Osinergmin

Organismo Supervisor de la Inversión en Energía y Minería

CRITICAL CONTROLS for TAILINGS DAMS

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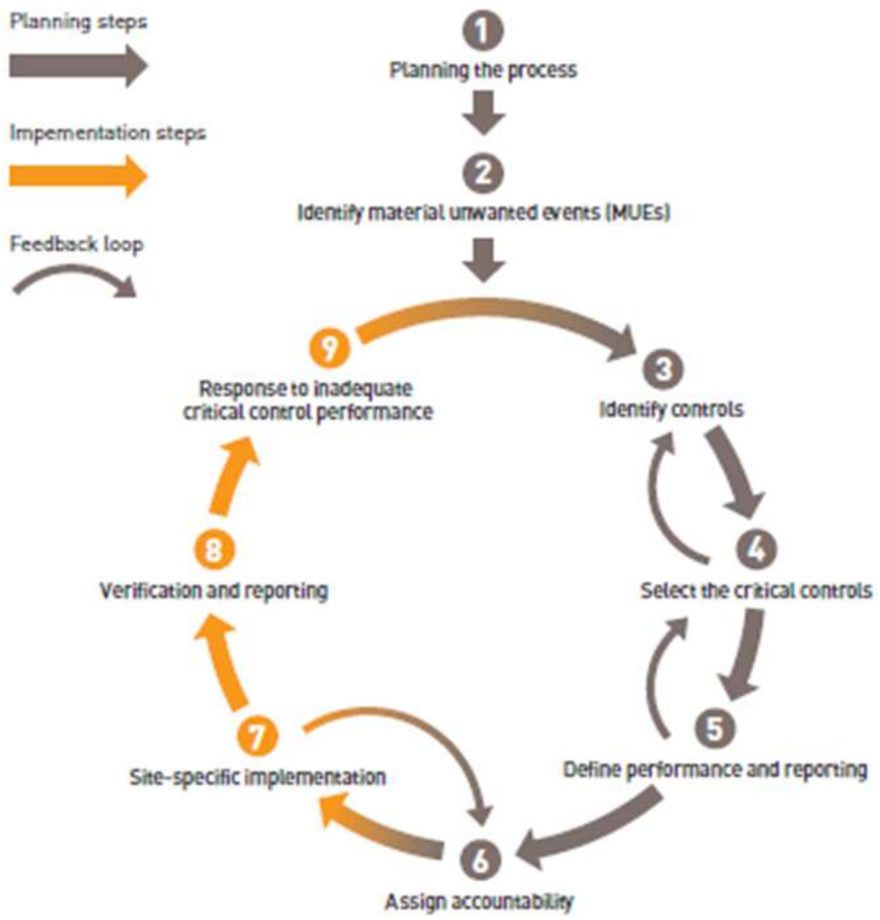
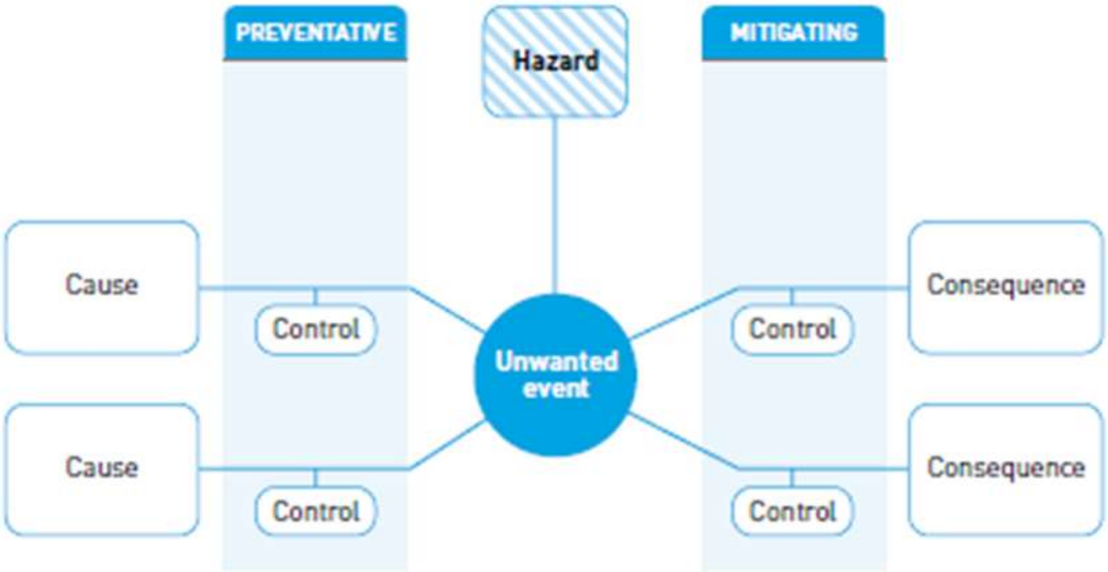
CRITICAL CONTROLS

