C.5 Panel Discussion: What Design Features, Monitoring and Resources are Required to Maintain the Long-term Performance of a Dry Cover?

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plus

BC MEM ML/ARD Guidelines for Dry Covers

PANEL DISCUSSION ON THE LONG-TERM PERFORMANCE OF DRY COVERS

The Panellists

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Topic for Discussion (see appended MEM ML/ARD Guidelines for Dry Covers)

Background: The design of a dry cover must ensure adequate performance over the required mitigation period and the expected range in climatic conditions and biological parameters. In most situations that means that the cover and any supporting facilities or structures must be designed, constructed, and operated in a manner that allows them to perform indefinitely. However the requirements to ensure long-term effectiveness are rarely addressed in the dry cover literature.

Question Posed: "What design features, monitoring, and resources for maintenance and replacement would you prescribe to ensure indefinite performance of a dry cover required to divert 98 %[1] of the incident precipitation in an environment like Smithers? Factors to consider include the effects of potential settling, chemical weathering, desiccation, freeze/thaw cycles, erosion, root penetration, and burrowing by animals."

Initial Comments by Harvey MacLeod (see appended presentation)

Geotechnical Aspects of Covers - How Much Insurance Can You Get?

Cover design must include consideration of the following:

- Understanding of Geology, including soil formation, composition and uniformity of glacial tills, and surrounding geology
- Design and Monitoring Features to Optimize Performance of Cover, including material selection, QA/QC particularly for moisture and gradation control, redundancy in design i.e. increase factor of safety, possible PVC layer for backup, monitor water quality at exit point
- Sensitivity Analysis, Risk of What Ifs, including probability and consequences of failure
- Understand Design, including control of water, air and metal uptake, use of theoretical modelling, design criteria (50 yr. wet/dry) and longevity
- Understand Realities of Construction, including requirements for QA/QC, equipment, compaction curves

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[1] 98% was selected as the type of performance that might be required if a dry cover is selected as a stand alone mitigation measure capable of replacing drainage collection and treatment.

- Understand Soil Properties, compatibility, frost susesptibility, suction and SWCC, cracking resistance, etc.

Initial Comments by Bruce Brown

Considerations in addition to those mentioned by Harvey include:

- Coarse rock layer can be very effective for protecting barrier layer - prevent desiccation, burrowing, root penetration
- Critical period for precipitation infiltration occurs during freshet i.e. Nickel Plate
- Surface must be designed for revegetation and erosion control
- 1000 year event is practical design constraint, if we design for more than the 1 in 1000 year event our knowledge of hydrology is extremely limited
- Design criteria should be based on sensitivity analysis and the consequence of failure if design conditions are exceeded
- What is the overall risk we are prepared to take 0.1%? 0.001%?
- Dry covers avoid the risk of catastrophic failure associated with wet covers
- Design life is different than designing for a 1 in 1000 year event

Comments by the Audience

Design Life

- Required longevity will depend on many factors including other mitigation measures in the closure plan and risk assessment.
- Modelling approaches exist (deterministic considered more appropriate than probabilistic for cover design) to design cover for long time periods.
- US Forest Service use 1000 years as a goal for engineers to design a structure.
- Canadian Nuclear Safety Commission (CNSC) requires that discharges from a uranium waste storage facility be predicted over a 10,000-year period (10,000 years = ice age).
- In Europe a 1000-year dry cover design life is conceivable because man-made structures constructed over 1000 years ago still exist. For example, in Turkey there are mosques that can be dated past 1000 years.
- Structure longevity in North America is more difficult to predict via comparison as structures of 1000 years do not exist.
- Long-term erosion, which may be very important for soil covers, is difficult to predict and incorporate into design. This is one of the many factors that could be significantly impacted by global warming.

Climate

- Long-term-hydrology and climate records are limited in North America. This is a major constraint, especially in remote regions of the province.
- Over a 1000-year period, one could expect major climate event(s)
- Level of confidence in climate data may be hard to determine.

