MINING AND MINERAL PROCESSING

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1.0 SCOPE

This data sheet contains property loss prevention guidance for mining, mineral processing, hydrometallurgical and electrometallurgical processing, and associated operations, including the following:

A. Mining of metal and non-metal minerals including surface (open-pit, cast, or strip), underground, mineral dredging of shallow bodies of water and in-situ solution mineral ore extraction.

B. Ore preparation including crushing, sizing, screening, milling, ore and waste rock handling and storage, and blending of ores in stockpiles.

C. Wet and dry processing of prepared mineral ores using beneficiation (ore dressing, concentration) processes such as washing and cleaning, froth flotation, atmospheric leaching, filtration, thermal drying, precipitation and crystallization.

D. Hydrometallurgical ore concentration processes such as mineral solvent extraction using ignitable liquids and leaching using elevated pressure and temperature including acid leaching (PAL or HPAL), oxidation leaching (PoX) and alumina refining (Bayer Process).

E. Electrometallurgical metal production using electrowinning or electrorefining.

F. Recovery and production of gold doré bullion at the mine site.

G. Rail and slurry pipelines for transport of concentrate or product.

H. Tailings disposal facilities associated with beneficiation.

The following operations are not covered in this data sheet.

- Underground coal, oil shale, petroleum, and natural gas mining, extraction and processing.
- Heavy duty mobile equipment (HDME) used for mining and transportation of ore or final products. Refer to Data Sheets 7-40, *Heavy Duty Mobile Equipment* and 1-62, *Cranes* for guidance.
- Cement processing plants; however, an associated limestone mine should be addressed by this data sheet.
- Deep-sea extraction of minerals.
- Use of underground mines for non-mining purposes such as storage, manufacturing, or scientific research.
- Solvent extraction outside of mineral processing and refining. Refer to Data Sheet 7-14, *Fire Protection for Chemical Plants*, and 7-111D, *Oilseed Extraction*.
- Pyrometallurgical roasting, smelting, converting and casting conducted in a hot or molten state for metals such as steel, aluminum, copper, lead, zinc, nickel; and acid plants whether producing sulfuric acid for use (sulfur burning) or removing sulfur dioxide from emissions. For these processes, refer to the following FM Data Sheets.

  o For molten metal processing or handling, refer to Data Sheet 7-33, *Molten Metals and Other Materials*.

  o For primary aluminum production, refer to Data Sheet 7-64, *Aluminum Smelting*.

  o For pig iron and basic oxygen steel production, refer to Data Sheet 7-25, *Blast Furnace Ironmaking and Basic Oxygen Steelmaking*.

  o For direct-reduction iron (DRI) production, refer to chemical processing data sheets.

  o For sulfuric acid plants associated with pyrometallurgical or hydrometallurgical processing, refer to chemical processing data sheets.

This data sheet focuses on hazards and exposures unique to mining and mineral processing operations. Other FM data sheets are also applicable at mining and mineral processing facilities. Apply these other data sheets when appropriate; however, the guidance contained within this data sheet supersedes that presented in other data sheets. Examples of other data sheets that may be relevant in mines and mineral processing occupancies include, but are not limited to: 13-7, *Gears*; 5-17, *Motors and Adjustable Speed Drives*; 5-19, *Switchgear and Circuit Breakers*; 5-31, *Cables and Bus Bars*; 5-4, *Transformers*; 7-110, *Industrial Control Systems*; 7-98, *Hydraulic Fluids*; 7-40, *Heavy Duty Mobile Equipment*, and 7-11, *Conveyor Belts*. Appendix C contains a more comprehensive list of additional data sheets that may be applicable at mining and mineral processing facilities.

1.1 Hazards

Mines and mineral processing facilities contain many common hazards found at other facilities. Below is a discussion of several hazards and exposures that have resulted in recent losses.

1.1.1 Fire

Mines and mineral processing areas typically contain fire hazards found in many other occupancies such as belt conveyors and ignitable liquid systems supporting production equipment (e.g., lubricant and hydraulic). Though the hazards are similar, the exposures may be more severe given remoteness or seasonal conditions that can hamper manual firefighting and recovery efforts.

Historically mineral processing within concentrators have featured mostly noncombustible construction and occupancy. While combustibles may have been present, continuity of combustible materials was rarely present. Today the use of plastics and rubber is increasing in the form of heavy structural plastic screens, extensive plastic/rubber linings in equipment and piping, grouped power cables or control wiring, insulated metal panels for building envelop construction, and rubber conveyor belts are common and may represent high localized combustible loading. In recently fires, usually started by hot work, plastic screens and rubber lined equipment have caused severe localized thermal damage to equipment and building areas of origin as well as adjacent equipment and building areas. While fixed automatic fire protection is currently rare in concentrators, the need for localized protection is growing as process areas begin to evolve using plastic or other combustible materials.

Some forms of hydrometallurgical processing, such as solvent extraction, use large quantities of ignitable liquids, often in plastic piping and equipment. Process safety principles should be used to understand and manage these unique fire hazards.

1.1.2 Boiler and Machinery

Miners move large amounts of overburden and ore, and handle and process large quantities of mineral ore using conveyance and production equipment often located in remote areas. An unexpected breakdown of long lead-time production-critical equipment can greatly impact the ability to extract and process mineral ore. Production-critical equipment with long-lead time parts or replacements, should have a formal asset integrity program to oversee operation and maintenance activities to ensure they remain within the integrity operating window as intended, and any deterioration is detected early enough to limit recovery/repair duration or long-range budgeting for a replacement.

Some metallurgical processes, such as pressure leaching under high pressure and temperature, feature vessels and piping exposed to highly corrosive environments or process upsets resulting in overpressure. These damage mechanisms and operating conditions can result in a rupture of the pressure vessel causing widespread pressure and projectile damage as well as release of corrosive materials into surrounding process areas. Elements of process safety should be in place to manage this hazard.

1.1.3 Mining-Specific Hazards

The unique hazards present at mines are listed below. While physical safeguards may be in place to monitor for or mitigate the exposure, human element policies are critical for managing these hazards and their exposure.

- Underground mine water inundation
- Underground mine seismic earth movement
- Open pit mine wall slope failure
- Tailings disposal facility failure

1.2 Changes

July 2022. Interim revision. Minor editorial changes were made.

2.0 LOSS PREVENTION RECOMMENDATIONS

2.1 General

Apply the following recommendations to mines, mineral processing, and all other associated operations covered by this standard.

2.1.1 FM Approved Products

2.1.1.1 Use FM Approved fire protection equipment, building materials and assemblies, and miscellaneous equipment whenever applicable and available. Select and install FM Approved products and services in accordance with the *Approval Guide* listing. For a list of FM Approved products and services, refer to the *Approval Guide*, an online resource of FM Approvals.

2.1.2 Location and Construction

2.1.2.1 Locate buildings and process structures as well as critical production, utility, or support system equipment in areas not exposed to natural hazards. When unavoidable, provide mitigative solutions in sections 2.1.2.3 and 2.1.4.2. The following natural hazards often expose mines, while other natural hazards may also be present.

- Freeze
- Windstorm including hurricane, typhoon and cyclone
- Flood including surface sources such as stormwater and riverine
- Wildland fires
- Earthquake
- Volcanic activity
- Snow loading collapse
- Avalanche
- Slope collapse due to soil subsidence

2.1.2.2 Locate critical production, utility, or support system equipment such as piping, conveyors, tramways, and electrical distribution systems in areas not exposed to mechanical impact (e.g., vehicles or during construction). When unavoidable, provide mitigative solutions in section 2.1.4.1.

2.1.2.3 When building and process structure locations exposed to natural hazards are unavoidable, construct aboveground buildings and process structures to withstand the exposures as follows.

A. Design buildings and structures to withstand natural hazard exposures in accordance with the respective FM Data Sheet (e.g., 1-27, *Wind Design*; or 1-54, *Roof Loads for New Construction*) and local jurisdictional requirements.

B. Use FM Approved exterior building assemblies capable of withstanding the natural hazard exposure, where appropriate. Examples of building construction where FM Approved assemblies are often recommended include insulated metal panel installed as walls and roofs and insulated steel deck roof assemblies. Install FM Approved building materials and assemblies in accordance with the manufacturer’s guidelines and the FM Approval listing.

2.1.2.4 Construct aboveground buildings, process structures, and subsurface enclosures using noncombustible building materials. If use of combustible or plastic building materials are unavoidable, use FM Approved building materials. Examples of building construction where FM Approved materials or assemblies are often recommended to address the fire hazard posed by plastic building construction include but are not limited to insulated metal panels installed as a wall or roof assembly, an insulated steel deck roof assembly, and interior plastic wall or ceiling facing such as fiber-reinforced plastic (FRP) panels. Install FM Approved building materials and assemblies in accordance with the manufacturer’s guidelines and the FM Approval listing.

