Steel grates are relatively inexpensive and can be fabricated off-site and transported into the field for installation.
- Placement inside the mine opening results in minimal visibility of the closure method.
- Grates permit mine water to drain from sub-horizontal openings.
- Grates are relatively inexpensive to remove or replace if future access is necessary.

Disadvantages

- Steel grates are subject to earth movements, corrosion and possible vandalism, potentially necessitating regular inspection and maintenance.
- Installation may require chipping or trimming of rock around the entrance.
- Intact rock or concrete collar around the opening is required for attachment.
- Installation may be difficult due to potential need to install rock bolts or rebar anchor pins, requiring a rock drill and generator.
- Grates covering vertical openings may necessitate perimeter fencing and signage proximal to openings.
- Grates covering vertical openings allow surface water to flood workings.
- Placement over vertical openings presents risk to small wildlife.

Northern Considerations

- Regular inspection and maintenance of steel grate barricades is expensive for remote locations.
- Required materials and equipment necessary for installation may be flown into remote sites.
- Does not prevent snow or ice from entering the opening.

6.2.2.4. Steel Plate Closure

Description of Method

Steel plate closures offer the highest level of security for restricting access to underground mine workings of the noted temporary remediation measures. Access to the hazard is restricted; however, removal is possible if entry into the mine is required.

Construction

Installation considerations for steel plates are similar to those previously stated for steel grates and, as such, will not be repeated.

Effective Design Life

The functioning life of a steel plate is approximately 30 years, which can be extended with regular inspections and maintenance. Other more durable materials may be developed which may extend the effective design life and reduce maintenance.

Advantages

- Steel plate barriers provide the highest level of security for the underground workings of all the temporary closure methods, restricting unauthorized and unintended entry by humans and wildlife.
- Maintenance should be minimal.
- Post-construction inspection requirements are the least of most other temporary methods.
- Life expectancy is highest of all temporary methods.
- Can be custom fabricated off site, minimizing QA/QC concerns in manufacturing of plate.
- With a little forethought during design and installation, plates may be easily removed or replaced if future access is necessary.

Disadvantages

- Does not permit free flow of air drainage or effective drainage of mine water.
- Steel plates are subject to earth movements and corrosion, but maintenance can be minimized with occasional inspections and minor efforts such as applying corrosion resistant paints.
- Thick steel plates covering a large surface area can be expensive compared to other temporary closure methods, though installation costs are not excessive. Other durable materials may be less costly to install.
- Intact rock or concrete collar around the opening is required for attachment.
- Installation may be difficult due to potential need to install rock bolts or rebar anchor pins, requiring a rock drill and compressor.

Northern Considerations

- Transportation of the steel plate to site likely requires land /winter road access to remote northern sites or more costly transportation by large aircraft or helicopter.
- Lack of drainage from sub-horizontal mine openings may lead to build up of water pressure behind the steel plate.
- Due to restricted airflow, steel plates may encourage ice plugs to form.
- Plates must be designed to facilitate fluid outflow from sub-horizontal openings and resist corrosion.

6.3. Long Term Remediation Measures

Long term remediation methods seal and prevent entry into a mine opening, but still preserve the general condition of the opening. The method of closure is applicable to openings which present a hazard, but which may also have potential future economic or historical value or where permanent closure is not practical (e.g. deep vertical openings where backfilling is impractical). Appropriate long term closure methods for mine openings include:

- Concrete Cap
- Concrete Bulkhead
- Polyurethane Foam (PUF) Plugs
- Disused Tire Plugs

The life expectancy of long term remediation measures generally exceed 30 years.

6.3.1. <u>Concrete Caps</u>

Description of Method

Concrete caps are capable of completely securing on open shaft or raise. If future re-entry to the site is anticipated, locking hatches can be built into a concrete panel design. Alternatively, most structural caps can be removed using heavy construction equipment. Concrete caps can be cast-in-place or constructed as pre-fabricated panels or monolithic caps.

Construction

Concrete caps are suitable for installation at vertical or near-vertical shafts, raises and stopes with various opening shapes. If the site characteristics permit the use of a standardized design, the cap can be prefabricated and transported for installation. Monolithic concrete caps are most often employed where subsidence of surface soil or fill has occurred into the opening. In these cases, the mine opening is often still covered and not visible. If acid drainage is a concern, sulphate resistant cement, or additives that achieve the same effect, should be used. Vents may be incorporated into the concrete cap design to allow airflow and prevent pressure buildup.

The concrete cap must be anchored to competent rock, so the area around the perimeter of the opening generally requires some excavation and stripping of overburden to expose the rock conditions. Further excavation, clearing, chipping or trimming may be necessary to remove loose, weathered or otherwise deteriorated rock to establish a stable collar for the cap. Cap dimensions are based on the size of the opening and surrounding unstable areas, as caps will not prevent the collapse of shaft sidewalls. In most cases it will not be safe or practical to conduct mapping to obtain rockmass structural data, so the limits of the cap should be adequately conservative to accommodate the largest potential failure mode. In most cases, construction requires a trackhoe and bulldozer.

Installation procedures vary with the selected cap type. Precast concrete panels should be positioned on a gravel leveling pad placed around the shaft opening. If the panels require the added support of support beams, a level bearing surface can be maintained by positioning the beams in indentations cut into the bedrock and setting them on a gravel base or concrete leveling course. Precast concrete panels can also be placed directly on a competent concrete shaft collar.

Cast-in-place concrete caps are cast directly into the top of an existing competent concrete shaft collar. The framework should be built to extend a distance below the top of the collar that permits the new cast in place cap to be “keyed” into the existing shaft opening. If a concrete shaft collar is not present but competent bedrock is, forms should be constructed around and over the opening using wood or stay-in-place galvanized metal formwork. As required, forms can be installed within the shaft or raise opening. To assist with drainage, non-corrodible pipes can be installed through the concrete.

Following closure, caps constructed below grade on bedrock should be backfilled and contoured to promote drainage.

Concrete caps constructed at or above grade can be either left exposed or covered with a surficial layer of granular material. Leaving concrete caps exposed increases the potential for degradation due to exposure to climatic conditions; however, visual inspections of the concrete quality are easier when left exposed. Covering with granular material can lessen the impacts of climate to the integrity of the concrete but makes visual inspection more difficult. A low permeability liner such as GCL can be incorporated into the cover to promote drainage and further lessen the impacts of climate on the integrity of the concrete. The final decision to cover or leave concrete caps exposed is dependent on site-specific considerations.

Monolithic concrete caps may be applied at areas where surface depressions have developed or where overlying soil or fill has begun to cave into the underlying openings. Ensuring subsidence cone stability prior to cap placement is extremely important. The cap is cast directly onto the bottom of the subsidence feature using the sides of the subsidence cone to contain the concrete. Modifying the base of the subsidence feature may be necessary to enlarge the slab relative to the opening and seal voids created by continued subsidence, as well as support the load of added backfill.

Effective Design Life

Due to the potential for physical deterioration of the concrete, the effective design lives of concrete seals range from 50 to 100 years. Long-term durability of concrete can be impacted by the following:

- Alkali-aggregate reaction;
- Chemical resistance;
- Corrosion of reinforcement;
- Freeze-thaw effects;
- Abrasions; and,
- Erosion.

Proven Northern Application and Performance

Cast-in-place concrete seals have been constructed during the Northern Contaminated Site Program at numerous locales throughout Northern Canada, including Discovery, Giant Mine, Tundra, Port Radium, Silver Bear and North Inca mine sites. Concrete seals at each of these sites have been installed in the last 10 years and performance to-date has been acceptable.

Advantages

- The mine opening is completely sealed and secured against unauthorized and unintended entry by humans and wildlife.
- The life expectancy of concrete caps generally exceeds 50 years and may be extended with proper design and construction methods.
- Maintenance should be minimal; however, periodic inspections are recommended to check for deterioration of the concrete.
- Generally an accepted practice for closure of mine openings in all jurisdictions throughout North America and has been used at many sites throughout northern Canada; regulatory and stakeholder approval is anticipated to be straightforward due to familiarity with use.
- Could be left exposed for monitoring purposes with limited impacts to physical integrity.
- Physical integrity likely will not be affected by forest fires.

Disadvantages

- Heavy equipment is typically required for excavation, mixing placement and casting of concrete.
- Qualified personnel are required to be present or accessible for field modifications.
- Concrete caps require extensive QA/AC during construction and concrete testing.
- Due to the material and construction equipment required, air or winter road access into sites is generally required.
- Costs associated with concrete caps are generally higher than many other methods.
- Design can be complex and may need field modification following removal of existing infrastructure and removal of loose rock from around opening area.
- Concrete caps could be susceptible to deterioration due to interaction with acidic mine and or surface waters (may be at least partially offset by use of sulphate resistant cement or incorporating additives that achieve the same effect).
- Construction of concrete caps is labor intensive and requires some advance preparation work within the construction area to provide drainage, ventilation and stabilization of the opening for protection for workers from possible rock falls.

Northern Considerations

- Harsh climate conditions may reduce life expectancy.
- Northern sites often have limited availability of locally available granular resources suitable for use on concrete production, potentially requiring these materials to be transported to site.