Risk (Probability and Consequences of Failure)

- Must consider consequences of failure both during and after the design period.
- Engineered structures do not disintegrate after the design period.
- Level of risk more important than the design life.
- Need to consider the failure modes, the causes and mechanisms of failure and the consequent impact? Requirement for long-term performance results in need to consider relatively slow processes such as erosion, weathering and biological development. Geochemistry and therefore consequences of failure will change with time. Each waste and therefore the consequences of its failure are different.
- Risks should be compared with those of other mitigation and mining options. For example what would be the risk for the population located downstream of a tailings impoundment with a dry versus a wet cover.
- Major flood event may not cause significant impact if cover is undamaged and pollutant could safely dissipate over environment via dilution.
- Definition of cover failure will depend on the purpose of cover.
- Great deal of uncertainty with dry covers. Still learning about the technology. The level of uncertainty may have significant implications.
- Risk assessments should provide public with information on issues such as uncertainty. Risks, which are often portrayed as a relatively simple issue are not necessarily so in reality.
- When applying for permit to operate, industry doesn't want to admit to the uncertainty. Level of uncertainty noted during this discussion is not reflected in consultant and mining company presentations at public hearings. If industry were more forthright it would increase the industry's credibility to the public. Perceptions of the relative risk associated with different activities (i.e., familiar versus unfamiliar) make it difficult to discuss risk rationally.
- While there is a risk in saying we don't know what we are doing, there is an increased risk in saying we know what we are doing, having failure and then pleading ignorance.
- Contingency measures are required if there is significant risk.
- Case studies are a good way to communicate ML/ARD information. Information on risk could be transferred to the public via well-documented case studies.
- Public risk increases if there is incomplete access to information or access to information does not occur in a timely manner.
- Public groups like the MEND 2000 Program are a very useful source of information.

Dry Covers Design Philosophy

- Dry covers should not be viewed as a walk-away solution, but rather as a control measure for minimizing the impacts of acidic drainage.
- For a cover to last for a long time, it should be easy to monitor, maintain and repair (e.g. fix cracks).
- The self-healing aspects of soil covers should be introduced into design.
- Resources should be available to support long-term maintenance.
- At Equity Silver, the cover is used to reduce the volume of ARD, ARD costs and the security bond amount. Offsite impacts from ARD are prevented by collection and treatment of ARD.
- The use of covers is one of many tools that could be applied to control acidic drainage. New methods of dealing with acidic drainage are continually emerging (e.g. co-disposal). For example if Equity Silver were built today it would likely use technologies to prevent acidic drainage.
- Engineers should not build structures to last 1000 years under the assumption that technology will advance and after 1000 years take care of the problem. Who will pay for development and application on new technologies to site? Will the company still be around?
- Depending on the purpose for which it is designed, the benefits of a cover may not be evident for a number of years.
- In Canada there seems to be a preference to place sulphidic wastes underwater. Subaqueous disposal is not a panacea for everything, e.g., arsenic. Lots of options – must select mitigation option most appropriate for the site.

Monitoring and Monitoring Issues

- Must monitor to understand what is happening in the field. Disservice to technology if application is not monitored.
- Cannot anticipate every eventuality. Therefore need long-term care and maintenance.
- For most designs the flaws will emerge in first 50 years.
- Monitoring programs should identify any release of effluent, which is considered unacceptable and could result in ecological damage.
- Extending the life of the dry cover system through proper design is possible by taking into account the factors that affect long-term performance. This effort will provide a significant positive impact on the net present value of any contingency plan required for failure of the dry cover system. The key is to prevent the dry cover system from failing in the short term. The objective should be for the dry cover system to "fail" over geologic time, augmented by minimal maintenance, such that the natural environment is capable of accepting the incremental "failure".