2.1.3 Protection

2.1.3.1 Provide fire protection for underground and aboveground belt conveyors in accordance with Data Sheet 7-11, *Conveyors*.

2.1.3.2 Provide fire protection for buildings/structures with occupancies that are not unique to mining or mineral processing in accordance with the respective FM Data Sheet. The following are common occupancies that are not unique to mining and mineral processing along with the respective data sheets containing fire protection guidance.

• General maintenance shop per Data Sheet 3-26, *Fire Protection for Nonstorage Occupancies*

• Parts warehouse per Data Sheet 8-9, *Storage of Class 1,2,3,4, and Plastic Commodities*

• Core storage in combustible containers per Data Sheet 8-9

• Utility building and/or enclosure per Data Sheet 3-26

• Employee housing per Data Sheet 3-26

• Office per Data Sheet 3-26

• Light to medium-duty mobile equipment shops per Data Sheet 3-26; however, refer to section 2.3.2.1 for heavy-duty mobile equipment [HDME] shops)

• Control rooms per Data Sheet 7-110, *Industrial Control Systems*

• Laboratories per Data Sheet 3-26

2.1.3.3 Provide exterior fire hydrants and/or monitors around buildings, process structures, and equipment in accordance with Data Sheet 3-10, *Installation/Maintenance of Private Service Mains and Their Appurtenances*. Often the design and installation of hydrants and other exterior manual firefighting equipment is driven by the process safety program and fire emergency response plans taking into account: fuel packages within or surrounding buildings, process structures, and process equipment; safe firefighting access to fire exposed areas; presence and accessibility of interior manual firefighting equipment; and presence of active fire protection systems.

2.1.3.4 When operating at elevation, adjust the flash point of ignitable liquids based on the following relationship. Flash points decrease with an increase in elevation. Flash points are often adjusted relative to mean sea level (MSL).

$F_C = F_{sl} - 0.06\,(760 - P)$

(Derived from ASTM D56 Standard Test Method for Flash Point by Tag Closed Cup Tester)

Where:

F_C = the flash point (°F) corrected to desired elevation.

F_{sl} = flash point (°F) at MSL.

760 mm Hg = the assumed barometric pressure at MSL.

P = average barometric pressure at the given elevation, expressed in mm Hg.

2.1.3.5 If low flash point additives are used in the diesel fuel, use the actual tested flash point of the mixture (i.e., diesel fuel plus additive).

2.1.4 Equipment and Processes

2.1.4.1 When locations exposed to mechanical impact hazards are unavoidable,protect outdoor production-critical utility, or support system equipment including transfer piping, conveyors, tramways, and electrical conductors against mechanical impact by mobile equipment traffic, or during construction or excavation activities. Protection may consist of signage defining safe clearances and/or bump guards.

2.1.4.2 When locations exposed to natural hazards are unavoidable, protect outdoor production-critical equipment with safeguards in accordance with the respective FM Data Sheet (e.g., 1-27, *Wind Design*; 1-40, *Floods*; or 1-54, *Roof Loads for New Construction*) and local jurisdictional requirements.

2.1.4.3 Install appropriately rated electrical equipment areas that routinely or may become exposed to ignitable liquid and/or an flammable atmosphere such as gas/vapor or combustible dusts. Define hazardous/ classified areas in accordance with Data Sheet 5-1, *Equipment in Hazardous (Classified) Locations* or per the local jurisdiction.

2.1.5 Operations and Maintenance

2.1.5.1 Manage hot work throughout the facility in accordance with Data Sheet 10-3. Use the FM Hot Work Permit System or equivalent to prevent hot work fires during any temporary or routine work activities that involve open-flame or hot surfaces, and/or generate sparks or molten metal of sufficient energy to ignite combustible, ignitable, and/or flammable materials. Examples of hot work operations include torch-applied roofing, pipe brazing or soldering, arc or torch welding, radial-mechanical or torch cutting, grinding, and post-weld heat treatment using a gas-fired burner or electrical resistance heater.

Hot work is a leading cause of fire in mining and mineral processing facilities. combustibles most commonly ignited by hot work are plastic/rubber-lined equipment (RLE) including piping, and plastic equipment such as spirals and screens. Extra effort should be given towards identifying where rubber-lined equipment is located and sound hot work precautions implemented to prevent ignition when working on, in or near plastic/RLE or exposed plastic components.

A. During hot work preparations (i.e., filling out the hot work permit), take the following required precautions listed in Data Sheet 10-3 to limit the likelihood and/or consequences of a hot work fire involving combustible or combustible-lined equipment.

1. Define the hot work area based on the work and work area in accordance with Data Sheet 10-3, *Hot Work Management*. Take into account aspects of the work area such as work at elevation or presence of openings in walls, floors, equipment enclosures, or above open and dry plastic/rubber-lined equipment.

2. Prepare the previously defined hot work area by removing combustibles, and confirming any non-moveable combustibles are protected by FM Approved hot work blankets and pads or other additional required precautions discussed below. Non-moveable combustibles may include but are not limited to plastic/RLE such as open hoppers and piping, or exposed exterior combustible components such as screen covers, plastic filter presses, plastic hydrocyclones, and rubber conveyor belts.

B. During hot work preparations (i.e., filling out the hot work permit), take any additional required precautions offered in Data Sheet 10-3, and/or listed below, to limit the likelihood and/or consequences of a hot work fire involving combustible or plastic/RLE.

1. Install gate valves within plastic/rubber-lined grinding circuits to facilitate equipment isolation and/or flooding during hot work.

2. Install spool pieces in rubber-lined grinding circuits to be removed and blanked during hot work creating a temporary fire break within plastic/rubber-lined grinding circuits. Clearly mark the fire-break spool piece and include these activities in standard operating procedures (SOPs).

3. Provide normally closed, permanently affixed process or fire water connections to plastic/rubber-lined equipment in order to facilitate flooding of the equipment prior to hot work or upon detecting a fire in the equipment. Alternatively, develop procedures for temporarily connecting equipment to water sources. Clearly label these firefighting connections, and train personnel on their use.

4. Position charged (pressurized) firefighting hoses near the hot work area.

2.1.5.2 For the following processing operations, implement a comprehensive process safety program in accordance with Data Sheet 7-43, *Process Safety*. The facility complexity, hazards, and exposures present in these operations often warrant a comprehensive process safety program.

- Flotation reagent storage and handling
- Mineral solvent extraction
- Pressure leaching including alumina refining

Other mining operations would also benefit from core elements of a comprehensive process safety program tailored based on facility complexity, hazards, and exposures. In less complex mining operations, consider employing the following process safety elements (e.g., coal preparation and drying).

• Process knowledge

• Process hazard analysis (PHA)

• Management of change (MOC)

• Asset integrity

• Incident investigation

• Contractor management

• Operators

2.1.5.3 Develop and maintain standard operating procedures (SOPs) and emergency operating procedures for utility, support, and production systems in accordance with Data Sheet 10-8, *Operators.* For example, provide procedures for the following events and activities.

• Identification and response to a frozen load within a grinding mill.

• Elevated vibration or other abnormal condition on the grinding mill.

• Investigation of trip condition prior to crusher, grinding mill, or rotary kiln restart.

• Modification of operating parameter or alarm/trip threshold on production-critical equipment (i.e., part of the management of change program).

• Implementing, operating with, and removal verification of jumpered safety device or function, or software force.

2.1.5.4 Implement an operator training program for utility, support, and production systems in accordance with Data Sheet 10-8, *Operators.* Cover standard operating procedures, emergency operating procedures, and emergency response plans in the initial and refresher training.

2.1.5.5 Implement emergency response plans in accordance with Data Sheet 10-1, *Pre-Incident Planning*. Involve operators and maintenance personnel in the development of the response plans and include them as members of the emergency response team. Formally document the response plans. Audit response plans at least annually to ensure that the plan remains up to date (i.e., the management of change program has assessed the impact of physical or personnel changes on the plan). Consider developing responses to the following fire scenarios.

• Fire involving underground mining equipment (e.g., haul truck, scoop tram)

• Fire involving surface mining equipment (e.g., dragline or shovel)

• Fire involving a surface haul truck

• Fire involving material handling equipment including conveyor belt

• Fire within the concentrator building involving pressurized hydraulic or lubricating oil systems.

• Fire involving or exposing electrical equipment or control equipment supporting critical production equipment (e.g., crushers and mills)

• Fire involving plastic/RLE or plastic equipment such as spirals or screens.

2.1.5.6 Implement an asset integrity program for key equipment in utility services, support systems, and/or production systems in accordance with Data Sheet 9-0, *Asset Integrity* and original equipment manufacturer (OEM) guidelines. The goals of the asset integrity program are to ensure production-critical equipment operates reliably, maintains a high degree of availability, and the end of service life is managed appropriately (i.e., asset replacement planning). Inspection, testing, and maintenance as well as deficiency management procedures are core components of any asset integrity program.