- Site remoteness and climate conditions can make on-site production of high quality concrete challenging, potentially affecting the short and long term performance of the mine opening seal.

6.3.2. Bulkhead Closure

Description of Method

Bulkheads consist of a barricade or wall constructed across horizontal to sub-horizontal mine openings. Bulkheads provide a secure seal that completely eliminates access into an abandoned adit, decline or stope and is suited for sites not requiring access for wildlife or natural airflow. Entry can still be gained into the mine opening for mineral exploration or historical purposes by demolition of the bulkhead or incorporating a locking hatch into the bulkhead design.

Construction

Bulkheads can be constructed from native rock, prefabricated concrete blocks or cast-in-place concrete. Prior to installation, loose rock around the perimeter of the opening, including the floor, should be removed to ensure a stable foundation. Uneven floors may need to be leveled and smoothed. The seal between the foundation, back (roof), walls and the bulkhead should be tight and any remaining gaps should be sealed with concrete or grout. A drainage pipe should be installed if there is any water present as bulkheads are not typically structurally designed for water retention or excessive ice action. It should be noted that mitigation of the potential impact of freezing fluids in the drainage pipe must be considered in the design stage, especially in northern locations. Ends of drainage pipe should be enclosed in wire mesh to prevent ingress of small wildlife.

Effective Design Life

Unless damaged, the estimated life of native rock or concrete block bulkhead is between 40 and 50 years (Government of Nova Scotia, 1997).

Advantages

- The mine opening is completely sealed and secured against unauthorized and unintended entry by humans and wildlife.
- The life expectancy of bulkheads generally ranges from 40 to 50 years and may be extended with proper design and construction methods.
- Maintenance should be minimal; however, periodic inspections are recommended to check for deterioration of the concrete.
- Generally an accepted practice for closure of sub-horizontal mine openings in many jurisdictions throughout North America and has been used at some sites throughout northern Canada; regulatory and stakeholder acceptance should be straightforward.
- Could be left exposed for monitoring purposes with limited impacts to physical integrity.
- Physical integrity will not be affected by forest fires.

- Native rock may be locally available in sufficient quantities from adjacent waste rock piles. Though bulkheads constructed of rockfill may be difficult to construct tight to the top (crown) of the opening.
- Bulkheads can be installed inside the opening to reduce the visibility of the seal.

Disadvantages

- Construction of bulkheads is labor intensive and requires some advance preparation work within the construction area to provide drainage, ventilation and stabilization of the opening for protection for workers from possible rock falls.
- Unless native rock is available, concrete blocks must be transported to site – an expensive option in remote locations lacking infrastructure.
- Concrete bulkheads require competent bedrock around all sides, and stable structural environment.
- Grouting may also be required if the bulkhead is to retain water to reduce the permeability of the surrounding rockmass.
- Heavy and/or specialized equipment is typically required for excavation, placement or casting of concrete.
- Due to the material and construction equipment required, winter road or air access into site is generally required.
- Costs associated with concrete bulkheads are substantially higher than many other methods applied in similar locations.
- Design can be complex, possibly requiring structural reinforcement and erection of form work. Field modification may be needed following removal of existing infrastructure and loose rock from around opening area. It is advisable to remove existing infrastructure and loose rock from the opening prior to designing the bulkhead.
- Could be susceptible to deterioration due to ground movements and interaction with acidic mine waters (may be at least partially offset by use of sulphate resistant cement, ceramic drainage pipes or lining the bulkhead areas which may be exposed to acid solutions).
- As a result of deterioration, qualified persons may be required to undertake field modifications to bulkhead design.

Northern Considerations

- Harsh climate conditions may reduce life expectancy.
- Northern sites often have limited availability of locally available granular resources suitable for use on concrete production, potentially requiring these materials to be transported to-site.
- If rockfill is used to construct the bulkhead, freezing ground temperatures may enhance strength of the bulkhead but this strength would be susceptible to climate change and may not be reliable over the long term.
- Site remoteness and climate conditions can make on-site production of high quality concrete challenging, potentially affecting the short and long term performance of the mine opening seal.

- Where drainage of mine waters from the opening is expected, the design of flow/seepage control measures must ensure that excessive water pressure does not build up behind the bulkhead. Excessive water pressure may result in failure of the bulkhead and discharge of possibly contaminated mine water to the environment.

6.3.3. Plugs

Plugs provide a long term, low maintenance method for closing mine openings. Two innovative plug designs involve the use of compressed mine tires or polyurethane foam (PUF) to construct a plug at the mine opening. Further information regarding each of these methods is provided in the following sections.

6.3.3.1. Tire Plug Closures

Description of Method

Used tires from the mine site or proximal areas provide an alternative closure method developed by N. Tribe & Associates Ltd. (Tribe et al. 1999). In this method, a stack of tires connected with galvanized steel cables is compressed by an excavator and forced into the vertical or sub-vertical mine opening. Once in place, the tires expand to fill the void, forming the plug.

Construction

A working platform is placed above the plug. The matte layer, also constructed from tires linked together with cable, should be anchored to a one metre wide ledge, excavated around the end of the opening. Each tire links to four adjacent tires, forming a square pattern. Geotextile polypropylene plastic and fiber layers overlie the matte, preventing the passage of fines into the mine opening. A minimum of one metre of gravel or broken rock, containing significant fines should be placed next, covered by top soil and allowed to revegetate. Final contours should establish drainage away from the opening.

Effective Design Life

Limited information is available about the lifespan of the tire plug, as the method was first employed in the 1990's.

Proven Northern Application and Performance

There are no documented uses of this method in northern Canada. The method has been employed at some sites in Alberta.

Advantages

- Pressure applied to the opening sides enhances stability of the opening.
- Tire plugs are dynamic, expandable, flexible and capable of adapting to a dynamic strain environment in surrounding bedrock.
- Reduces cost of waste removal, by recycling disused mine equipment.

Disadvantages

- Heavy equipment is required for excavation and tire compression. Air or land (winter road) access is necessary to remote sites.
- A source of used tires proximal to- or on-site is necessary.
- There is uncertainty regarding long term of the interactions of acidic mine drainage with tire compounds.

Northern Considerations

- Many abandoned sites in northern Canada do not contain a sufficient volume of used tires to implement this option.
- There is no documented use of this method being implemented at mine sites in northern Canada.
- Extremes of climate may accelerate degradation of tires prior to- and post-emplacement.

6.3.3.2. Polyurethane Foam (PUF)

Description of Method

The use of polyurethane foam (PUF) to close abandoned mine openings began in the 1980's in the United States and is now extensively used to close abandoned mine openings throughout North America. PUF is now used to close approximately 30 to 50% of abandoned mine openings in the US[1]. PUF plugs are suitable for the closure of most vertical mine openings and horizontal openings sloped at less than 35°.

Construction

Installation requires the construction of a lightweight column form that is positioned in the mine opening entrance and covered with a mixture of the catalyst and resin reagents. An exothermic reaction results, causing the foam to expand and cure quickly into an inert solid mass that completely fills the void (Burghardt, 1994). The thickness of the plug is generally about twice the shortest dimension of the opening. The plug is constructed below grade and subsequently covered with clean fill to protect the plug from UV radiation and heat from forest fires. The plug could also be covered with nonstructural concrete to provide a similar level of protection.

Construction of PUF plugs should be undertaken while ambient air temperatures are between 5 and 35°C, ideally with overcast skies. At extremely high air temperatures and high angle sunlight, the PUF may be flammable.

In permafrost conditions, heat should be applied to the rock walls to permit a proper bond to seal the PUF to the rock.

The compressive strength of the PUF is relatively low (10-15 psi (70-100 kPa) for the standard 2-pound foam) compared to concrete, so PUF may not be suitable for locations where heavy vehicle transport is anticipated.

---

[1] Personal communication with Foam Concepts LLC. September 2010.

Effective Design Life

The effective design life of PUF plugs is generally accepted to be approximately 30 years. However, if properly installed, the realized design life may exceed this figure. In 2010, some PUF plugs installed in mine openings in the USA approached 30 years since installation. Further refinement of the design life may be expected as long term performance continues to be monitored.

Proven Northern Application and Performance

While the use of PUF plugs in the USA has been relatively extensive over the past 20 years, the use of PUF plugs in northern climates is relatively recent. PUF plugs have been installed in abandoned mine openings at the Venus Mine in the Yukon and at the Port Radium Mine (in 2008) in the NWT. PUF has been used quite extensively to close abandoned mine openings in Alaska and at high elevation sites in Colorado. Several PUF plugs have also been used to close abandoned mine openings in Manitoba and British Columbia.

Advantages

- The mine opening is completely sealed and secured against unauthorized and unintended entry by humans and wildlife.
- The life expectancies of PUF plugs are typically 30 years or more.
- PUF plugs can be installed in remote locations without the need to access heavy equipment.
- PUF plugs can be installed on steep slopes, where other methods would be more difficult to construct.
- Maintenance should be minimal; however, periodic inspections are recommended to check for subsidence of the plug.
- Materials and required equipment can be transported to remote sites via air or land.
- Ease of removal if future development becomes an option or reopening the workings is necessary.