- Covers can reduce rate of release, slowing down leaching process to acceptable levels. When /if cover is removed in the long term, say 1000 years, the effluent may be acceptable. (BP - *By slowing down the leaching rate, a cover may cause an accumulation of soluble contaminants, causing maximum loadings to the environment in the future when the cover performance deteriorates. If a cover prevents oxidation but permits carbonate dissolution, it may increase the impacts in the event it fails.)*
- A key issue with respect to long-term maintenance is whether personnel will be available to conduct the maintenance, as opposed to ensuring that adequate financial assurance will be in place to cover the maintenance costs.
- Difficulties in completing a mass balance for waste sites are a problem noted in long-term monitoring of covers (e.g. surface runoff difficult to quantify, errors high)

Panel Discussion on Dry Covers

Presentation by Harvey McLeod, Klohn Crippen Consultants Ltd.

- Geotechnical Aspects of Covers
- How much insurance can you get?

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Understand Geology

- Soil formation processes: glacial, weathering, sedimentary – different structures and different behaviour
- Glacial tills: e.g. ablation versus basal, gradation changes, permeability and soil behaviour varies.

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Design and Monitoring Features to Optimize Performance of Smithers Cover

- Material selection, glacial till variations
- QA/QC, particularly moisture and gradation control

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Design and Monitoring Features to Optimize Performance of Smithers Cover

- Redundancy in design, i.e. Increase factor of safety
- Possible PVC layer for "backup"
- Monitor water quality at "exit" point

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Sensitivity Analysis
Risk of What ifs?

- Material and quality control issues lead to more conservative assumption of material properties.
- Longer term effects of roots, burrowing animals, meteorological cycles: wet/dry, freeze/thaw, settling, desiccation

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Sensitivity Analysis
Risk of What ifs?

- Simulate cracking and check permeability of cracks
- Murphy law, especially with soil mechanics
- Consequences of deficiencies

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Understand Design

- Control water
- Control air
- Control metal uptake
- Theoretical modelling
- Design criteria: e.g. 50 yr wet/dry year?
- Longevity: 1,000 years?

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Understand Realities of Construction

- Compaction curves vary for similar materials (family of curves)
- Have the right equipment (e.g. Rome discs, water trucks, rollers, etc.)
- QA/QC: variations in measuring moisture content and rock corrections plus normal personnel & equipment issues

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Understand Soil Properties

- Basic: plasticity, gradation, compaction curves
- Frost susceptibility:
  - expansion of water 9%
  - <0.02mm and uniformity 25%

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Understand Soil Properties

- Suction and Soil Water characteristic Curve (SWCC)
  - d_{50} 1mm 10^{-3}cm/s with 6 cm capillary rise
  - d_{50} 0.06mm 10^{-5}cm/s with 90 cm capillary rise
  - matrix suction varies 1 to 1000 kPa (higher m.c.less suction)
  - Air and water permeability (effect of saturation)
- Cracking resistance: well graded low plastic (poor) compact wet of optimum.

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Ministry of Energy and Mines Guidelines for Metal Leaching and ARD for **DRY COVERS**
(Price & Errington. 1998.)

GENERAL PRINCIPLES

Ability and Intent - A mine proponent must demonstrate that they have the necessary understanding, site capacity, technical capability, resources and intent to operate a mine in a manner which protects the environment. Mitigation[1] plans must meet the environmental and reclamation objectives for the site and be compatible with the mine plan and site conditions.

Prediction and Prevention - The primary objective of a ML/ARD program is prevention. This will be achieved through prediction, design and effective implementation of appropriate mitigation strategies.

Contingency - Additional mitigation work or contingency plans will be required when existing plans create unacceptable risks to the environment as a result of uncertainty in either the prediction or primary mitigation measures. The timing and degree of preparation required will depend on the risk, when the potential event of concern may occur and the resources required for implementation.

Cautious Approach - Cautious regulatory conditions based on conservative assumptions will be applied where either the ML/ARD assessment or the current level of understanding is deficient.

Financial Security - As a condition of a Mines Act permit, financial assurance will be required to ensure sufficient funds are available to cover all outstanding reclamation obligations, including long-term costs associated with monitoring, maintenance, outstanding mitigation requirements and collection and treatment of contaminated drainage.

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[1] The term mitigation refers to all measures taken to avoid a negative impact on the receiving environment, including ML/ARD prevention, reduction and treatment.