Assess the criticality of a system or equipment based on the exposure posed by the breakdown of that equipment including collateral damage, which may be driven by the subject damage mechanisms and/or failure mode. The equipment breakdown scenario should account for damage sustained to the equipment of origin as well as any connected or adjacent equipment, and/or buildings. Equipment damage results in an unplanned outage affecting upstream and downstream operations while recovery efforts are undertaken, which may also include deploying an equipment contingency plan.

2.1.5.7 Inspect the floor and roof of buildings or process structures, and outdoor equipment enclosures subject for accumulations of crushed ore or other solid process materials, that if allowed to continue, may overload structural supports resulting in collapse. Of particular concern are transfer points between conveyors, and conveyor loading and unloading stations where material may pile-up. Consider starting with quarterly inspections then adjusting the inspection frequency based on previous inspection results. assessing any operating changes or alterations/repairs that may result in new release points or increases in accumulation rate.

2.1.6 Equipment Contingency Planning

When a mining equipment breakdown would result in an unplanned outage to site processes and systems considered key to the continuity of operations, develop and maintain a documented, viable mining equipment contingency plan per Data Sheet 9-0, *Asset Integrity*. See Appendix C of that data sheet for guidance on the process of developing and maintaining a viable equipment contingency plan. Also refer to sparing, rental, and redundant equipment mitigation strategy guidance in that data sheet.

In addition, include the following elements in the contingency planning process specific to mining equipment and processes:

2.1.6.1 Mining Equipment

Consider the need for equipment breakdown sparing as part of the mitigation strategy, when appropriate, and/or implementing the equipment contingency plan (ECP) to expedite recovery efforts and reduce downtime in the event of an equipment breakdown. Evaluate bottleneck equipment breakdowns of mining utility, support system, or production system equipment poses for site operations.

Consider materials of construction, purpose-built specialty production and utility equipment and lined equipment repair/replacement options and lead times.

2.1.6.2 Ring Gears

For ring gears driving production-critical mills, the ECP should address all aspects of gear repair and/or replacement to expedite recovery efforts and resume production. This includes consideration of an equipment breakdown spare ring gear and pinion as a mitigation strategy. Ring gear-specific ECP considerations include the following elements:

- Grind (excavation) and/or weld repair.
- Reverse or flip gears.
- Recut or recondition the gear onsite or offsite if sufficient material remains on the flanks.
- Obtain a temporary (“soft”) gear, while the permanent gear is being manufactured.
- By-pass the out-of-service equipment and reconfigure the grinding circuit using onsite or temporary/rented assets to resume or increase production.
- Maintain ring and pinon gear design documentation up-to-date including drawings, specifications, and any other design aspects required for promptly ordering a replacement gear (e.g., tooth profile, or web/flange and face materials whether cast iron (grey/gray cast iron), ductile (cast) iron, forged steel, or fabricated steel).
- Identify a competent third-party (e.g., OEM or consultant) to perform a fitness for service (FFS) evaluation and root cause analysis of gear damage, and when necessary, develop a remediation plan for repairs or replacement.
- Define any changes in inspection, testing, and maintenance (ITM) activities required to closely monitor gear health during continued operation on a damaged or repaired gear. More frequent or more comprehensive operator walkdowns, vibration monitoring, or gear inspections (e.g., NDE, thermographic imaging) may be warranted.
- Establish alternate standard operating procedures to minimize the likelihood of failure during continued operation on a damaged, or reworked or repaired gear. Procedures may include running at reduced load.
- Identify contractors capable of conducting repairs.

• Identify multiple ring gear manufacturers capable of fabricating temporary or permanent replacements. Also discuss options to expedite fabrication.

2.1.6.3 Pressure Leaching

2.1.6.3.1 The ECP for pressure leaching focuses on critical utility and support system equipment which does not benefit from a high-reliability design as discussed in section 2.5.1.10 (e.g., N+1 or N-1). Consider the following pressure leaching process support equipment and systems in the ECP.

• Slurry pumps feeding ore to autoclaves (digesters)

• Pumps circulating slurry between other process phases downstream

• Waste tailings pumps (e.g., red mud feed pumps at alumina refineries)

• Water wash pumps (e.g., red mud washing or dilution at alumina refineries)

• Vacuum pumps for seed separation filtration and hydrated alumina “production” filtration at alumina refineries

• Ore-handling equipment (e.g., feed conveyors or stacker reclaimers)

2.2 Underground Mining

Refer to Surface Mining (Section 2.3) for fire protection guidance within heavy-duty mobile equipment shops servicing or repairing underground equipment such as scoop trams.

2.2.1 Location and Construction

2.2.1.1 Locate production-critical underground equipment within utility, support, and production systems (e.g., electrical, compressed air, dewatering, or ore crushing) in areas not exposed to vehicle impact, ground fall or rock bursts, air blasts, fire, explosions, and other hazards present in underground mines. When not feasible, protect equipment with noncombustible enclosures and other physical safeguards.

2.2.1.2 Use noncombustible materials in ground control systems such as lagging for passageways and drifts, and liners for shafts. Noncombustible material options may include the ore body rock formation, concrete, aluminum, steel, and cementitious spray coating such as “Shotcrete” or “Gunnite.”

2.2.1.3 Enclose underground ignitable liquid storage or handling areas in fire resistive construction rated for a minimum 1 hour (per ASTM E119, Standard Test Methods for Fire Tests of Building Construction and Materials). If the expected fire scenario duration exceeds 30 minutes, increase the fire rating to 2 hours. The walls (ribs), floor and back (ceiling) of a non-combustible ore body provide equivalent fire rating to special construction. Provide fire rated doors across rock alcoves or other room enclosures. When ignitable liquids are stored in an open drift without enclosures, provide a space separation of 100 ft (30 m) between the ignitable liquid storage or handling area and adjacent combustibles (e.g., timber sets) accounting for any floor slope that may allow liquid to flow towards and/or pool near combustibles. Spill containment (i.e., curbs) may be warranted depending on the release and fire scenario designed and installed in accordance with Data Sheet 7-83, *Drainage and Containment Systems for Ignitable Liquids*.

2.2.2 Protection

2.2.2.1 Provide automatic fire protection systems on underground mobile equipment in accordance with Data Sheet 7-40, *Heavy Duty Mobile Equipment*.

2.2.2.2 Provide automatic fire protection inside hoist wire rope demisters, other enclosed lubricating equipment, and where excess lubrication oils or grease accumulate. An FM Approved special protection system may be the preferred fire protection option due to concern with sprinkler water damaging ropes; however, automatic sprinklers are acceptable as well.

2.2.2.3 Provide automatic fire protection safeguards for hydraulic and/or lubrication systems supporting underground mining operations such as hoists in accordance with Data Sheet 7-98, *Hydraulic Fluids*. Relevant fire protection features may include the following: (1) use of an FM Approved industrial fluid in hydraulic systems; or (2) local protection such as automatic sprinklers over the supply console containing the reservoir and pump (or alternatively a special protection system) plus automatic interlocks to depressurize the ignitable liquid system in the event of a fire or activation of a fire protection system. If hydraulic systems contain ignitable liquid (i.e., not FM Approved or water-based) and are unable to be depressurized for life safety concerns, provide other fire protection safeguards to protect hoist equipment from direct flame impingement and/or smoke damage until the system can be depressurized.

2.2.2.4 Provide fire protection for underground ignitable liquid storage and use in accordance with Data Sheet 7-29, *Ignitable Liquid Storage in Portable Containers*, 7-88, *Ignitable Liquid Storage Tanks*, and 7-32, *Ignitable Liquid Operations*.

2.2.2.5 Do not use low-flash point liquids with a flash point less than 73 F (23 C) in underground mines.

2.2.2.6 Do not use compressed flammable gases (e.g., liquified petroleum gas LPG like propane or butane) in underground mines.

2.2.2.7 Protect concentrations of combustible materials in underground mines in accordance with appropriate FM Data Sheets. For example, provide fire protection for combustibles in shelves or racking per Data Sheet 8-9, *Storage of Class 1,2,3,4, and Plastic Commodities*, ignitable hydraulic systems per Data Sheet 7-98, *Hydraulic Fluids*, and electrical transformers per Data Sheet 5-4, *Transformers*.

2.2.2.8 Install FM Approved 1½ in. (38 mm) hose stations near areas containing combustibles. Design and install hose stations in accordance with Data Sheet 4-4N, *Standpipe and Hose Systems*.

2.2.2.9 Design and install fire protection water supplies for underground mines in accordance with Data Sheet 3-2, *Water Tanks for Fire Protection*, and 3-7, *Fire Protection Pumps*.

2.2.2.10 Provide redundant feed mains to underground fire protection systems (e.g., looped main supplied by two separate shafts) in the event one feed is damaged by a rock fall. Additionally, provide sectional control valves on feed mains and loop mains to minimize impaired protection following rock falls. Locate sectional control valves in areas accessible to responders.