Disadvantages

- PUF can deteriorate if exposed to sunlight thus requires a surficial cover of earth or concrete to prevent loss of integrity.
- PUF is flammable and needs to be covered with earth or concrete to prevent loss of integrity due to extremes of heat (e.g. forest fires).
- Has not been widely used in northern Canada; thus regulatory and stakeholder approval may be difficult to obtain, especially for high risk openings (e.g. close to population base).
- Interaction of PUF with contaminants, including gases.
- Some specialized health and safety measures may need to be considered during construction.
- PUF plugs would not meet regulatory compressive strength parameters, requiring a waiver from the Mine Inspector.

- Many technical uncertainties remain regarding the long term performance of PUF as a mine closure method.

Northern Considerations

- Installation is recommended to be conducted in ambient air temperatures exceeding +5°C, thus limiting the construction timeframe in some locations.
- The impacts of the foam placement on the thermal regime in the immediate vicinity of the mine opening should be considered.
- The impact of permafrost ground conditions on curing of foam is not yet well understood.

6.4. Permanent Remediation Measures

Permanent closure methods completely close off an abandoned mine opening and eliminate access. This option is applicable to openings which present a significant hazard, are readily accessible to the general public or have no economic or historic value. Appropriate methods to permanently seal a mine opening include the following:

- Backfilling; and,
- Closure through blasting.

Permanent remediation measures are suitable where replacement or reactivation of permanent closure methods is not anticipated. Only minor maintenance would be expected. Due to practical construction considerations, permanent closure methods may not be appropriate for every opening. Discussion regarding permanent closure methods for mine openings is provided in the following sections.

6.4.1. <u>Backfill Closures</u>

Description of Method

Backfill closures completely seal horizontal or shallow vertical mine openings with on-site or imported fill. Generally, backfilling is carried out using heavy equipment (bulldozers, loaders, or excavators); however, for small openings in isolated areas, filling may be done manually. Following closure by this method, future access via the opening is not possible and entry for wildlife, fluid and natural airflow is impeded.

Construction

Backfill material should consist of well graded, durable rock fill and coarse rip-rap. If water is present in the underground mine workings, the fill should be inert, or material that poses no additional threat to mine water quality. Overburden or native till may also be required for a cover soil to permit re-vegetation, where possible.

Well graded rock fill should be used in backfilling vertical shafts, inclined shafts, raises and subsidence features. Coarse, graded rip-rap material should be placed in the bottom of the opening to a height extending above the roof of any intersecting tunnel. In deep or water-filled openings, filling should continue until the rip-rap is visible from the edge of the opening. The remainder of the opening should be backfilled with a graded rock fill.

Once filled, the opening should be covered with native till or overburden and permitted to re-vegetate or armour to prevent erosion. Final contours should establish a mound over the shaft cap to allow for post-construction settlement and a gentle slope down to the original surface to promote drainage.

Adits, declines and stopes should be backfilled to a minimum length equal to the largest opening dimension. Note that additional design work may be required if the backfill is to provide support for crown pillars adjacent to sub-horizontal openings. The use of well graded rock intermixed with large boulders will discourage people from digging into the backfill. A bulkhead should be established across the mine opening at the end of the fill to provide a backstop against which the rock fill can be pushed. If drainage is required, a drainage pipe could be installed in the opening prior to the commencement of backfilling. Design of drainage measures must factor in freeze/thaw and blockage due to mineral precipitates.

Mechanical or manual backfill methods can be used to place the rock fill as close as possible to the top of the opening along the entire length of the backfilled section. Once full, extend the rock fill past the adit or inclined shaft opening, mounding it over the top of the entrance to completely seal the opening and compensate for settlement. The fill outside the entrance should be covered with either a coarse rip-rap, to reduce erosion, or a native till, to permit vegetation.

Backfilling with competent rock should provide a permanent seal of the abandoned mine opening. Those sealed with less competent or chemically responsive backfill, such as shale, sandstone, limestone and other soft friable rocks, tend to degrade and erode resulting in settlement and over time.

Proven Northern Application and Performance

Backfilling vertical and horizontal mine openings has been used at many mine sites in northern Canada. Examples include portals and raises at the now closed Nanisivik and Polaris mines in Nunavut.

Advantages

- The mine opening is permanently sealed and secured against unauthorized and unintended entry by humans and wildlife.
- Maintenance should be minimal; however, periodic inspections are recommended to check for settlement of the backfill or erosion of the exposed portion of the backfill.
- Environmental conditions permitting, the backfill surface area may be re-vegetated and restored.
- The backfill will provide some support to the abandoned opening, possibly reducing or preventing caving or subsidence around the mine opening.
- Backfill with on-site material, if suitable, can reduce mine waste volumes at surface.
- Backfilling is generally an accepted practice for closure of shallow vertical and sub-horizontal mine openings in many jurisdictions throughout North America and has been

used at many sites throughout northern Canada; regulatory and stakeholder acceptance should be attainable.
- Construction costs are moderate if suitable materials and equipment are available on site.

Disadvantages

- Backfilling of deep openings may not be practically feasible from a construction standpoint.
- If groundwater pressures are anticipated to build within the mine workings upon closure, backfilling may not be suitable unless constructed in combination with an engineered concrete bulkhead and appropriate drainage measures.
- Backfilled openings result in the loss of wildlife habitat and historical or economic value of the mine opening.
- Backfilling generally requires heavy equipment which requires air or land access to remote sites.
- It is difficult to completely backfill tightly against the crown of a horizontal opening.

Northern Considerations

- Many abandoned mine openings are partially backfilled with debris from previous mining activities or an ice plug may have formed within the mine workings due to the presence of permafrost. If either of these conditions exists, the physical integrity of the backfill may be compromised in the long term due to potential collapse of the debris plug or melting of the ice plug.
- Permafrost may aggrade into the backfill at some locations, potentially enhancing the stability and integrity of the backfill. However, if drainage is required, this option may not be suitable.

6.4.2. Blast Closures

Description of Method

Blast closures permanently seal adits, declines or stopes by filling them with broken rock produced by controlled blasting. Access into the abandoned mine opening is fully restricted and generally resistant to damage from vandalism and natural deterioration. This method is suitable if there is no need for maintaining site access to wildlife, retaining airflow and there is no likelihood of future economic recovery of minerals from the opening.

Construction

Blasting plans are designed on the basis of information gathered in investigation of the site including detailed geotechnical analysis of local ground stability. In accordance with the blasting plan, blast holes are drilled above and around the entrance of the adit or inclined shaft. If possible, blast holes should also be drilled inside the mine opening to ensure more complete closure, if access can be safely accomplished.

Post-blast, loose rock above and around the opening should be removed or secured. A full year following completion, inspection of the site should assess if settlement of blasted rock has exposed the top of the opening.

The structural and chemical competency of wall rock, hydrologic stability of the crown pillar, movement of fluids, and nature of the rock mass filling the opening are among the most important features influencing the lifespan of a blast closure. Competent rock provides a permanent seal; but, openings sealed with easily erodible or chemically responsive rocks, such as shale, sandstone, limestone and other soft, friable rocks, may result in settlement and exposure of the abandoned mine opening, unless a robust armour material is applied at surface.

Proven Northern Application and Performance

Blast closures have been implemented at northern mine sites in Canada for decades. Typically this method has been implemented for crown pillars over near surface stopes, adits or near horizontal declines.

Advantages

- The mine opening is completely sealed and secured against unauthorized and unintended entry by humans and wildlife.
- Does not require warm temperatures for construction and can be completed within on winter road season.
- Maintenance should be minimal; however, periodic inspections are recommended to check for settlement or erosion of the backfill, or presence of contaminated drainage.
- Blast closures are particularly useful in remediation of unstable openings (e.g. openings in close proximity to pillar recovery operations which are typically part of final mining activities).
- Rockfill at the entrance of the opening can be covered with soil and vegetated as required.
- Generally, blast closures are an accepted practice for closure of shallow vertical and sub-horizontal mine openings in many jurisdictions throughout North America and has been used at many sites throughout northern Canada, regulatory and stakeholder acceptance should be attainable.

Disadvantages

- Drilling and blasting operations require specialized equipment, which would require transportation to site via land or air.
- Significant volumes of fill may be required to level the trench/hole created by the infill of the void space.
- Costs associated with the construction of blast closures may be significant, especially if the drilling and blasting equipment is required solely for this purpose.
- Unstable ground proximal to the opening requires implementation of detailed safety measures during design, construction and blasting.
- Blasting exposes fresh rock faces to the air, which could lead to increased acid mine drainage.

- A licensed blaster is required and a safe, efficient blasting plan must be designed and approved by a qualified person for each site.
- Blasting may not be possible or permitted near residential or commercial sites due to hazards such as structural damage, vibration and fly rock.
- Any historical, future economic or land use resources associated with the mine opening are potentially lost.
- Effectiveness of this method is reduced if unsafe conditions prohibit access for blast hole drilling.
- If the adjacent crown pillar remains unstable following the blast, the periphery of the opening may fail over the long term.