GENERAL PRINCIPLES FOR MITIGATION

Mitigation Plans - Mines with the potential to create significant impacts to land and watercourses from ML/ARD must provide detailed mitigation plans demonstrating how contaminant loadings will be reduced and receiving environment objectives will be achieved. Mitigation plans are required for the entire minesite and for individual mine components with a potential for ML/ARD. Potential mitigation strategies for individual mine components should be evaluated in terms of their contribution to the cumulative risk, liability and land use impact of the entire mine.

Compatibility with the Mine and Environment - For a mitigation strategy to be successful, it must be compatible with the mine plan, the biogeoclimatic conditions of the site and the surrounding land uses. Waste handling and mitigation plans must be based on detailed site-specific studies of the minesite, the surrounding environment and the excavated and exposed material. Important biogeoclimatic conditions in addition to the geochemical and hydrogeological conditions, include soil resources for covers, water balance for underwater storage, waste proportions for blending and ground conditions for drainage collection, bulkheads and flooded impoundments. While successful mitigation requires a compatible mine plan, the converse is also true. Mitigation requirements can play a determining role in the economic feasibility and environmental impact of all, or parts of, a project.

Selection of the Best Mitigation Strategy - Selection of the best mitigation strategy for a potentially problematic material or mine component should be done in two phases:

1. Identify strategies that will prevent negative impacts to the receiving environment.
2. Evaluate the relative abilities of potentially effective strategies to satisfy the general environmental protection and reclamation objectives of minimizing liability, risk and post-mining alienation of land and water resources.

Long-term Mitigation Requirements - Most ML/ARD mitigation facilities or structures must be designed, constructed, operated and if possible decommissioned in a manner that allows them to perform indefinitely. Successful long-term operation requires sustained vigilance and regular monitoring to identify possible upset conditions. Conservative design criteria are typically required to achieve operational objectives during and after extreme climate events. Plans and resources must be available to enable timely maintenance.

COVERS

GENERAL CONSIDERATIONS

Engineered covers can be used to reduce the supply of oxygen to sulphide oxidation. They can also be used to reduce leaching and contaminant loads resulting from the infiltration of incident rainfall and snow melt. Cover use for ML/ARD mitigation has been limited. Most cover use in Canada has been to reduce drainage infiltration into already acidic wastes with the objectives of decreasing leaching, the volume of discharge and water treatment costs.

The ability of a cover to decrease drainage infiltration and/or air ingress will depend on the cover design, the characteristics of available construction materials, the geotechnical stability (i.e., little or no cover erosion or dump settling) and site-specific climatic conditions. At several sites around the world, covers have been shown to prevent convective air movement and reduce oxygen diffusion. Under humid British Columbian conditions, some drainage infiltration is expected through most covers; thus with regards to infiltration, covers are generally considered to be a reducing mechanism rather than a preventing mechanism. While it is possible to prevent infiltration with a multi-layer geotextile cover, for large waste volumes this is only feasible under very favourable economic conditions.

Cover use as the primary mitigation strategy will depend on the degree of reduction in infiltration and/or air ingress versus that needed to meet discharge quality requirements. Two important areas of uncertainty in cover design and drawbacks to their use are long-term performance and the measures required to ensure the necessary degree of effectiveness. Long-term performance is required for most covers. Since few existing covers are more than 10 years old, further operational testing is required to determine the long-term design criteria and complementary monitoring, maintenance and replacement requirements. Further operational testing is also required to determine the relationship between cover performance and design constraints. In general, covers are expected to be most easy to construct and maintain on fine textured, level or gently sloping wastes.

In addition to the properties of the cover, the ability of a cover system to delay ARD onset or enable receiving environment objectives to be met will depend on the presence of other air and drainage sources and the amount of weathering that occurs prior to cover installation. Important contributing factors include the characteristics of the waste, mine scheduling and design, the timing of cover placement and the hydrology of the disposal site.

Covers proposed for ML/ARD mitigation must be designed to be compatible with site-specific conditions and constructed according to the clearly defined specifications required to meet performance objectives. Cover design and construction supervision must be carried out by qualified and experienced professional engineers.