2.2.2.11 Protect underground fire protection piping and devices against mobile equipment impact, rock falls, earthquake, and freezing.

2.2.2.12 Design and install underground fire protection systems in accordance with relevant FM Data Sheets similarly to aboveground protection system installations. Select materials with MAWP capable of withstanding expected head pressure created by extreme elevation differences within an underground mine. When warranted, install pressure-reducing valves in accordance with Data Sheet 3-11, and maintained per Data Sheet 2-81, *Fire Protection System Inspection, Testing and Maintenance and Other Fire Loss Prevention Inspections*.

2.2.3 Equipment and Processes

2.2.3.1 Select underground equipment in utility (e.g., electrical), support (e.g., dewatering), and production systems for use under the anticipated environmental conditions which may include moisture, heat, vibration, diesel fumes, and dust/particulates. When not feasible, protect equipment with enclosures and other safeguards in accordance with the original equipment manufacturer guidelines and the applicable FM Data Sheet.

2.2.3.2 Provide a dewatering system that has a high degree of reliability and availability, and is capable of meeting the probable worst-case inflow from groundwater and production water sources. Systems designed and maintained using N+1 or N-1 pumping capability meet this system design guideline. These installations have redundant pumps, power feeds, and power sources (e.g., onsite diesel generation or diesel-driven pumps with a fuel supply capable of lasting beyond the anticipated outage duration).

2.2.3.3 Protect dewatering systems and associated power supplies against external exposures such as fire, rock falls, mechanical or vehicle impact, and inundation damage. Refer to the hydrogeological inundation assessment discussed in section 2.2.4.8 when assessing and managing inundation hazards exposing dewatering systems

2.2.3.4 Protect dewatering stations with dikes or walls to prevent premature overtopping/submergence during periods of high inflow.

2.2.3.5 Protect surface openings such as portals, hoist shafts, ventilation shafts, and bore holes from water entry during ravine flooding or stormwater entry during periods of heavy rainfall.

2.2.3.6 Do not locate mine openings below manmade impoundments containing water such as water retention dams, tailings disposal facilities (TDF), or levees protecting against lake or river flooding. When unavoidable, construct diversion channels or barriers to protect openings.

2.2.3.7 If high sulfide-content (HSC) ores or coal deposits are susceptible to spontaneous heating or combustible dust flash fires or explosions, provide the following safeguards.

A. Install appropriately rated electrical equipment an areas that routinely or intermittently contain an explosible combustible dust atmosphere in accordance with Data Sheet 5-1, *Equipment in Hazardous (Classified) Locations* or per the local authority having jurisdiction.

B. When it has been identified that drilling or blasting may form an explosible dust atmosphere, provide measures to control the combustible dust and ignition sources.

C. When deposits have been identified as having spontaneous heating potential, continuously monitor the deposits using carbon monoxide analyzers to warn of smoldering combustion. Establish acceptable limits and thresholds driving personnel to take action.

2.2.3.8 If methane or other flammable gases are present underground, provide the following safeguards.

A. Install appropriately rated electrical equipment in areas that routinely or may contain a flammable gas atmosphere in accordance with Data Sheet 5-1 or per the local authority having jurisdiction.

B. Continuously monitor ventilation flow with FM Approved combustible gas detectors. Trend changes in flammable gas concentration and sound an alarm at a minimum of 100 ppm concentration in air. Refer to Data Sheet 5-49, *Gas and Vapor Detectors and Analysis Systems* for design, installation, and inspection, testing, and maintenance (ITM) guidance. Establish acceptable limits and thresholds where procedures drive personnel to take action.

2.2.4 Operations and Maintenance

2.2.4.1 Consider increasing the frequency and/or scope of inspection, testing and maintenance (ITM) activities when utility, support, and production equipment is exposed to harsh conditions underground such as dust/particulate, vibration, heat, and/or moisture.

2.2.4.2 Implement an asset integrity program for hoist systems in accordance with section 2.1.5.6 and the following guidance. Perform a baseline examination of structural components at installation, and follow-up examinations at least every 3 years. Hoist components of interest may include but not limited to drum/wheel, sheave hubs/spokes, trunnions, drive shafts, gears, and brakes. In addition to structural components include inspections of equipment securement and foundation condition as well as fastener tightness checks.

2.2.4.3 Inspect, test and maintain (ITM) hoist wire ropes and brakes in accordance with the original equipment manufacturer (OEM) guidelines and the jurisdiction.

2.2.4.4 Implement an emergency response plan to address fire hazards present within the hoist house per section 2.1.5.5. Fuel packages within hoist houses may include ignitable liquid systems such as wire rope lubrication, bearing lubrication, or hydraulic systems along with electrical insulation on power cabling and switchgear, and plastic lagging and control equipment.

2.2.4.5 Conduct a geological assessment of both the deposit and country rock near the mine to evaluate the impacts these may have on ground control and stability. Complete the assessment during initial development, and review and update the assessment at least every 5 years. The assessment should provide a clear understanding of the principal structural domains, the dominant joint sets and structures, and their potential impact upon the underground mine design in terms of both present and future. The assessment should also consider rock mass conditions, rock mechanics, rock strength data, and identify highly stressed rock subject to rock bursts.

2.2.4.6 Based on the geological assessment, develop a mine management plan that defines, as appropriate to the type of mine, permissible stope dimensions, room heights, span widths, pillar sizes, road dimensions and gradients, drilling, blasting and loading practices, roof and wall scaling procedures, and ground control management plan.

2.2.4.6.1 When practical, do not conduct retreat mining in soft rock room and pillar supported mines. When retreat mining is practiced, conduct a geotechnical assessment to determine the minimum permissible amount of material that must remain.

2.2.4.6.2 Conduct face and roof inspections for negative conditions described in the mine management plan at an established frequency. Develop inspection procedures and train inspectors on the procedures. Document inspection findings and provide a protocol for prioritizing findings and promptly communicating high priority findings

2.2.4.6.3 Implement communication protocols and/or a training program to ensure the geological assessment and mine management plan are both understood and govern operating activities, and updates are communicated amongst mine management, mine engineers, and geotechnical engineers.

2.2.4.7 Based on the mine management plan, develop a ground control management plan (GCMP) and update it at least every 2 years. The GCMP should address all geotechnical issues that might exist within the underground mine and apply sound geotechnical engineering principles to control these hazards over the life of the mine. The GCMP should cover all support system installations whether using timber, steel arches, mesh and concrete, or roof bolts and include application requirements, installation procedures, and maintenance and inspection activities. Update the GCMP based on audit findings, operating conditions (experience), or when changes are made in the mine management plan. Where access to an underground mine is via an open pit, ensure the stability of the surface mine is assessed and managed per section 2.3.3.4.

2.2.4.7.1 Use roof support systems based on sound geotechnical engineering principles. This should include clear design guidelines for support spacing and installation procedures.

2.2.4.7.2 Develop procedures and train all underground mine personnel in the hazards present, identification of geotechnical and geological deficiencies, and the reporting procedures.

2.2.4.8 Conduct a hydrogeological inundation assessment of the underground mine from bodies of water on the surface, stormwater, and groundwater sources during initial development. Review and update the assessment at least every 5 years to ensure exposures are well understood and managed. The study should address the potential of hidden water bodies, brine anomalies and underground aquifers and procedures to prevent accidental penetration of a hidden water body.

2.2.4.9 Develop an inundation emergency response plan with procedures to combat the exposing water sources. Refer to Data Sheet 1-40, *Flood* for guidance on developing and maintaining the plan.

2.2.4.10 When exploring or production drilling in geotechnical formations known to have, or suspected of having, water or brine anomalies or underground lakes, include precautions within standard operating procedures to prevent accidentally “striking” the hidden water body in a zone outside of the main ore body. For example, use small-bore drilling techniques to detect hidden bodies of water or seismic mapping techniques.

2.2.4.11 When present, implement an emergency response procedure for a deep-seated HSC ore or coal fire per section 2.1.5.5, which may include ventilation control, specialized firefighting measures or techniques, and emergency passageway sealing.

2.2.4.12 When present, implement emergency response procedures to high or rising flammable or toxic gas concentrations per section 2.1.5.5, which may include ventilation controls or emergency sealing passageways techniques.

2.3 Surface Mining

2.3.1 Location Construction

2.3.1.1 Locate heavy duty mobile equipment (HDME) service and repair shops in a separate buildings detached from other occupancies such as offices or warehousing. When not feasible, separate the HDME shop from other occupancies using a 1 hr. fire-rated wall.