Northern Considerations

- Heavy equipment such as blast hole drills are costly to transport to remote sites and generally require air or winter road access.
- For a proper and effective blasting program to be conducted, a detailed understanding of the adjacent underground workings is required. Detailed mine plans and geotechnical analyses from abandoned mine sites are often non-existent (in the case of geotechnical studies), limited or no longer available.
- Presence of ice in workings should be considered during design.

6.5. Other Considerations

6.5.1. Monuments

Once each mine opening is remediated using a long term or permanent method, a monument or marker should be installed to assist in locating the openings for post-construction monitoring. Monuments can consist of any of the following:

- a vent pipe embedded in the concrete seal;
- a concrete filled, re-bar reinforced pipe affixed to the concrete or embedded in backfill; and,
- a boulder fence around the closed mine opening, which can identify the opening and or crown pillar area and can also deter vehicle traffic from the mine opening area.

It is recommended that monuments/markers be surveyed to define the exact location of the mine opening. In the case of backfilled closures, monuments may also be surveyed as part of the post closure performance monitoring program to monitor the settlement of the backfill. Information regarding the mine opening such as name, type, construction date, may be affixed to the monument on brass tags. This information should also be submitted to the relevant federal or territorial regulatory organization (for e.g. Mines Inspector), stored in a mine closure database and periodically updated as monitoring/inspections occur.

6.5.2. Mine Openings Subjected to Ground Water Pressures

Special note should be taken regarding the remediation of mine openings that are expected to be subjected to ground water pressures related to flooding of the underground mine workings.

Any opening that is expected to retain mine water and be subjected to associated ground water pressures requires a significantly increased level of design with respect to the closure method. Detailed geotechnical, hydrogeological and often hydraulic engineering studies are required to formulate an appropriate design. If mine water drainage from the opening is anticipated, design of hydraulic structures such as pipes and flumes should include considerations to mitigate their freezing, flow blockage and deterioration due to their chemical interaction with mine water. Any buildup of pressure behind the plugged mine opening could potentially lead to its failure in an uncontrolled release of mine water to the receiving environment. It should also be kept in mind that retention of significant water pressures by a portal plug could possibly result in mine seepage emerging from a different location other than the opening.

6.5.3. Venting

In closing a mine opening, design should consider the need to ventilate internal mine gases. These gasses can build up significant pressures or be toxic to humans and wildlife at elevated concentrations. Common mine gases include methane, carbon monoxide, carbon dioxide, hydrogen sulfate, sulpher dioxide, hydrogen and radon. Incorporating a ventilation system into the closure method will reduce the tendency for mine gases from building up or concentrating within the closed underground working.

7. SELECTION OF APPROPRIATE REMEDIATION MEASURES

The appropriate closure method for each individual mine opening must be suited to the proposed remediation design life and the severity of risk posed by the hazard, which are determined by site and opening-specific characteristics. Site specific information should be collected to characterize the individual mine opening(s), such as the following:

- principal dimensions and conditions of the underground workings;
- depth below ground surface;
- thickness and type of overburden, if present;
- quality and stability of surrounding rock mass;
- surface and groundwater movement;
- quantity and quality of water discharge; and,
- proximity to human and wildlife activity.

Several considerations must be taken into account when selecting the most appropriate closure method for a mine opening. Key considerations are discussed in the following sections.

7.1. Risk Associated with the Hazard

The primary concern is the potential risk to the safety of humans and wildlife. Different levels of risk can be associated with each type of mine opening, depending on the nature of the opening, such as the condition of the underground workings, proximity to human and wildlife activity and environmental sensitivity of the area. For example, a vertical opening such as a shaft or raise may be unmarked and covered with debris or snowdrifts. They can be open to depths ranging from tens to hundreds of metres, which could cause death or serious injury if the opening was inadvertently accessed. Other openings such as shallow trenches or short horizontal adits may not pose the same level of risk, or pose only a similar risk as the natural surrounding topography and may not warrant the same level of remediation. In summary, openings associated with higher levels of risk may necessitate using a more robust remediation method than openings posing lower levels of risk.

Abandoned mine sites located in remote areas should never be assumed to have a low risk to human health and safety. As a general remediation objective, the site should have no greater risk than the surrounding natural, terrain.

7.2. Security of Opening

The level of security for the opening offered by each individual closure method should be considered during the selection process. Temporary measures offer limited security for the mine opening, whereas long term and permanent measures offer higher levels of security, preventing inadvertent access into the underground mine workings. The required level of security is generally linked to the risk associated with the hazard discussed in Section 7.1 and the desire to reduce the liability of Crown or current property owner.

7.3. Required Design Life

The required design life of the closure option is determined based on a cost-benefit analysis comparing the one-time construction of a permanent solution, with the repeated installation of temporary and long term solutions. Every closure method requires repeated inspections until risk is satisfactorily mitigated; however, their frequency is lessened for more long term and permanent methods.

Temporary opening obstructions, such as steel wire screens and steel grates, are useful where future access to the opening is anticipated, as in the case of sites with historical or potential future economic value.

For most abandoned mine sites in the Northern Canada, a more permanent remediation is likely required. However, the remote location of many of these sites results in costly maintenance and repeat inspections associated with temporary solutions. Long term methods, such as concrete structural seals and polyurethane foam plugs, are suitable in many cases; however, these methods are not permanent solutions. The design life of concrete structural seals has been estimated at approximately 50 years. PUF, as a new technology, cannot be guaranteed to a design life much in excess of 30 years.

The only permanent closure methods are to backfill or blast the closure; however, maintenance and inspections are still required to ensure that excessive settlement and deformation does not occur post-construction. The re-inspection schedule can be relaxed once site conditions have appeared to stabilize, and risk is reduced.

7.4. Costs

Cost-related items include preconstruction site investigation and assessment, component design, site access, temporary infrastructure and logistical support during construction, materials, equipment and time associated with demolition of existing infrastructure and preparation of the area proximal to the opening for construction of the closure feature. Costs associated with QA/QC monitoring during construction and post-construction monitoring must also be included in the evaluation. Further guidance regarding cost estimation is provided in Section 8.

7.5. Difficulty of Installation

Installation requirements for each closure method vary greatly. For example, installation of cast in-place concrete seals can involve intricate placement of re-bar and steel beams embedded into solid rock, as well as batching and placement of small to moderate volumes of concrete on-site in often challenging environmental conditions. In contrast, backfilling of sub-vertical or sub-horizontal openings is relatively straightforward with the biggest concern being potential bridging of materials. The difficulty of installation may influence post-construction performance if issues arise during construction.

7.6. Expected Maintenance Requirements

Expected maintenance requirements should be considered when selecting a preferred closure method. Post construction maintenance can be costly; especially in the case of remote abandoned sites where mobilization costs to support maintenance efforts can be significant.

7.7. Inspection Requirements

Post-construction inspection requirements should be considered due to the costs associated with accessing the site to support the inspection efforts. Costs associated with inspections can quickly exceed construction costs if frequent inspection to a remote site is required.

7.8. Site Access Requirements

Site access requirements need to be considered in the closure option selection process due to the potential constraints access can pose on closure methods, risk to human safety and post-closure tampering. For example, sites that can only be accessed by air may not be amenable to methods that require heavy equipment or a significant amount of heavy construction materials such as pre-cast or cast in-place concrete seals. If the airstrip at the mine site is also decommissioned at closure, future access to the site may be severely restricted (i.e. limited to helicopter access, winter road, boat, etc.)

Accessibility of the opening location within the site should also be considered in the selection process. The site may be accessible by ground for the transport of heavy equipment and materials; but the opening location may not be as easily accessible.

7.9. Future Underground Access Requirements

Closure design should consider whether future access to underground workings may be required. Changes in technology and economics can renew interest in developing once abandoned sites. Additionally, there may be historical value in preserving access to the mine. If future access is anticipated, the closure method should be designed to permit re-entry. The type of closure should not be prohibitively costly to reopen, nor should it create new hazards.

7.10. Proven Performance in Northern Locations

Most of the methods described in these guidelines have been implemented at various sites around northern Canada. Some methods, such as the use of PUF plugs were developed more recently and have less of a proven track record in northern Canada. Proven performance enhances the likelihood of regulatory and stakeholder approval and also increases the confidence level in the estimate of post-construction maintenance requirements and design life/ expected replacement frequency.