- Framework
- Bowties
- Material Unwanted Events (MUE)
- Tailings Dams Failure Modes and Controls
- Monitoring Methods for Critical Controls
- Monitoring Technologies



Bowties

- Good tool for communicating and "binning" the critical controls
- Sometimes overly complicated and lacking in substance or missing failure modes
- Should be underpinned with a failure modes effects assessment (FMEA)



Material Unwanted Events (MUE)

Dam failure and release of tailings (assumed to be catastrophic)

- Foundation
- Dam Slope
- Piping
- Overtopping

Release of tailings/water – environmental effects (potential to lead to catastrophic failure)

- Decant
- Erosion
- Geohazards
- Water Contamination

MUE - Foundation ---- Preventative Controls

Material Unwanted Events (Threat/Causes) [Failure Modes]	Preventative Controls
Foundation	Site investigation
	Dam design
	Deformation monitoring
	Pore pressure monitoring
	Design – static stability
	Design – seismic stability

- Weak layers
- Undrained shear strength
- Apparent over consolidation due to desiccation

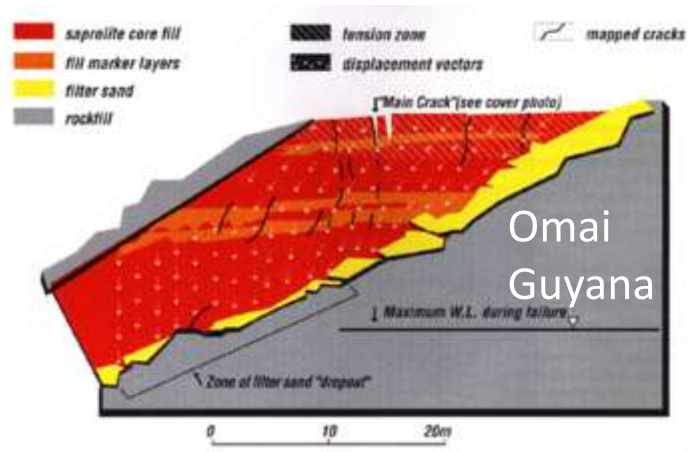
MUE – Dam Slope --- Preventative Controls

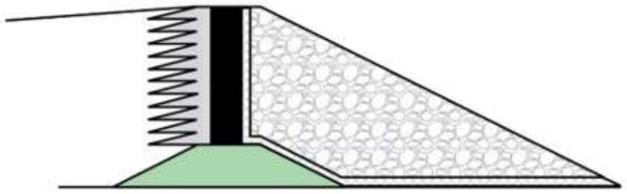
Dam Slope	Material characterization
	QA/QC
	Design – static stability
	Design – seismic stability
	Monitoring – pore pressure
	Monitoring - deformations

- Upstream dams are vulnerable
- Static liquefaction and undrained behavior
- Dams over 35 m high begin to develop high stress concentrations
- Seismic analysis – hazard and response