2.3.1.2 Provide ignitable liquid emergency drainage for each vehicle bay in a HDME service and repair shop. Slope the service bay floor towards drains that discharge through a flame trap to a safe location (e.g., outdoor and remote). Design the drainage system in accordance with Data Sheet 7-83, *Drainage and Containment Systems for Ignitable Liquids*; however, less floor slope is acceptable given the nature of the occupancy and rolling equipment hazards often present. Preferably, coordinate trench drains with fire protection system operating areas if floor slope is not possible (e.g., a trench drain separating bays which may correspond to a single foam-water system zone), or position trench drains under vehicles where ignitable liquid releases are likely with floors pitched slightly towards the drain preventing a burning pool fire from exposing the tires.

2.3.2 Protection

2.3.2.1 Provide automatic fire protection within HDME service and repair shops per section 2.3.2.1.1 or 2.3.2.1.2 based on ceiling height.

2.3.2.1.1 For shops with ceiling heights of 45 ft (13.5 m) or less, provide ceiling-level automatic sprinklers designed and installed in accordance with Data Sheets 3-26, *Fire Protection for Nonstorage Occupancies* and 2-0, *Installation Guidelines for Automatic Sprinklers as Hazard Category No. 3*.

2.3.2.1.2 For shops with ceiling heights greater than 45 ft (13.5 m), provide a combination of ceiling-level automatic sprinkler protection along with low-level compressed-air foam (CAF) protection. Design and install protection as follows.

A. Design and install ceiling-level sprinkler protection in accordance with Data Sheets 3-26, *Fire Protection for Nonstorage Occupancies* and 2-0, *Installation Guidelines for Automatic Sprinklers* as a non-storage, Hazard Category No. 3 occupancy with ceiling height less than 30 ft (9 m).

B. Design low-level compressed-air foam (CAF) system to discharge through automatic oscillating monitors in accordance with the manufacturer's guidelines, the FM Approval listing, and Data Sheet 7-32, *Ignitable Liquid Operations*.

1. Position at least two monitors in opposing corners of each service bay providing coverage along each side of the bay. Elevate the monitors to limit the potential for equipment, parts, or tools from obstructing monitor discharge from reaching combustible components of the mobile equipment (e.g., a haul truck) from above the cab down to underneath the truck. If a single monitor is designed to provide coverage for multiple service bays, increase the operating area to account for this larger discharge area.

2. Hydraulically design low-level CAF for discharge in three service bays. Adjust horizontal monitor travel within each service bay for at least 25% overlapping coverage into any adjacent service bay(s).

3. Actuate the CAF system using fire detection dedicated for each service bay or zone. Design and install fire detection in accordance with Data Sheet 5-48, *Automatic Fire Detection*, and manufacturer's guidelines.

4. Provide a manual actuation of each service bay or zone.

C. Size the water supply for a balance of the ceiling-level sprinklers and low-level CAF plus a 250 gpm hose stream allowance for at least 60 minutes. If common water supply piping is used for sprinklers, CAF, and hose valves, incorporate at least a 100 gpm of the hose stream allowance within the shop. Size the foam supply for at least a 20 minute discharge.

2.3.2.2 Provide steel columns subject to direct flame impingement during an ignitable liquid release with protection in accordance with Data Sheet 7-32

As an alternative to column protection, position steel columns outside areas exposed to a pool fire or pressurized spray fire. Ignitable liquid spill containment and/or emergency drainage controls may be employed to steer an ignitable liquid pools or flow away from building and crane-rail columns.

2.3.2.3 Provide minimum 1.5 in. (38 mm) diameter hose valves spaced sufficiently along the perimeter of the building to allow a manual firefighting attack through open overhead doors from both sides of the building. Design and install hose stations in accordance with Data Sheet 4-4N, *Standpipe and Hose Systems*. In unheated areas, arrange standpipes on manual or dry-pipe systems.

2.3.2.4 Protect ignitable liquid operations and storage within the shop in accordance with the appropriate data sheet such as: 7-29, *Ignitable Liquid Storage in Portable Containers*; 7-32, *Ignitable Liquid Operations*; and/or 7-88, *Ignitable Liquid Storage Tanks*. Common ignitable liquids within shops include but are not limited to diesel fuel, lubricating oil, antifreeze, and hydraulic oil. Ignitable liquids may be stored in portable containers (, or gravity fed from elevated tanks or pumped from an outdoor storage tanks.

A. If ignitable liquid is stored in portable containers, provide ignitable liquid safeguards for portable contains in accordance with Data Sheet, 7-29. Preferably, locate ignitable liquid storage in portable containers outdoors, remote from the shop and any production critical buildings and equipment.

B. If bulk ignitable liquid is transferred and dispensed, provide ignitable liquid safeguards for these systems and the surrounding areas in accordance with Data Sheet 7-32, *Ignitable Liquid Operations* and 7-88, *Ignitable Liquid Storage Tanks*. Key protection aspects from these standards include limiting quantity of fuel within the building, automatically depressurizing and isolating transfer systems during a fire or when not in use, and constructing liquid-containing equipment and piping of materials resistant to mechanical impact or thermal damage (e.g., steel with welded connections).

2.3.3 Operations and Maintenance

2.3.3.1 Implement a haul truck inspection program to prevent haul trucks suspected of imminent ignition (hot tires) or fuel release from entering the HDME service and repair shop.

2.3.3.2 Implement an emergency response plan for a fire in a HDME service and repair shop in accordance with section 2.1.5.5. Consider the following actions when responding to the various fire scenarios.

- Verifying actuation and assessing effectiveness of automatic protection systems.
- Maintaining fire protection systems operational (e.g., managing water or foam supplies).
- Isolating ignitable liquid or flammable gas supplies.
- Evaluating the fuel burning and potential secondary fuel packages.
- Assessing tire explosion concerns.
- Removing uninvolved mobile equipment or other fuel packages.
- Launching a manual firefighting attack, and apparatus and/or equipment to be used.

2.3.3.3 Conduct a geological assessment of both the deposit and country rock near the mine to evaluate the impacts these may have on wall slope control and stability. Complete the assessment during initial development, and review and update the assessment at least every 5 years. The assessment should provide a clear understanding of the principal structural domains, the dominant joint sets and structures, and their potential impact upon the surface mine design in terms of both present and future.

2.3.3.4 Based on the geological assessment, develop a mine management plan that defines, as appropriate for the mine type, permissible slope angles, bench spacing and sizing, road dimensions and gradients, drilling, pre-split blasting procedures and excavation practices.

2.3.3.5 Based on the mine management plan, develop a ground control management plan (GCMP) to address all geotechnical issues including most notably slope wall failure potentials that might exist and apply sound geotechnical engineering practice to control these issues over the life of the mine to prevent unexpected slippage. The plan should cover operating procedures, updating geological and geotechnical assessments, auditing, training, and documentation. Update the GCMP based on audit findings, operating conditions (experience), or when changes are made in the mine management plan.

2.3.3.6.1 Install a slope monitoring system when required in the mine management plan.

Slope monitoring may vary from low technology inclinometers and crack gauges to high sophisticated ground positioning radar systems. The type of equipment is based on the likelihood and degree of exposure as determined by a geotechnical risk assessment.

2.3.3.6.2 Develop a written procedure and frequency for inspecting slope wall conditions including required documentation.

2.3.3.6.3 Develop procedures and train all mine personnel in the identification of geotechnical, hydrogeological and structural geological deficiencies or pending slope wall failure indicators and the associated reporting protocol.

2.3.3.6.4 Do not locate important production equipment in areas known to be subject to slope failure or stressed rock bursts. In areas with increasing risk of slope wall failure, protect or relocate critical fixed utility or production equipment.

2.3.3.6.5 Implement an emergency response plan to move critical mobile equipment to a safe area when an impending slope wall failure potential is identified in accordance with section 2.1.5.5.

2.4 Ore and Mineral Processing

2.4.1 Location and Construction

2.4.1.1. Cover high sulfide content (HSC) ores stored outdoors to prevent stormwater contact, which may promote oxidation and spontaneous combustion.

2.4.1.2 Rotate the pile based on coal piles outlined in Data Sheet 8-10, *Coal and Charcoal Storage*.

2.4.1.3 Locate reactive reagent storage in remote, detached structures such as oxidizers or reagents that decompose producing flammable gas/vapor. Provide sufficient separation distance to limit exposure of critical buildings, production equipment, or utility or support systems to a fire or energic release.

2.4.2 Protection

2.4.2.1 Select reagents that are not an ignitable liquid. When use of such a reagent is not feasible, select the reagent with the highest flash point. Preferably, select a reagent considered a high flash point ignitable liquid (greater than 200°F or 93°C).

2.4.2.2 When reagents are used that are an ignitable liquid, provide fire protection for storage and transfer systems in accordance with Data Sheet 7-88, *Ignitable Liquid Storage Tanks* and Data Sheet 7-32, *Ignitable Liquid Operations*.

In addition to automatic fire protection systems, provide other ignitable liquid safeguards in accordance with the applicable standard. Other relevant ignitable liquid safeguards may include: location and construction features such as detached, remote location, or fire-resistive building construction; liquid spill containment and/or emergency drainage; automatic fire interlocks to depressurize and isolate ignitable liquid supplies; and appropriate construction of ignitable liquid-containing piping and equipment such as steel construction. Preferably locate bulk storage of ignitable liquid reagents outdoors and away from critical production buildings or equipment.