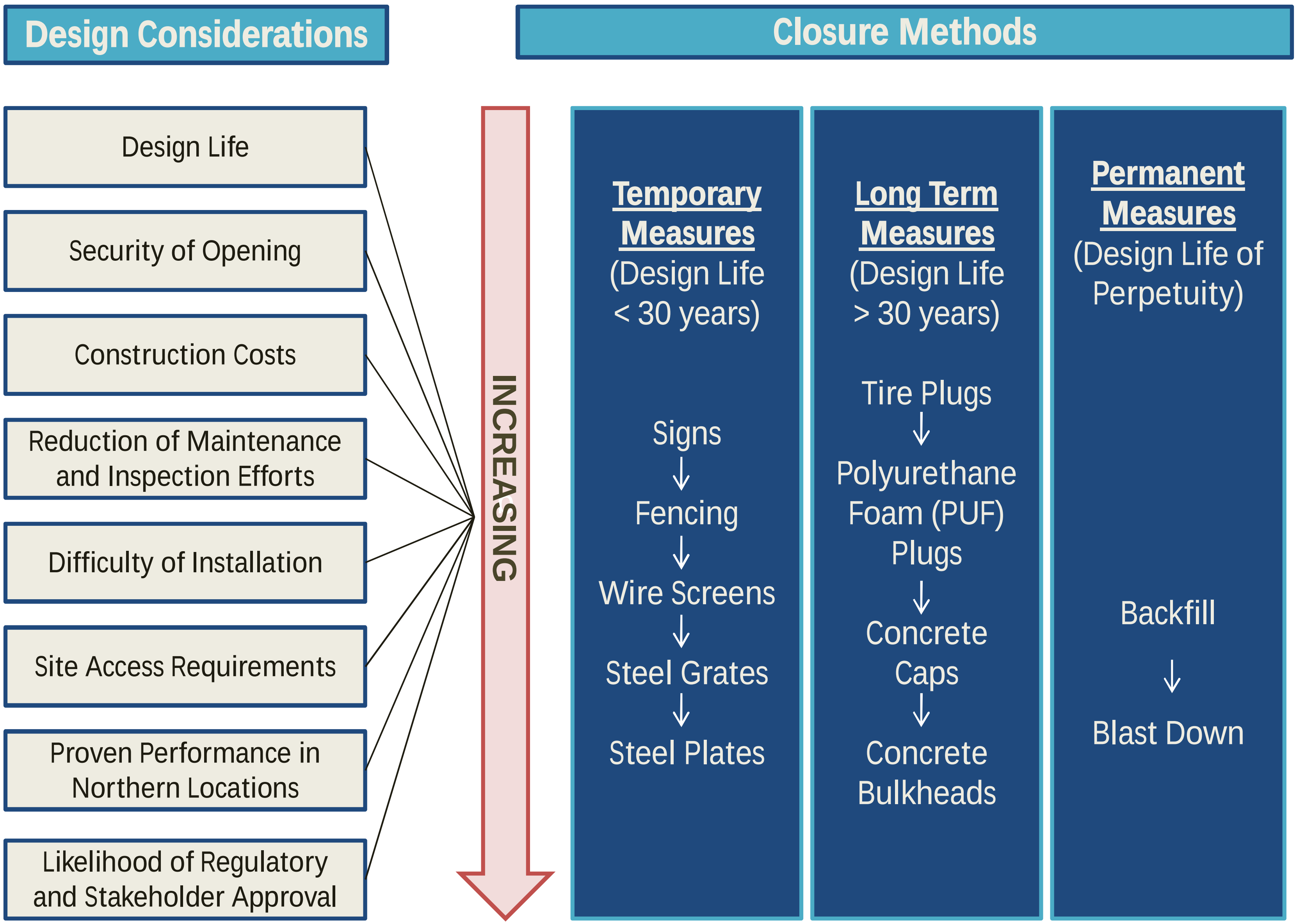
7.11. Regulatory and Stakeholder Approval

Implementation of a closure method for a mine opening will require approval of both regulatory and stakeholders (e.g. local communities) and regulators (e.g. land and water boards). The likelihood of each stakeholders and regulators approving a closure plan for a mine opening should be considered during the selection process. The selection process must involve consultation with these groups.

7.12. Decision Making Flow Chart

To aid in the process of selecting the most appropriate closure method for an abandoned mine opening, a flow chart has been developed and is presented in Figure 1. This flow chart illustrates how the various closure options rank with respect to each of the considerations presented on Sections 7.1 through 7.11. While the flow chart illustrated in Figure 1 is a useful tool in assessing closure options with respect to abandoned mine openings, it must be supplemented with site specific information for each opening. Due to the various parameters requiring consideration in the selection process, similar openings at different sites may require completely different closure methods.

Figure 1: Selection of Abandoned Mine Openings Remediation Measures



8. COST CONSIDERATIONS

Costs associated with the construction of various remediation measures for abandoned mine openings are highly variable and depend on a number of site-specific and opening-specific parameters, including but not limited to the following:

- Design – Depending on the closure method selected, design efforts can range from minor to significant. In the case of backfilling, design may be limited to assessment of backfill materials and material volume requirements. In the case of engineered concrete bulkheads, design may involve detailed geotechnical, hydrogeological and structural engineering components.

  It should be noted that the introduction of conservative contingency measures into the design may increase the construction cost, but can increase the likelihood of satisfactory post-construction performance. In other words, increasing upfront construction costs to build in design contingency (thicker concrete, more structural reinforcement, etc.) can have beneficial long term cost implications for both long term and temporary closure options.

  Additionally, design of closure methods for abandoned mine openings in northern Canada requires an understanding of the unique challenges associated with constructing in these latitudes (see Section 5).

- Site location/remoteness – The location of the mine site impacts the lead times and costs associated with transportation (mobilization and demobilization) of equipment, labor and materials to site. Materials and equipment required to construct the various remediation measures generally need to be transported to site using seasonal shipping routes. This may require construction of long winter roads, which can be costly to build and maintain throughout the construction season. Additionally, site remoteness is directly proportional to costs associated with logistical aspects, such as required camps and fuel. Seasonal limitations and variable climate may affect the construction period and substantially increase costs.

- Logistical Considerations – The transportation of materials to the mine site and the construction of the closure design are most cost-effective when they can be carried out in the same season. For example, both the material transport and construction completion of a blast closure can be conducted in winter. Concrete cap or polyurethane foam methods, on the other hand, may require transport of materials in the winter, while construction likely must take place in the summer.

- Material Costs – Materials such as cement, re-bar, steel beams and polyurethane foam generally require transportation to site. If natural deposits of fine and coarse-aggregate are needed, but are not available in sufficient quantity or quality proximal to the site, these materials may also need to be transported to site, at significant cost to the project.

- Equipment Costs – Equipment such as concrete mixers, excavators and loaders require transportation to site months prior to construction of the remediation measures, as they may necessitate the use of seasonal shipping routes, such as winter roads or shipment by barges to coastal staging locations. As such, costs associated with both operating the equipment and staging it at site over the winter months may be added to the project. These costs will also be incurred during the demobilization phase after the site work is completed. Fuel supply, equipment operating and maintenance costs may be significant in remote locations.

- Construction Costs – Construction activities related to decommissioning abandoned mine openings may include any of the following:
    - Site preparation for construction, including camp facilities, fuel storage, water supply and sewer treatment / disposal.
    - Demolition of existing surface infrastructure (e.g. headframe).
    - Diversion, pumping, treatment and disposal of water.
    - Preparation of the surface of the opening for construction of the remediation measure (e.g. clearing debris, overburden and loose rock from perimeter of opening).
    - Installing ventilation and stabilization measures to create a safe work site.
    - Construction of the remediation feature.

  The level of effort and costs associated with surface preparation and construction will vary with the remediation measure to be constructed.

- Construction QA/QC – Appropriate Quality Assurance/ Quality Control measures need to be implemented during construction of remediation measures to ensure that the design intent and specifications are being met. In the case of concrete caps or bulkheads, this may include sampling and testing concrete mixtures for a variety of parametres. In the case of PUF plugs this may include sampling and testing of the foam for density. Photographic record and GPS location data should also be collected as part of construction QA/QC. As-built surveys and drawings of all closure measures should be conducted following construction.

Specific cost considerations associated which each of the long term and permanent closure methods are provided in Appendix B.

Costs associated with materials and labor for a variety of remediation measures from various published references are provided in Table 1.

Table 1: Summary of Published Costs for Various Closure Options for Mine Openings

Reference/ Method	Application	Government of Nova Scotia (1997)	Bétournay, (2009)	Reclaim Model (V6.1, 2009)
Signs		$5-$25 per sign	<$200 each	$10-$35
Fencing		$100-$200 per metre	$80-$200 per metre	$12-$180
Steel Wire Screen	Vertical and Sub-vertical Openings	$400-$800 per opening		
	Horizontal and Sub-horizontal Openings	$400-$800 per opening		
Steel Grate Closure	Vertical and Sub-vertical Openings	$500-$2000 per opening		
	Horizontal and Sub-horizontal Openings	$500-$2500 per opening		
Concrete Caps	Pre-Cast Panels	$1500-$4000 per opening	$4500/m^2 of area of coverage	$572/m^2
	Cast-In-Place	$1800-$5000 per opening		$1890/m^2*
	Monolithic Cap	$1500-$3500 per opening		$254 - $1890/m^3**
Bulkhead Closure	Native Rock	$500-$1500 per opening		
	Concrete Block	$800-$2200 per opening		
Backfill Closures	Vertical and Sub-vertical Openings	$600-$4500 per opening	$40/m^3	
	Horizontal and Sub-horizontal Openings	$700-$5000 per opening		$221/m^3***
Blast Closures	Horizontal and Sub-horizontal Openings	$800-$4000 per opening	$15/m^3	

*Hand construction, remote site.
**Cost varies depending on size of pour and forming requirements.
***To excavate and backfill collapsed portal.