Piping	Design - limiting hydraulic gradients
	Design - filter compatibility
	QA/QC of filters

- Omai
- Tailings are "forgiving"
- Designs to reduce hydraulic gradients
- Hydraulic fracturing risk when rockfill placed upstream of core





CORE ZONE ROCK FILL / EARTH FILL

MUE – Overtopping --- Preventative Controls

Overtopping	Design criteria
	Design -flood storage capacity
	Design - spillway capacity
	Monitoring water levels
	Monitoring flows

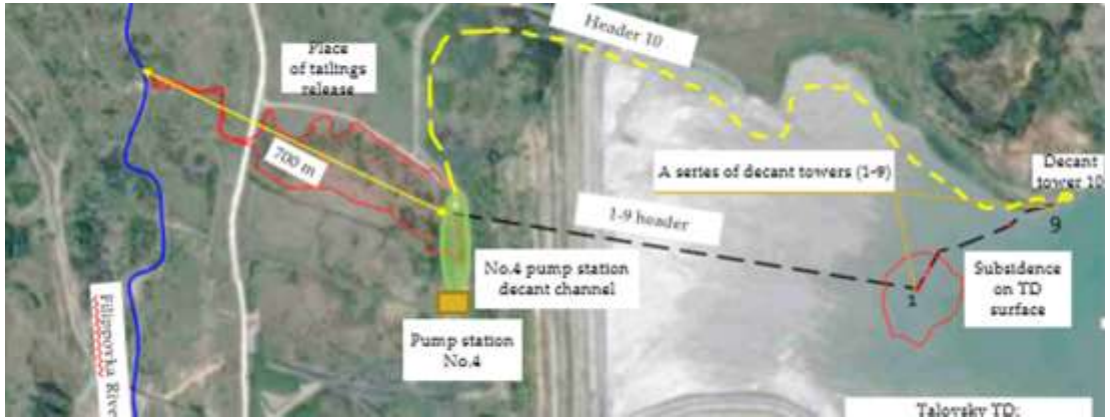
- Kolontar and Baia Mare
- Design criteria varies Internationally
- Dam break analysis often underestimate consequences

MUE – Decant, Erosion and Geohazards--- Preventative Controls

	Monitoring flows
Decant	Design decant structure
	Operations and maintenance procedures
	Monitoring flows
Erosion	Design erosion controls
	Inspection and maintenance
Geohazards	Design geohazard controls
	Monitoring slopes, snowpack, deformations

Flood Erosion Coal Mine BC

- River erosion at toe of dam
- Decant break
- Rock or snow avalanches



Decant Failure Kazakhstan

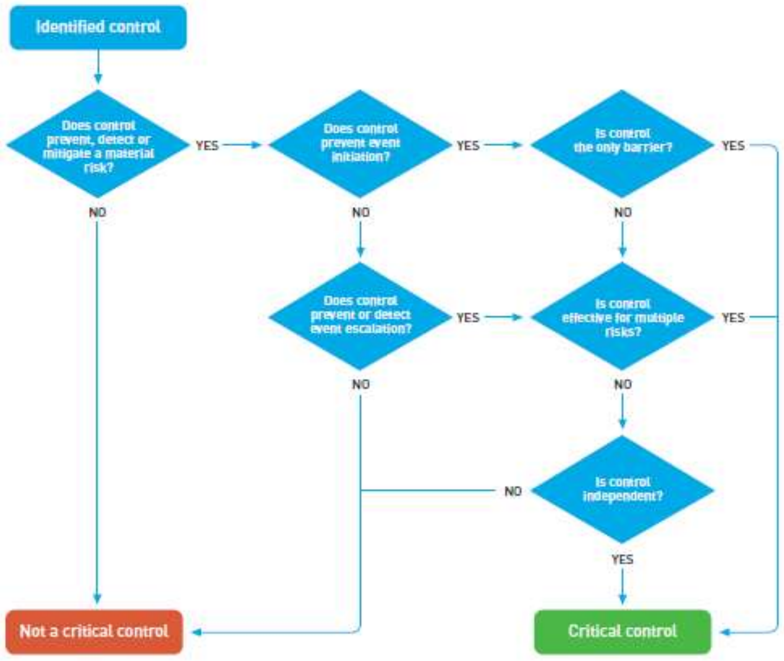
MUE – Environment --- Preventative Controls