INFORMATION AND DESIGN REQUIREMENTS

A cover proposal requires a detailed design and supporting testwork that demonstrates effective performance for the intended period of use. The proposed design must include the cover type, the mechanism for reducing water and/or oxygen ingress, cover material characteristics, construction requirements, measures for cover protection, procedures for verification of predicted performance, instructions for maintenance and/or replacement, descriptions of proposed surface reclamation and the identification of air or drainage sources which may circumvent the cover or otherwise compromise the mitigation objectives.

While the focus of the following discussion is mainly soil covers, most of the comments and information requirements also pertain to covers constructed with other unconsolidated or synthetic materials. The following items should be considered in cover design and addressed in a cover proposal:

Mitigation Objectives - The first step of cover design is selection of feasible mitigation objective(s). Proponents must provide a detailed description of the minimum mitigation performance required for environmental protection. For a drainage reducing cover this should include the required reductions in drainage infiltration and overall dump discharge.

After the mitigation objective has been chosen, the proponent must develop an understanding of the components of ML/ARD and the contributing factors that the cover intends to reduce. For a cover whose objective is to reduce metal loadings in drainage, this will include potential sources of metals, present and future weathering conditions, waste hydrogeology, influential climatic conditions, sources of dump drainage and overall site drainage conditions. A review of the factors contributing to the targeted problem and the ability of the cover to reduce them will determine whether a cover is potentially an effective means of achieving the mitigation objective.

One aspect will be the predicted performance of the cover. For example, drainage inputs along with the estimated number of defects in geotextile liners recommended by Giroud and Bonaparte (1989) was used to estimate the flow through a geotextile barrier (Redfern, 1997). The effectiveness of a cover designed to reduce leaching as a means to reduce site metal loadings will depend in part on the proportion of metal leaching that results from groundwater drainage inputs as opposed to surface water infiltration. For logistical reasons, wastes are often placed in topographic depressions or at the bottom of slopes. These areas are often zones of groundwater discharge with high rates of flow during periods of the year. Under these circumstances, leaching will continue even if the cover effectively limits surface infiltration.

In many cases, the combined effect of the cover on leaching and oxidation will be very important. Where there continues to be some leaching either through surface infiltration or groundwater inputs, the effectiveness of an oxygen-ingress-limiting cover in reducing metal discharge will depend on the initial waste solubility and the timing of cover placement relative to the rate of production of soluble weathering products. If the wastes are already strongly weathered prior to cover placement, leaching of residual weathering products will maintain high metal loadings in the discharge, even if the cover effectively limits further oxidation.

Design Principles - The design principle refers to the physical features and mechanisms by which the cover will achieve the mitigation objectives. For example, reduction in the infiltration of precipitation could result from cover features which increase surface runoff, absorption and evapotranspiration. Important processes that a cover should be designed to handle include infiltration, runoff, evaporation, transpiration, erosion, metal movement into the zone of plant uptake and oxygen diffusion. External factors that may affect these processes include dump settling, climate, plant growth and burrowing animals.

Characteristics of Proposed Cover Materials - Covers can be constructed from a wide range of materials including soil, synthetic materials, various organic substances and composites. Possible cover materials will depend on the mitigation objectives, material availability and costs, instillation limitations and site-specific climatic considerations. Major costs may be incurred in purchasing, transportation, installation and monitoring and maintenance. Often the most cost-effective option is to construct a cover using waste materials that exist at the minesite. For example, desulphurized tailings might be used as a geochemically inert, barrier to oxygen diffusion.

To date, the majority of cover work in British Columbia has been with natural soil materials. Benefits of soil covers include cost, compatibility with surface reclamation goals and their predicted longevity. Due to performance and economic considerations, soil covers are usually constructed using unconsolidated materials available in the vicinity of the minesite. Synthetic covers are often simpler to install, more predictable, and a more reliably effective option than natural covers. Disadvantages that restrict synthetic cover use include the high costs and questionable longevity.