Due to the remoteness of northern mine sites, costs would likely be greater than the amounts derived from Government of Nova Scotia (1997) and Betournay (2009), which are based on mine sites in southern Canada. Many of these mine sites are serviced by road links to regional supply centres.

Costs associated with the construction of PUF plugs include $200-$300/m^3 for materials and $50-$100/m^3 for installation[2].

[2] Personal communication with Foam Concepts September 2010.

Costs associated with the remediation of abandoned mine openings in the State of Alaska are published on the Abandoned Mine Lands web site. (http://dnr.alaska.gov/mlw/mining/aml/index.htm). The available information regarding closure costs of these abandoned mine openings is summarized by the following:

- Cost information for 110 abandoned mine openings is available, including 62 vertical openings and 48 portals.
- The average cost per closure of vertical mine opening was approximately $14,000, with a maximum cost of approximately $55,000.
- The average cost per closure of horizontal mine opening (portal) was approximately $11,000, with a maximum cost of approximately $45,000.

It should be noted that no information was provided regarding closure method or date of closure. Additionally no details were provided for what was included in the cost.

9. POST CONSTRUCTION PERFORMANCE MONITORING

9.1. Monitoring Activities

Post-construction performance monitoring activities for remediated mine openings are summarized in Table 2. These measures are intended to confirm the physical integrity of the remediation measures and identify possible maintenance or future replacement requirements. Temporary closure method inspections need not be performed by professional engineers; however, long term or permanent measures do require an appropriately qualified professional engineer to conduct the visual inspections.

Table 2: Post Construction Performance Monitoring Considerations

Remediation Measure	Potential Performance Monitoring Activities
Temporary Measures (Signs, Fencing, Steel Wire Screens, Steel Grates. Steel Plates)	Visual inspection of measure for physical integrity and hazard to human life and wildlife.
Concrete Seals and Bulkheads	Visual inspection of seal for indications of deterioration of the concrete (pitting/spalling). Visual inspection of surface area surrounding seal for vertical deformation as a potential indication of failure of the concrete or rock surrounding the seal (crown pillar). Visual inspection of the surface area for ponding of surface water which could impact the long term integrity of the seal.
PUF Plugs	Visual inspection of surface for indications of failure of the plug such as settlement of the surficial UV/Thermal barrier.
Backfill (vertical openings)	Visual inspection of the backfill for settlement of the surface mound.
Backfill and Blast Closures (horizontal/ inclined openings)	Visual inspection of the surface of the backfill plug for erosion or chemical deterioration. Visual inspection of the crown pillar around the opening for signs of deformation. Visual inspection of the backfill plug area for amount and nature of seepage emanating from mine workings.

9.2. Monitoring Frequency

The frequency of post-construction performance monitoring is not prescribed in any mine remediation guidelines published throughout the various jurisdictions within Canada. Monitoring frequency largely depends on the type of measure installed. Practical experience suggests that remediation measures be monitored annually for the first two to three years following construction to establish a performance baseline. Following this initial time period, remediation measures are generally visually inspected approximately every five years. However, site-specific factors (i.e. design life) may influence the return frequency. Under certain circumstances, seasonal effects may impact monitoring requirements as well (i.e. following freshet).

It should be noted that temporary measures such as signage and fencing should be inspected annually as the integrity and effectiveness of these measures is more easily impacted by human and environmental factors.

10. SUMMARY

Remediating abandoned mine openings in northern Canada offers many unique challenges. The remoteness of the sites, presence of permafrost, extremes of climate, potential cultural effects, direct and indirect costs and sensitivity of the surrounding environment require consideration during the selection process. These Guidelines provide information regarding the following topics:

- The current standard of practice in Canada with respect to the closure of abandoned mine openings.
- Specific considerations with respect to the application of various closure measures in northern locations.
- Guidance on the selection of appropriate closure methods.
- Considerations with respect to the cost of various closure methods including references to published information from various jurisdictions.
- Guidance with respect to post-construction performance monitoring requirements.

The Guidelines were developed with input from various regulators, consultants, contractors and manufacturers from various jurisdictions throughout Canada and the United Sates.

The intent of these Guidelines is to provide INAC staff, regulatory bodies and stakeholders with a document that conveys the various considerations required in the selection, construction and monitoring of remediation measures for abandoned mine openings in northern Canada. Due to the uniqueness of each individual mine opening and mine site, the Guidelines are not intended to provide a prescriptive approach to selecting closure methods for mine openings. The information provided within the Guidelines must be supplemented with site specific information regarding each mine opening and integrated within the overall site remediation plan in order to select the most appropriate closure measure for each mine opening.

The construction costs, experiences and post-construction performance of various remediation measures implemented at the various sites within the Northern Contaminated Sites Program should be collectively documented and reviewed on a regular basis and used to update these Guidelines.

11. FUTURE CONSIDERATIONS

As more closures of abandoned mine openings are undertaken in the Canadian North, information regarding their design, costing, implementation and degree of success can be assembled. This would strengthen the existing knowledge base of the closure methods discussed in the Guidelines. Consolidation of data collected from each of these sites will reveal new information about construction challenges, degradation mechanisms, life spans and monitoring requirements of each method in the context of their northern setting. It is recommended that INAC amalgamate the existing data for closed mine openings in the North and continues to incorporate new data as closures are undertaken in the future.

REFERENCES

Bétournay, M.C. 2009. Abandoned Metal Mine Stability Risk Evaluation. In Risk Analysis, Vol. 29, No. 10.

Brodie Consulting Ltd. 2009. Reclamation Cost Estimating Model (Version 6.1). March 2009.

Burghardt, J. E. 1994. Polyurethane Foam Applications in the Closure of Abandoned Mine Openings. National Park Service Geologic Resources Division.

Colorado Division of Minerals and Geology 2002. Best Practices in Abandoned Mine Land Remediation: the remediation of past mining activities. Colorado, U.S.A.: State of Colorado.

Government of British Columbia, Ministry of Energy, Mines and Petroleum Resources, Mining and Minerals Division 2008. Health, Safety and Remediation Code for Mines in British Columbia.

Government of Manitoba, Ministry of Industry, Trade and Mines, Mines Branch 2006. Manitoba Mine Closure Regulation 67/99 – General Closure Plan Guidelines.

Government of Ontario 2007. Mining Act – Ontario Regulation 240/000 – Mine Development and Closure.

Government of Quebec, Ministry of Natural Resources 1997. Guidelines for Preparing a Mining Site Rehabilitation Plan and General Mining Site Rehabilitation Requirements.

Indian and Northern Affairs Canada 2007. Mine Site Remediation Guidelines for the Northern Canada.

Nova Scotia Department of Natural Resources 1997. Abandoned Mine Openings Hazard and Remediation Handbook. Information Series ME23, 1997.

Saskatchewan Ministry of Environment 2008. Guidelines for Northern Mine Decommissioning and Remediation.

State of Alaska, Department of Natural Resources, Division of Mining, Land and Water 2004. Mining Laws and Regulations.

Tribe, N. L., & Tribe, L. J. (1999). A successful method of reclaiming subsidence in abandoned mine areas. 23rd Annual British Columbia Mine Remediation Symposium (pp. 212-222). Kamloops: The Technical and Research Committee on Remediation.

Yukon Government 2008. Yukon Mine Site and Remediation Closure Policy – Financial and Technical Guidelines.

APPENDIX A

Various Relevant Mine Closure Guidelines

Yukon Mine Site and Remediation Closure Policy – Financial and Technical Guidelines (Government of Yukon, Department of Energy Mines and Resources 2008)

The Technical Guidelines embedded within the Yukon Mine Site and Remediation Closure Policy provide direction on remediation and closure objectives that mine owners and government administrators must or should consider in developing and implementing a remediation and closure plan. Guideline #T-07 provides specific guidance on the remediation of underground workings and openings to surface.

A summary of the guidance provided by Guideline #T-07 is provided by the following:

> At final closure, all surface openings to underground workings (raises, shafts, excavations, tunnels, chutes) must be blocked utilizing a suitable method as designed by a qualified, professional engineer and capped with reinforced concrete where specified by the Occupational Health and Safety Regulations of the Occupational Health and Safety Act.
>
> Where there is a demonstrated risk, and potentially significant consequence, that mine water pressures are likely to build to dangerous levels, drainage of excess mine water through a long term drain shall be included.
>
> Ensure final crown pillars that are to remain in place provide long term structural stability. The crown pillar must sustain its own weight and other anticipated surface loads, including static and dynamic loading. Stability calculations will be based on current standards and a design certified by a qualified professional engineer must be provided.