- Geochemical characterization
- Geomembrane liners
- Risks with dry stack of acidic tailings

Water Contamination (groundwater and surface water)	Waste and water characterization
	Design of seepage controls
	Design of filters for ARD precipitates
	Monitoring water quality
	Monitoring water flows

	Aquatic	Drinking	Agricultural	"Dairy" Cattle	Wildlife
Cadmium	.000 02	None	0.000 5	0.080	None
Cyanide	0.005	0.20	None	None	None
Copper	0.007	0.50	0.20	0.30	0.30
Molybdenum	0.002	0.25	0.05	0.08-0.2	0.05
Zinc	0.033	0.5	2.0	2.0	None
Sulphate	100	500	None	None	None
Selenium	0.002	0.010	0.010	0.030	0.004

MUEs --- Critical Controls and Mitigating Controls



Source: Adapted from BHP Billiton.

Material Unwanted Events (Threat/Causes) [Failure Modes]	Preventative Controls	Unwanted Event	Mitigative Controls	Consequences
Foundation	Site investigation	Dam failure and release of tailings	ERP Unload crest of dam Load toe of dam Move pond Minimize pond volume	Catastrophic failure
	Dam design			
	Deformation monitoring			
	Pore pressure monitoring			
	Design – static stability			
	Design – seismic stability			
Dam Slope	Material characterization			
	QA/QC			
	Design – static stability			
	Design – seismic stability			
	Monitoring – pore pressure			
	Monitoring - deformations			
Piping	Design - limiting hydraulic gradients		ERP Move pond Minimize pond volume Place inverted filters	
	Design - filter compatibility			
	QA/QC of filters			
Overtopping	Design criteria		ERP Build emergency spillway Move pond Minimize pond volume Pump	
	Design -flood storage capacity			
	Design - spillway capacity			
	Monitoring water levels			
	Monitoring flows			
Decant	Design decant structure	Release of tailings and water	ERP Plug decant Move pond Minimize pond volume	Environmental and social impacts
	Operations and maintenance procedures			
	Monitoring flows			
Erosion	Design erosion controls	Release of sediment	ERP Repair eroded zones Move pond Minimize pond volume	Operation upsets
	Inspection and maintenance			
Geohazards	Design geohazard controls	Dam overtopping Release of sediment and water	ERP Avalanche controls Increase freeboard Stabilize slopes Minimize pond volume	Operation upsets
	Monitoring slopes, snowpack, deformations			
Water Contamination (groundwater and surface water)	Waste and water characterization	Contaminated water release	Design of filters and slope stability Interception wells Seepage cutoff walls Attenuation ponds Design change for saturation of tailings	Environmental and social impacts
	Design of seepage controls			
	Design of filters for ARD precipitates			
	Monitoring water quality			
	Monitoring water flows			

Monitoring Methods for Critical Controls

Foundation	Site Investigation	Peer review External review boards Dam Safety Review (DSR)
	Dam design	
	Deformation monitoring	Survey monuments and Inclinometers
	Pore pressure monitoring	Piezometers, Dam Safety Inspection (DSI)
	Design – static stability	Peer review External review boards DSR
	Design – seismic stability	
Dam Slope	Material characterization	As-constructed records Data records DSI
	QA/QC	
	Design – static stability	Peer review External review boards DSR
	Design – seismic stability	
	Monitoring – pore pressure	Piezometers, DSI
	Monitoring - deformations	Slope surveys, Lidar, inclinometers, drones, satellite, DSI