2.4.2.3 Provide automatic fire protection for ignitable liquid reagents in portable containers in accordance with Data Sheet 7-29, *Ignitable Liquids in Portable Containers*.

In addition to automatic fire protection systems, provide other ignitable liquid safeguards in accordance with Data Sheet 7-29. Other relevant ignitable liquid safeguards may include: location and construction features such as detached, remote location, or fire-resistive building construction; or liquid spill containment and/or emergency drainage. Preferably locate portable container storage of ignitable liquid reagents outdoors and away from critical production buildings or equipment.

2.4.2.4 Provide ceiling-level automatic sprinklers throughout concentrators when either combustible construction is present, or the occupancy is combustible. A combustible occupancy contains sufficient fuel loading to support horizontal fire spread across a given building area in the absence of sprinkler protection, or a concentration of fuel loading that could cause significant damage to the building structure and/or production-critical equipment. For design and installation guidance, refer to Data Sheet 3-26, *Fire Protection for Nonstorage Occupancies* and 2-0, *Installation Guidelines for Automatic Sprinklers*. Given the predominantly plastic combustible loading, a concentrator is likely a Hazard Category No. 3 occupancy.

2.4.2.5 Provide automatic fire protection over combustible screen decks or noncombustible screen decks exposed by an internal equipment fire involving rubber/combustible-linings. Two protection options may include: ceiling-level automatic sprinklers; and low-level automatic deluge protection. Design and install either protection option in accordance with the following guidelines.

A. Ceiling-Level Automatic Sprinklers

1. Design and install ceiling-level automatic sprinkler in accordance with Data Sheet 3-26 and Data Sheet 2-0 as a Hazard Category No. 3 occupancy. Determine the ceiling height based on the lowest combustible surface of the screen up to the underside of the ceiling.

B. Low-Level Deluge System

1. Design low-level deluge system to deliver 0.3 gpm/ft^2 (12 mm/min) over the surface area of the screen.

2. Size the water supply to include a 500 gpm hose stream allowance and size the source for a minimum duration of 60 minutes.

3. Install deluge system in accordance with Data Sheet 2-0, *Installation Guidelines for Automatic Sprinklers* for non-storage sprinklers and 4-1N, *Fixed Water Spray Systems for Fire Protection*.

4. Incorporate automatic actuation of the deluge system in accordance with Data Sheet 5-48, *Automatic Fire Detection* and the deluge valve FM Approval listing. Automatic actuation options may include optical fire detection located at ceiling level, or low-level spot heat or linear heat detection.

5. Provide a means to manually actuate the deluge system from a control room or locally from an area expected to remain accessible under anticipated fire conditions.

2.4.2.6 Provide automatic fire protection for combustible filter presses (i.e., presses with plastic platens). Depending on the press size, select the appropriate protection option below.

A. For smaller filter presses, design and install ceiling-level automatic sprinkler protection in accordance with Data Sheet 3-26, *Fire Protection for Nonstorage Occupancies* and 2-0, *Installation Guidelines for Automatic Sprinklers as a Hazard Category No. 3* occupancy. Extend protection the greater of 20 ft or two sprinklers beyond the combustible footprint. Where open grating is installed above the press (no solid flooring), either install solid flooring or provide automatic deluge protection similar to section 2.4.2.5.B.

B. For larger filter presses, design and install ceiling-level automatic sprinkler protection in accordance with Data Sheet 8-9, *Storage of Class 1, 2, 3, 4 and Plastic Commodities* and 2-0, *Installation Guidelines for Automatic Sprinklers*. Protect filter presses as solid-pile storage of uncartoned unexpanded plastic. Ensure any shielded areas beneath the press are provided with coverage, and extend protection the greater of 20 ft or two sprinklers beyond the combustible footprint.

2.4.2.7 Protect hydraulic systems associated with filter presses in accordance with Data Sheet 7-98, *Hydraulic Fluid*.

2.4.2.8 Provide automatic fire protection for rubber-lined, noncombustible hydrocyclone clusters or combustible hydrocyclone clusters as follows.

2.4.2.8.1 Provide automatic fire protection around the exterior of rubber-lined or combustible hydrocyclone clusters. Design and install automatic fire protection in accordance with section 2.4.2.5. Determine the ceiling height based on the discharge flange of the individual hydrocyclones up to the underside of the ceiling.

2.4.2.8.2 Provide automatic fire protection within rubber-lined or combustible hydrocyclones when the circuit is shutdown. There are several means to prevent a fire starting low in the circuit from spreading vertically through the circuit. Consider the following options when providing protection

A. Configure the slurry/mud pump to start and circulate process water upon fire detection, or install water connections high in the circuit and shutoff valves low in the circuit to flood process piping and equipment upon fire detection. Be aware of combustible connections that may burn or melt through early in the fire compromising water retention.

B. Install heat detectors or a temperature sensor atop the hydrocyclone cluster to alarm in the control room and automatically actuate fire protection.

C. Provide a means to manually actuate fire protection in a remote location that will remain accessible under the anticipated fire conditions.

2.4.2.9 Provide automatic sprinkler protection for gravity spiral separator systems. Design and install automatic sprinkler protection in accordance with the following guidelines.

2.4.2.9.1 Install a solid floor beneath the spirals to separate them from the launders, plastic or rubber-lined collection piping, and tanks below.

2.4.2.9.2 Provide automatic sprinkler protection beneath the solid floor containing launders, collection piping, and tanks in accordance with Data Sheet 3-26, *Fire Protection for Nonstorage Occupancies* and 2-0, *Installation Guidelines For Automatic Sprinklers*. Provide low-level protection beneath elevated tanks when shielded from ceiling level sprinklers above. Given the predominantly plastic combustible loading, this area is likely a Hazard Category No. 3 occupancy.

2.4.2.9.3 Provide automatic sprinkler protection over spiral separators. Select the appropriate protection from the list below based on design height, and presence of a roof above the spiral structure, and if so, roof slope.

A. When the spirals are covered by a roof with slope less than or equal to 10 degrees, design and install ceiling-level automatic sprinkler protection in accordance with: Data Sheet 8-9; Data Sheet 2-0 as storage sprinklers; and the following guidelines.

1. Protect the spiral arrays as open-frame rack storage arrangement containing uncartoned unexpanded plastic.

2. Define the design height for this arrangement as the distance from the solid-floor beneath the spirals to the underside of the roof as shown in Figure 1.

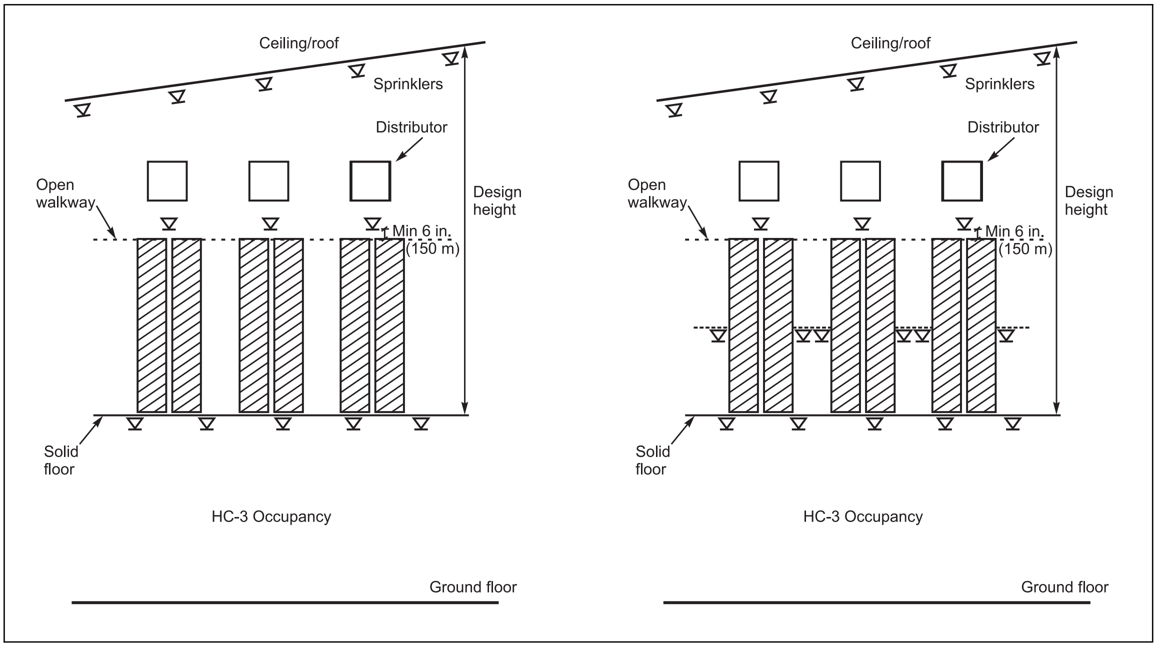

Fig. 1. Ceiling-level spiral protection (elevation)

3. Install automatic sprinklers beneath spiral distributers and piping. Use the same sprinklers and piping design used for ceiling-level protection. Position sprinklers centered within the spiral bank longitudinal flue space at every-other transverse flue space as shown in Figure 2. If present, offset these sprinklers from intermediate sprinklers installed around the spiral bank (i.e., the two sets of sprinklers are out of sight from each other). Provide at least 6 in. (150 mm) of vertical clearance between sprinkler deflector and top of spiral.