While the importance of different design parameters vary according to the cover material, its intended use, and the stresses placed upon it, they generally include a comprehensive list of hydraulic and geotechnical characteristics. For a natural soil barrier, this includes particle size distribution, soil water characteristic curve, hydraulic conductivity and oxygen diffusivity after compaction at different moisture contents.

A Multi-Layer, Capillary Barrier Soil Cover - The present state-of-the-art practice for a drainage reducing soil cover is a multi-layer capillary barrier system consisting of a fine textured layer sandwiched between upper and lower coarse textured layers. Drainage infiltration is restricted by differences in moisture retention between the fine and coarse textured layers and by the low hydraulic conductivity of the fine textured layer (Aubertin et al., 1996). Saturation of the fine textured layer will reduce air movement.

In a multi-layer capillary barrier system, the upper porous, coarse textured layer plays a number of roles including the provision of erosion protection, water storage to replace any losses from the middle layer, a surface for revegetation and evapotranspiration and an initial flow path for excess drainage that was unable to infiltrate the underlying layer. In some cover systems, the upper layer is divided with separate sub-layers provided for plant rooting, root restriction and water flow and storage (Aubertin et al., 1996).

The compact, fine-textured middle layer in a capillary barrier system serves as the primary barrier to water movement. Required properties include a low hydraulic conductivity to restrict the rate of flow and the ability to retain water under tension which restricts drainage loss to an underlying coarse textured layer. If the objective is to reduce air entry, the middle layer should retain a high degree of saturation under all climatic conditions.

The role of the underlying, porous, coarse textured layer is to create a suction gradient that reduces drainage losses from the middle layer and to form a capillary barrier that prevents upward contaminated drainage movement. While the capillary barrier will be strengthened by large contrasts in grain size between the fine and underlying coarse textured layers, this may also enhance the downward migration of fines. In some covers, waste rock is used as the lower coarse layer (Wilson et al., 1997).

Climate - Consideration of climatic variables and the use of climatic data in cover design is essential for effective cover performance (Vanapalli et al., 1997). The collection of detailed on-site climatic data is required both in the design of a cover and for performance monitoring. Important information includes the parameters required for a water balance and the properties of extreme wetting and drying events (including snow melt patterns).

Construction Conditions - An important feature of all covers are the construction requirements. Failures in construction are a common cause of reductions in cover performance and are blamed for the consequent environmental impacts (Danielson and McNamara, 1993). Construction specifications for an engineered cover include the requirements for initial site preparation, excavating and preparing cover materials (i.e., remove large boulders and organic debris from soil), cover construction (i.e., standards for moisture content, compaction, layer depths, and installation of monitoring equipment) and preventing erosion (i.e., runoff collection) required to achieve design objectives. Physical properties such as moisture content, which is critical in the construction of compacted soil covers, might restrict construction during certain seasons or during adverse weather conditions.

Erosion Protection - Covers which reduce drainage infiltration and create greater surface or near-surface runoff will increase the potential for erosion. Erosion protection requires measures to stabilize the cover surface and minimize overland drainage flow. Drainage control is particularly important for surfaces left exposed for a significant period of time before a vegetative cover can be established. A water management/surface stabilization/sediment retention system should be included in a cover design, with resources provided for monitoring, maintenance and repair.

Monitoring - Monitoring is required to determine cover performance during and after construction. Monitoring should include the measurement of critical cover conditions (i.e., QA/QC), climatic conditions and their effect on ML/ARD. Monitoring must also provide sufficient warning when additional design refinements, maintenance or repairs are required.

Long-term Performance - The design of an engineered cover must ensure future performance over the required period of time and the expected range in climatic conditions and biological parameters. Factors to consider include the effects of potential settling, chemical weathering, desiccation, freeze/thaw cycles, erosion, root penetration and burrowing by animals.

A critical concern with cover technology is the uncertainty regarding long-term performance. The design, monitoring and maintenance proposed must ensure the required longevity and satisfactory implementation of contingency measures, such as replacement, should they be required.