Monitoring Methods for Critical Controls

Piping	Design - limiting hydraulic gradients	Peer review External review boards DSR As constructed records
	Design - filter compatibility	
	QA/QC of filters	As constructed record, DSI
Overtopping	Design criteria	Peer review External review boards DSR
	Design -flood storage capacity	
	Design - spillway capacity	
	Monitoring water levels	Level recorders, cameras, DSI
	Monitoring flows	Flow meters, cameras, DSI

Monitoring Methods for Critical Controls

Decant	Design decant structure	Peer review External review boards DSR
	Operations and maintenance procedures	DSI Camera surveys and deformation monitoring
	Monitoring flows	Flow meters, DSI
Erosion	Design erosion controls	Peer review External review boards DSR
	Inspection and maintenance	DSI
Geohazards	Design geohazard controls	Peer review External review boards DSR
	Monitoring slopes, snowpack, deformations	Satellite, Lidar, inclinometers, snow gauges

Monitoring Methods for Critical Controls

	deformations	
Water Contamination	Waste and water characterization	Peer review External review boards DSR
	Design of seepage controls	
	Design of filters for ARD precipitates	
	Monitoring water quality	Peer Review Real time sensors, e.g. pH, EC, Neutron probes Lysimeters Sampling and testing
	Monitoring water flows	Stream gauges, seepage collection weirs

Monitoring Technologies

Equipment Measuring Device and Methods	Parameters Measured	Application	Research / Experience
Monitoring of Pore Pressures or Moisture Changes			
Electric piezometers with telemetry to process plant or phone	Pore pressure and temperature	Monitor pore pressure changes due to loading and changes in hydrogeological conditions	Standard practice at many mines. Strings at multiple depths are preferred
TDR, Neutron Probes	Saturations levels and temperature		
Self Potential	Passive electrical method which is sensitive to the flow of seepage water	Electrodes are placed on the dam surface both for investigation and monitoring	Research and long term field measurements have been performed especially in US, Canada, France and Sweden.
Distributed Fiber Optic sensing	Temperature and strain are measured in optical fibers using laser light.	Cables are installed in new or old dams for seepage evaluation using temperature and strain analyses to assess movements	Basic research since 1996 in Germany and Sweden. Further research especially in France, Austria, the Netherlands, UK and US. Challenges are calibrating measurements to site conditions.

Monitoring Technologies

Monitoring of Deformations			
Vibration Measurements	Dynamic response (modes and frequencies)	Long term monitoring of the integrity of concrete structures	Either forced or natural ambient loads are used for excitation. Change in dynamic response under the same loading conditions indicate changes in the integrity of the structure
Borehole Instruments (inclinometers)	Electro-Mechanical devices used to measure deformation	Devices are placed where movements/tilts may occur	Recent developments allow continuous monitoring both in vertical boreholes as well as longitudinally within the dam.
Settlement plates	Change in elevation	Monitoring of dam settlement	Common practice at dams sensitive to settlement and to understand the deformation and stress state of the dam.
Global Navigation Satellite System (GNSS)	Accurate distance measurements between orbits and sensor.	Local monitoring of movements.	Extensive research with improved accuracy for different applications.
Laser scanning and digital imagery	Accurate distance measurements using laser with high spatial resolution over surfaces	Provide a three dimensional geometric model of dam. Deformations can be detected by regular measurements	Technology continuously improving by lasers, sensors and digital image processing. Method is used in several countries as a normal procedure.
Satellite Synthetic Aperture Radar (Satellite SAR)	Photogrammetry method using Satellite images	Surveying of dams and impoundment and monitoring of movements at regular intervals	High resolution surface surveying method producing a digital3-D representation of the surfaces
Ground survey Aperture Radar (GBInSAR)	Photogrammetry method using ground station images	Surveying of dams and impoundments and monitoring of short term movements	High resolution surface surveying method producing a digital 3-D representation of the surfaces