Mine Site Remediation Guidelines for the Northern Canada (Indian and Northern Affairs Canada – 2007) (Currently being revised)

The Guidelines were developed to provide guidance on how to develop, operate and close mine sites in a manner that promotes effective remediation. Section 2.5 provides specific guidance on the remediation of underground workings:

- Objective:
  - Minimize access to underground workings and surface openings from to protect human and wildlife safety.
- Remediation Options and Considerations:
  - Seal all drill holes and other surface openings, especially those connecting the underground workings to the surface
  - Backfill with benign tailings and waste rock
  - Backfilling wood-lined shafts may not be acceptable because excessive settlement may occur as the wood decays
  - Backfilling shafts and raises with demolition waste may not be acceptable because of the potential for hang-ups and future settlement upon collapse of the hang-up
  - Secure underground shaft or vent raise openings using concrete to ensure permanent closure; wooden barricades are only suitable for temporary closure

- Secure adit openings using concrete, steel, rockfill (backfill the drift 2x width to height), or by collapsing a section of the adit to control access for situations where water quality issues are not a concern to ensure permanent closure; wooden barricades are only suitable for temporary closure
- Construct a reinforced concrete wall or a plug of weakly cemented waste if the barricade is for access control only
- Flood and plug workings to control acid generation and associated reactions if appropriate (engineered designs must consider hydrostatic heads and rock mass conditions – reinforced slabs should be avoided)
- Construct pillars to retain long-term structural stability after mining activities cease and to sustain their own weight and, if applicable, the weight of unconsolidated deposits, water bodies and all other surface loads
- Permanently support boundary pillar if practical and necessary
- Avoid the use of fencing for barricades in remote northern mine sites where regular inspection is not feasible
- Use inukshuks to deter wildlife where appropriate (guidance from local communities and Elders should be sought)
- Use ditches or berms as barricades except in areas of continuous permafrost; where continuous permafrost exists, inukshuks, fencing or some other method may need to be considered
- Remove all hazardous materials from the underground shops, equipment, and magazines (fuels, oils, glycol, batteries, explosives, etc.)
- Contour to establish natural drainage patterns and blend in with the surrounding topography or re-contour the surface to prevent natural surface and groundwater flow from becoming contaminated by mine water where appropriate

Guidelines for Preparing a Mining Site Rehabilitation Plan and General Mining Site Rehabilitation Requirements (Government of Quebec – Ministry of Natural Resources 1997)

The Guidelines were developed to inform proponents of how a rehabilitation plan is to be presented, its technical content and the general mining site rehabilitation requirements involved. Item 3.5.3 provides specific guidance on the safety of surface openings.

1) All surface openings must be sealed off as stipulated in the Regulation Respecting mineral substances other than petroleum, natural gas and brine (M-13.1,r.1, Chapter X).

2) Underground worksites with surface openings, should be backfilled and levelled to blend in with the surrounding topography. If this option is not technically or economically feasible, a fence respecting MRN regulatory standards must be built.

Note: When backfilling an underground worksite with surface openings, it is recommended that the proponent check with the MRN beforehand to determine whether the material used (solid waste, waste rock, etc.) is acceptable.

The regulation (M-13.1,r.1, Chapter X) referenced in Item 1) provides the following additional guidance with respect to the closure of mine openings

99. The holder of a mining right or an operator who temporarily or permanently discontinues mining operations shall seal off or cover surface openings of shafts, raises, adits, declines or any other similar access to underground works, by means of reinforced concrete slabs or stone, sand or gravel backfill. He may however provide an opening equipped with a grate giving access to bats, if the situation justifies it.

Mine shafts shall be sealed off or covered in accordance with this Division, even if the head frame or shaft house is left in place.
O.C. 1042-2000, s. 99.

100. Reinforced concrete slabs used to seal off the access to a mine shall have the following characteristics:

(1) where they are cast in place, be equipped with an opening of 100 mm in diameter topped with a metal tube 1 m high curved downward allowing ventilation;
(2) comply with or be equivalent to the standard specified in the plan appearing in Schedule III and have a minimum thickness of 150 mm where the concrete used in their fabrication has a strength of at least 30 MPa and neither the opening nor the slab have a width exceeding 1.50 m;
(3) be equipped with an engraved inscription indicating the year of their fabrication and the name of the mine where they are installed.

Reinforced concrete slabs must be proportionately thicker than what is prescribed under subparagraph 2 of the first paragraph in order to give them strength equivalent to that prescribed in that subparagraph where the concrete used in their fabrication has a strength of less than 30 MPa or when the width of the opening or slab used is greater than 1.50 m.
O.C. 1042-2000, s. 100.

101. Reinforced concrete slabs other than those cast in place may consist of several sections at least 1.50 m in width and must comply with or be equivalent to the standard specified in the plan appearing in Schedule III and be equipped with eye-bolts, openings or any other fixture in order to make it possible to move them.
O.C. 1042-2000, s. 101.

102. Reinforced concrete slabs used to seal off or cover the access to a mine must be placed on the concrete of the rims or directly on the bedrock where the openings are not made of concrete.

Where a slab of reinforced concrete is laid or cast directly onto the rock of the opening, the space between the latter and the surface level must be backfilled with sand, gravel or other similar material.
O.C. 1042-2000, s. 102.

103. Underground worksites with a surface opening shall be filled in with mineral substances and the land levelled so as to be harmonized with the surrounding topography.

Backfill may be replaced by a fence built around the worksite at a sufficient distance from the latter, established according to geotechnical considerations of rocky walls or overlying soils according to the following standards:

(1) the fence shall be made of 9-gauge galvanized link steel, with openings not exceeding 60 mm on a side;
(2) the fence shall be at least 2.50 m high and the wire mesh shall be welded to the posts and to the horizontal supports or fixed by fastening straps bolted or riveted or by any other fastening means that will prevent it from being stolen;
(3) the end and corner posts and the posts supporting gates shall be made of galvanized steel 90 mm in diameter; the others shall be 60 mm in diameter and shall not be more than 3 m apart;
(4) the top rail used as a horizontal support shall be made of galvanized steel pipe at least 45 mm in diameter;
(5) except when posts are inserted in rock, the holes in which posts are inserted shall be 1.20 m deep, 300 mm in diameter at the opening and they shall be filled with concrete when the posts are inserted;
(6) in rock, holes used to hold posts shall be at least 500 mm deep and have the necessary diameter to insert posts and concrete therein;
(7) gates shall be of the same height as the fence.
O.C. 1042-2000, s. 103.

104. Signs warning of the danger of the access to a mine and the underground worksites with a surface opening shall be placed at the entrance to the access road to the mine and on each of the sides of the fence or gate surrounding the danger sites, at an interval allowing their visibility, at a distance that may not exceed 30 m.

Warning signs shall be made up of a non-corrosive metallic substance and shall bear at least the word “danger”.
O.C. 1042-2000, s. 104.

105. Where the stability of surface pillars may not be insured on a long term basis, a fence built according to the standards prescribed in the second paragraph of section 103 shall be installed around the zone in question at a sufficient distance from the latter, established according to geotechnical considerations of rocky walls and overlying soils.

Signs warning of the danger of the zone in question shall be provided at the locations referred to in the first paragraph of section 104, at an interval allowing their visibility, at a distance that may not exceed 30 m.

The second paragraph of section 104 applies, with the necessary modifications, to the signs referred to in this section.
O.C. 1042-2000, s. 105.

106. The protective measures prescribed in this Division shall be checked annually and maintained in good order.
O.C. 1042-2000, s. 106.

Guidelines for Northern Mine Decommissioning and Remediation (Government of Saskatchewan, Ministry of Environment 2008)

The guidelines were developed to provide the proponent with an overview of the various factors to be considered during the development of a decommissioning and remediation plan for a mining site. Item 3.2.2 provides specific guidance on the remediation of Mine Openings and Workings.

> Adits, raises, shafts or other openings to surface should be backfilled entirely or at least down to an offset when one is present. It is preferable that this be done with clean waste rock but some special waste may be used if it can be shown that this will have negligible effects on groundwater quality. The waste rock should at least be flush with the entrance to prevent any entry or for larger openings an engineered bulkhead may be required to be placed at openings. Careful consideration of the long term risks posed by the accumulation of water behind waste rock barriers must be given. The backfilling of workings to the extent that pressure and/or erosion may eventually dislodge the material used to fill the adits and re-open the holes. This type of work may be done during the operating phase as part of progressive decommissioning.
>
> Underground workings(e.g. drifts and tunnels) should also be backfilled as much as possible during operations as part of progressive decommissioning. This will help reduce the amount of waste rock that remains on surface and will also help provide stability to the underground workings.
>
> Crown pillars, if they exist on a mine property, must be addressed for long term stability in order to select the most appropriate closure measures to ensure long lasting safety and compatibility with the post closure land use of the property. The assessment should ideally be done during the operational phase of the mine. Whenever possible, unrestricted surface use of the area above the crown pillar should be the ultimate objective in the final closure plan.

In addition to the guidelines prepared by the Ministry of the Environment, Part XX of the Occupational Health and Safety Act of Saskatchewan provides the following regulations with respect to abandoning mine openings.

407 – Openings to underground mines

(1) If a shaft, raise, adit or other opening to the surface is abandoned or if the workings are discontinued, the employer, contractor, or owner must ensure that the shaft, raise adit or other opening is secured against unauthorized entry in accordance with this section.