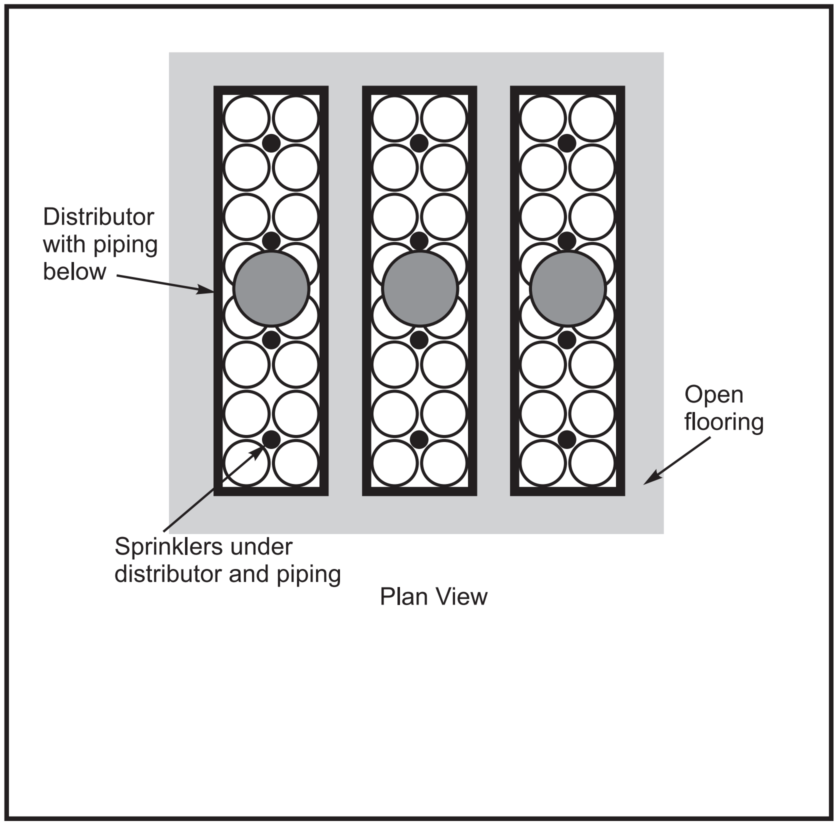

Fig. 2. Sprinklers positioned under distributor and piping

4. If multiple open-grated walkways (>70% open) or a solid walkway is installed around the spirals, install intermediate-level sprinklers under every-other open-grated walkway or every solid walkway. Use the same sprinklers and piping design used for ceiling-level protection. Position intermediate-level sprinklers within 6 in. (150 mm) horizontally of every-other transverse flue space around the spiral bank. Stagger sprinklers in every-other transverse flue space when encircling the spiral array as shown in Figure 3.

A single level of open-grating is permissible with ceiling-level sprinklers; however, a second-level of open-grating warrants intermediate-level sprinklers around the spiral arrays.

5. Hydraulically design spiral protection for ceiling-level sprinkler operation for a duration of 60 minutes including a 250 gpm (950 L/min) hose stream allowance. When designing intermediate-level sprinklers under walkways, use ceiling sprinklers and pipe sizing but do not include any intermediate sprinklers in the operating area design. If hose valves and sprinklers share supply mains, incorporate at least 100 gpm 100 gpm (380 L/min) of that hose stream allowance hydraulically balanced at the point of connection.

B. When the spiral design height exceeds the available ceiling only protection options in Data Sheet 8-9, the roof slope exceeds the maximum allowed 10^{o}, or the spiral banks are an open process structure without a roof, design automatic sprinklers beneath the top level of walkways and covers (typically atop the spiral banks) in accordance with Data Sheet 8-9, *Storage of Class 1, 2, 3, 4 and Plastic Commodities*, and the following guidelines.

1. Install solid covers atop of the individual spiral banks to collect heat and aid in sprinkler actuation.

2. Protect the spiral arrays as open-frame rack storage arrangement containing uncartoned unexpanded plastic.

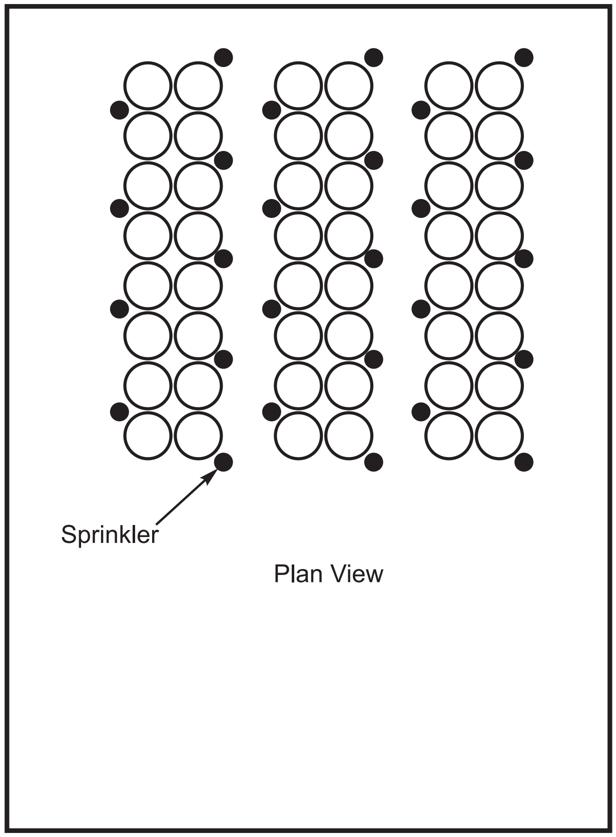

Fig. 3. Intermediate-level protection positioned beneath walkways (plan view)

3. Define the design height for this arrangement as the distance from the solid floor beneath the spirals to the underside of the flooring atop the spirals as shown in Figure 4.

4. Install automatic sprinklers above spiral plastic distributers and piping on a minimum 10 ft (3.3 m) spacing. Use K11.2 (K160) sprinklers rated for quick-response and an appropriate temperature rating for the environment (i.e., under a hot distributor cover).

5. Install automatic sprinklers beneath spiral distributers and piping. Use the same sprinklers and piping design used beneath the walkway. Position sprinklers centered within the spiral bank longitudinal flue space at every other transverse flue space as shown in Figure 5. Preferably offset sprinklers position within the longitudinal flue space to be out of sight of intermediate sprinklers installed around the spiral bank. Provide at least 6 in. (150 mm) of vertical clearance between sprinkler deflector and top of spiral.

6. Install sprinklers around spiral banks underneath the first level of walkways along with every-other open-grated walkway or every level of solid walkway below. Use the same sprinklers and piping design used beneath the walkway. Position intermediate-level sprinklers within 6 in. (150 mm) horizontally of every-other transverse flue space around the spiral bank. Stagger sprinklers in every-other transverse flue space when encircling the spiral array as shown in Figure 6.