Monitoring Technologies

Monitoring of Stresses			
Load cells	Stress	Monitor stresses at different locations in the dam	Applicable for high dams sensitive to stress and strain changes.
Other Monitoring Technologies			
Multi-beam bathymetry	Echo-sounding	Bathymetric survey of ponded water	High resolution underwater surveying producing a digital 3-D representation of the surfaces. Used on tailings ponds with a miniature submarine.
Drones and cameras	Visual record	Monitoring of spillways, beach lengths	Allows visual reconnaissance on a continual or periodic basis.
Seismographs (accelerometer)	Earthquake acceleration	Monitoring attenuation of earthquakes and the seismic response of the dam.	Common in high seismic setting.
Resistivity	Active electrical method that can detect changed material properties	Electrodes are placed on the crest or at the dam toe.	Research and long term field measurements have been performed especially in US, Canada, France and Sweden.
Ground Penetrating Radar (GPR)	Detect changes in properties of near surface soil layers, localization of defects or voids in concrete structures	Nondestructive and rapid method based on measuring transmission time for radar signals reflected from or transmitted through a media	Localization of seepage zones, sinkholes and deterioration of cores in embankment dams. Monitor remedial grouting of dams. Limited survey depth
Water quality sensors	Electrical conductivity and pH	Monitoring water quality to optimize attenuation/mixing with receiving waters	

Summary and Barriers to Critical Controls Applications

- Critical Controls is a good framework and is adopted by ICMM member companies
- Risk assessment methodology (low probability – high consequence)
- Bowties, risk assessments and critical controls can become overly generalized and complex
- Over-reliance on designers

BC Ministry of Mines --- Revision of Regulations --- Post Mt. Polley

- Ministry of Energy and Mines – Health Safety Reclamation Code Revision
- Revised following Mount Polley failure
- Reviewed legislation worldwide
- Developed components of good practice
- Generally not prescriptive

Regulatory Review – BC Ministry of Energy & Mines

- Regulations in some jurisdictions, such as Russia and Napoleonic Law countries, are typically more prescriptive with respect to design requirements and methodology.
- Regulation of tailings dams can be administered under a variety of Ministries (e.g. Mining, Environment, Water), which leads to a mix of regulatory expertise for tailings dams.
- Regulation of tailings dams is often an "add-on" to regulation of water dams and common regulations may apply.
- "Best Available Technology" guidelines become prescriptive and a regulatory requirement even if the technology has changed or improved.
- Regulations developed by different states or provinces may not be aligned and may also conflict with national regulations or national dam safety guidelines.
- Written regulations for tailings dams are general inadequate, with the following common deficiencies:
  - Regulations are not clearly written and measurable and, therefore, not easily regulated or enforced.
  - Regulations may adopt certain components from dam safety guidelines or calculation procedures from technical guidance documents, which may not be universally applicable to all dams.
  - Regulations do not address the important dam safety components and critical controls.
  - Regulations are difficult to change (parliamentary or state governments) and not easily adaptable to ongoing technological developments.

10.1.8 (1) <u>Seismic and flood design</u> criteria for tailings storage facilities and dams shall be determined by the engineer of record based on the consequence classification determined under section 10.1.7 of this code in consideration of the HSRC Guidance Document, subject to the following criteria:

(a) for tailings storage facilities that store water or saturated tailings,

(i) the minimum seismic design criteria shall be a return period of 1 in 2475 years,

(ii) the minimum flood design criteria shall be a return period 1/3rd of the way between the 1 in 975-year event and the probable maximum flood, and

(iii) a facility that stores the inflow design flood shall use a minimum design event duration of 72 hours;

(b) for tailings storage facilities that cannot retain water or saturated tailings,

(a) the minimum seismic design criteria shall be a return period of 1 in 975 years, and

(b) the water management design shall include an assessment of tailings facility erosion and surface water diversions as well as measures to prevent impounded tailings from becoming saturated that consider the consequence classification as determined under section 10.1.7 of this code.