(2) A shaft, raise, adit or other opening must be secured by covering the top of it with a bulkhead designed by a professional engineer of reinforced concrete at bedrock or at the top of the concrete collar of the shaft, raise, adit or opening.

(3) An employer, contractor or owner must ensure that the cover required pursuant to section (2) is clearly marked with a substantial 1 m high marker or sign that identifies the party responsible for the opening and the cover.

Mining Act – Ontario Regulation 240/000 – Mine Development and Closure (Government of Ontario 2007)

Closing Out

Part 24

(2) The proponent shall complete the following minimum rehabilitative measures in accordance with the applicable standards, procedures and requirements of the Code:

1. All shafts, raises and stopes open to surface shall be secured.

2. All portals of adits and declines shall be secured.

3. All other mine openings to surface that create a mine hazard shall be stabilized and secured.

Schedule I – Mine Rehabilitation Code of Ontario

Part 1 – Protection of Mine Openings to Surface

Section 2. (1) Subject to sections 11 to 14 (steel caps) and 17 (backfilling) of this Part, a reinforced concrete cap certified by a qualified professional engineer shall be used to stop shafts, raises and stopes.

Section 3. All reinforced concrete caps shall meet or exceed the following specifications:

1. The reinforced concrete cap shall be designed for the following minimum design live loads:
    a. 1.4 metres cover of saturated soil uniformly distributed with a unit weight of 19 kN/m^3, and
    b. The greater effect of either,
        i. An 18 kPa uniformly distributed load, or
        ii. An 81 kN concentrated load applied over an area 300 mm by 300 mm anywhere on the cap,

    and the weight of the cap as a dead load.

Section 16. The measures designed to permanently prevent access to adits, ramps, declines or portals shall be certified by a qualified professional engineer.

Section 17. If a shaft, raise or stope is to be backfilled rather than capped, the long term stability of the backfilled opening shall be certified by a qualified professional engineer.

Manitoba Mine Closure Regulation 67/99 – General Closure Plan Guidelines (Government of Manitoba – Ministry of Industry, Trade and Mines, Mines Branch, March 2006)

Item 5 – Underground and Open Pit Work

c) Safety of Surface Openings

All surface openings to underground work sites must be backfilled and leveled to blend in with surrounding topography, or should be concrete capped. If these options are not technically or economically feasible, a fence meeting regulatory standards must be built. (Refer to Workplace Safety and Health Act W210, Manitoba Regulation 228/94, section 19).

Note: When backfilling surface openings, it is recommended that the proponent check with regulatory authorities beforehand to determine whether the material to be used (solid waste, waste rock, etc.) is acceptable.

The regulation (228/94, section 19) referenced in Item 5 provides the following additional guidance with respect to the closure of mine openings

19(3) The employer shall ensure that every shaft, raise and portal that is subject to clause (1)(a) is

(a) Completely filled; or
(b) Solidly bulkheaded at the surface with reinforced concrete, which bulkhead shall
    a. Be set on bedrock or on a reinforced collar,
    b. Be designed to support a uniformly distributed load of 12 kPa or a concentrated load of 54 kN, whichever is the greater, but in no case shall the bulkhead be less than 300 mm in thickness, and
    c. Have a substantial permanent steel or concrete marker not less than 1 m high as approved by the director.

Guide to the Development of a Mining and Remediation Plan in New Brunswick – Province of New Brunswick Department of Natural Resources

APPENDIX B

Cost Considerations For Long Term and Permanent Closure Methods

Closure Method	Cost Considerations
Concrete Seals and Bulkheads	- **<u>Design:</u>** Design efforts for concrete seals and bulkheads can be significant. A detailed geotechnical assessment of the rock mass surrounding the opening is generally required. In the case of horizontal openings that may be expected to retain mine water and be subjected to associated pressures detailed hydrogeological investigations will be required. Structural engineering design will be required for all concrete seals and bulkheads to ensure that the structures meet the regulatory requirements with respect to strength. - **<u>Transportation:</u>** Costs associated with transporting materials and equipment to site for construction of concrete seals and bulkheads can be significant. This is primarily due to the mass of materials (cement, rebar, steel beams and potentially aggregate) that need to be brought to site generally needing to be transported to site using winter roads. If air strips (land or ice) are to be utilized, the construction and maintenance of these facilities should be considered. - **<u>Materials:</u>** Costs of cement, re-bar and steel beams can be significant. Sulphate resistant cement may be required if the seal is potentially going to be subject to acidic surface or ground water. Locally sourced aggregate may need processing which can add to material costs. Alternatively aggregates may be sourced in population centers and transported to site. - **<u>Equipment:</u>** Costs can be significant due to size of equipment that may be required (loader, excavator) the method of transport to the site and the fact that equipment may need to be stored at site for many months due to the need to mobilize and demobilize on winter roads. - **<u>Construction:</u>** Demolition of existing infrastructure can involve proper disposal of any hazardous materials such as asbestos and physical demolition of the surface structure such as head frames. Preparation of the surface of the opening for the construction of a concrete seal generally involves removing any loose rock from the perimeter of the opening and installation of stabilization measures (e.g. rock bolts, timbers etc) to make it safe for workers. If the opening has been partially backfilled with miscellaneous debris, this debris generally needs to be removed to an appropriate depth to permit the construction of the seal. Actual construction of the seal involves forming the opening, placement of re-bar, decking and any steel beams and batching and placement of the concrete. Some rock work may be required to tie the concrete seal into the surrounding bedrock.

	- **QA/QC:** QA/QC measures generally implemented during the construction of concrete seals and bulkheads includes inspecting the prepared surface of the surrounding bedrock, form work and re-bar/steel beam placement, grain size distribution of fine and coarse aggregate and slump, volumetric air content and samples of concrete for cylinder tests for compressive strength.
Polyurethane Foam (PUF)	- **Design:** Design development for PUF is less intensive compared to those involving structural concrete. An assessment of the rock mass surrounding the opening is required to determine the amount of surface preparation required to achieve a construction surface of intact rock. The design must also incorporate how the PUF seal will be formed. A structural assessment of the PUF plug may be required to assess the strength characteristics of the plug to achieve regulatory approval. - **Transportation:** Transportation costs are reduced compared to concrete seals and bulk heads due to the light weight and volume of materials required (note volume expansion of PUF is approximately 30:1). Materials and equipment required for construction of PUF plugs can easily be flown into remote sites potentially avoiding the need for costly winter roads, unless additional equipment is required for demolition of existing structures). - **Materials:** Costs of PUF and forming materials are reduced compared to concrete seals and bulkheads. Costs of PUF generally range from $400 to $500 per cu.yd. (expanded volume). Forms can be made from simple materials such as wood, corrugated metal sheets and cinder. In some instances, a thin layer of PUF itself can be used to construct a form. - **Construction:** Considerations with respect to construction of PUF seals includes the following: - Demolition of existing surface infrastructure. - Surface preparation – removal of loose rock from the perimeter of the opening (likely less effort required than for concrete seals). - Manual pour or spray application of PUF into opening. Generally requires 2-3 people and, depending on the size of the opening, could be completed in one day. Work area may need to be heated during construction to ensure quality of product. Ground and surface water may need to be managed during construction to ensure proper bonding of PUF to sidewalls of openings. Thermal/UV barrier of soil/rock/concrete required to be placed over PUF. - **QA/QC:** QA/QC measures generally implemented during the construction of PUF seals includes inspecting the prepared surface of the surrounding bedrock, form work and properties of the foam such as density, compressive strength and shear strength.

Backfilling	- **<u>Design</u>:** Design efforts with respect to backfill closure methods are generally less than most other closure methods. Generally, an assessment of material volume requirements is completed along with an assessment of the backfill materials to ensure placement of the fill materials will not have a negative impact on mine water quality. In the case of horizontal openings, an assessment of the adjacent crown pillar stability may be required to determine distance into the opening the backfill should extend. Also for horizontal openings, a design of the surface of the plug (surface grade, erosion resistance of the fill materials, slope stability assessment of the outside face of the fill plug) may be required to ensure the long term physical stability of the surface of the plug. - **<u>Transportation:</u>** Transportation costs are reduced compared to concrete seals and is generally related to the transport of required equipment such as loaders and excavators to site. - **<u>Materials:</u>** Backfill materials are generally locally available and comprise either natural or processed granular materials such as gravel and crushed rock. If natural unconsolidated granular deposits are locally available, material costs are generally low. If suitable, natural deposits are not available, costs associated with developing quarries to produce crushed rock can be significant. - **<u>Construction:</u>** Considerations with respect to backfilling includes the following: - Demolition of existing surface infrastructure. - Costs associated with backfilling mine openings include the placement of materials. In the case of vertical openings, material is placed into the opening from surface using a loader or excavator bucket. Material placement must be done such that bridging of the material in the opening is avoided. This generally requires slow placement of fill and regular measurement of the fill level during placement to confirm bridging has not taken place. - Drainage of surficial and mine waters into and out of the mine opening. - **<u>QA/QC:</u>** QA/QC measures generally implemented during the backfilling of mine openings includes regular measurement of the fill level during placement to confirm bridging has not taken place. Monitoring fluid and gas flow is also necessary.