(2) The environmental design flood criteria shall be determined by a Professional Engineer in consultation with other qualified professionals.

MEM – Minimum Design Standards

Design Slopes

10.1.9 For a tailings storage facility design that has an overall downstream slope steeper than 2H:1V, the manager shall submit justification by the engineer of record for the selected design slope and receive authorization by the chief inspector prior to construction.

Minimum Static Factor of Safety

10.1.10 For a tailings storage facility design that has a calculated static factor of safety of less than 1.5, the manager shall submit justification by the engineer of record for the selected factor of safety and receive authorization by the chief inspector prior to construction.

Breach and Inundation Study/Failure Runout Assessment

10.1.11 A tailings storage facility shall have a breach and inundation study or a failure runout assessment prior to commencing operation, or as required by the chief inspector.

Water Balance and Water Management Plan

10.1.12 (1) The manager shall ensure that a tailings storage facility has a water balance and water management plan for the permitted life of mine that is prepared by a qualified person.

(2) The manager shall notify the chief inspector if any unpermitted discharge of water occurs or is required.

Quantifiable Performance Objectives

10.1.13 The manager shall ensure that quantifiable performance objectives for a tailings storage facility are determined and reviewed by the engineer of record and the TSF qualified person.

MEM – Permitted Sites - Governance

10.4.2 **(1)** The manager of a mine with one or more tailings storage facilities shall

(a) develop and maintain a **Tailings Management System** that considers the HSRC Guidance Document and includes regular system audits,

(b) designate a **TSF qualified person** for safe management of all Tailings Storage Facilities,

(c) establish an **Independent Tailings Review Board**, unless exempted by the chief inspector.

(d) review annually the risk assessment for all tailings storage facilities and associated dams to ensure that the quantifiable performance objectives and operating controls are current and manage the facility risks,

(e) maintain tailings storage facility **emergency preparedness and response plans** integrated into the Mine Emergency Response Plan required under section 3.7.1 of this code, and

(f) ensure **document records** for key information are maintained and readily available for tailings storage facilities.

(2) The composition of an **Independent Tailings Review Board** established under subsection (1) (c) shall be commensurate with the complexity of the tailings storage facility in consideration of the HSRC Guidance Document.

(3) The manager shall submit the Terms of Reference for the Independent Tailings Review Board including the qualifications of the board members to the chief inspector for approval.

(4) The terms of reference for the Independent Tailings Review Board shall be developed or updated as required in consideration of the review under subsection (1) (d).

MEM - Reporting

Annual Reporting

10.4.4 The owner, agent or manager shall submit one or more annual reports in a summary form specified by the chief inspector or by the conditions of the permit by March 31 of the following year on the following:

(a) reclamation and environmental monitoring work performed under section 10.1.3 (e) of this code;

(b) tailings storage facility and dam safety inspections performed under section 10.5.3 of this code;

(c) the **activities of the Independent Tailings Review Board** established under section 10.4.2 (1) (c) of this code that describes the following:

(i) a summary of the reviews conducted that year including the number of meetings and attendees;

(ii) whether the work reviewed that year meets the Board's expectations of reasonably good practice;

(iii) any conditions that compromise Tailings Storage Facility integrity or of non-compliance with recommendations from the engineer of record;

(iv) signed acknowledgement by the members of the Independent Tailings Review Board, confirming that the report is a true and accurate representation of their reviews;

(d) a summary of **tailings storage facility and dam safety recommendations** including a scheduled completion date;

(f) updates to the tailings storage facilities register as required;

(g) other information as directed by the chief inspector.

SUMMARY

- Regulations should require good practice
- Regulations should not be too prescriptive
- Minimum standards to protect the public
- Responsibilities of Owner and Design Engineer need to be clear and accountable

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Muchas Gracias

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