7. Hydraulically design spiral protection for a 60 minute demand from the following: (a) all sprinklers located in the fire area positioned underneath the cover over the distributer piping at a minimum end-head pressure of 7 psi (0.5 bar); (b) the operating area (i.e., sprinkler count) at minimum end-head pressure selected from Data Sheet 8-9 based on design height and sprinkler type with sprinklers operating both under the distributer and the top walkway level encircling the spiral array; and (c) a hose stream allowance of 250 gpm (950 L/min). When designing intermediate-level sprinklers under lower walkways, use the sprinklers and pipe sizing from the upper level design but do not include any intermediate sprinklers in the operating area design. If hose valves and sprinklers share supply mains,

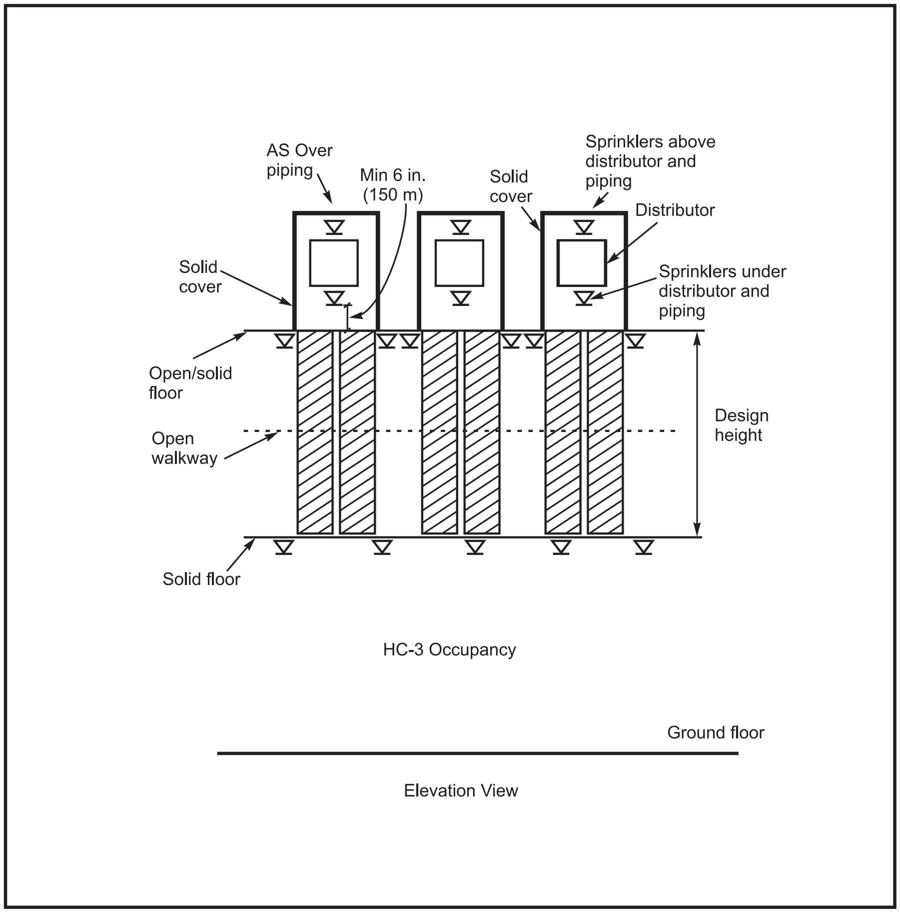

Fig. 4. Process structure spiral protection (elevation view)

incorporate at least 100 gpm (380 L/min) of that hose stream allowance hydraulically balanced at the point of connection.

2.4.2.10 Provide firefighting standpipes with hose connections at all operating levels of mineral process structures and buildings in accordance with Data Sheet 4-4N, *Standpipe and Hose Systems*. In unheated areas, arrange standpipe systems as manual or automatic dry-pipe.

2.4.3 Equipment and Processes

2.4.3.1 Use noncombustible equipment, equipment linings, and parts within grinding, separation, and floatation circuits. Noncombustible lining materials may include alumina, ceramic (e.g., nitride with silicon carbide), or steel alloy. When use of noncombustible linings is not feasible, minimize the use of combustibles and/or limit continuity between rubber-lined circuits or segments of a circuit.

2.4.3.2 Provide over-torque protection for rakes in thickeners/clarifiers found in concentrators, tailings disposal operations, and other product or waste separation processes. Protection should alarm at a lower level followed by initiate automatic shutdown of the rake drive at a higher level.

2.4.4 Operations and Maintenance

2.4.4.1 Institute a hot work management program to minimize the exposure posed by hot work in the vicinity of or on plastic/rubber-lined equipment (RLE), and/or internal plastic parts. Refer to section 2.1.5.1 for additional guidance.

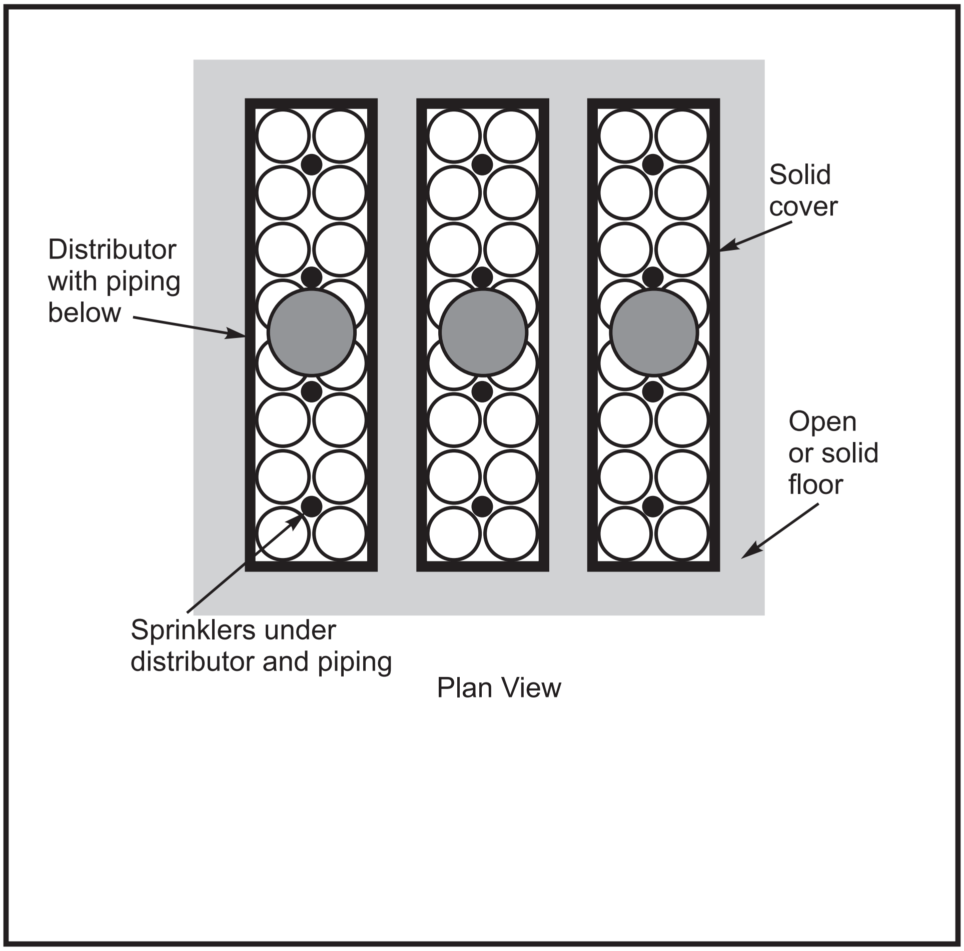

Fig. 5. Spiral protection under distributor and piping (plan)

Concentrating operations often have a large amount of RLE whether piping or equipment along with external plastic and rubber coatings (i.e., screen decks). If not labeled, RLE is often not known to be present by maintenance personnel. Hot work is often conducted in these areas (e.g., torch cutting to remove rusted bolts). The mining industry has had significant fires caused by the combination of poorly managed hot work ignition sources and lack of awareness of the hazards posed by hidden and unprotected (unsprinklered) RLE or plastic equipment hazards.

2.4.4.2 Institute a program to identify, document, and label/sign plastic/ RLE, and/or other equipment containing external or hidden internal combustible parts. The program should consist of the following components: documentation of equipment locations; signing or labeling requirements; auditing for changes in equipment including new installations; inspecting signage/labeling for deteriorated appearance including fading, obstruction by new coverings such as insulation, residues, or dust accumulations (i.e., no longer visible); and document retention. Examples labeled/signed RLE are provided below in Figure 7, Figure 8, and Figure 9.

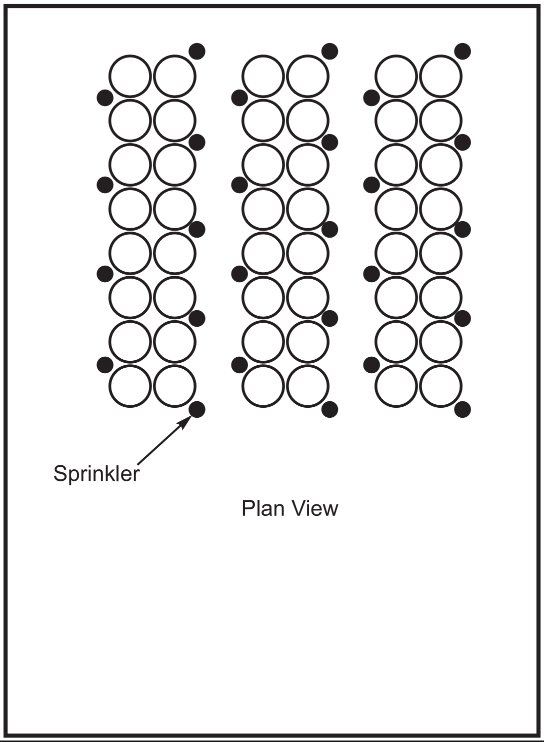

Fig. 6. Spiral protection beneath solid flooring

Fig. 7. Label warning of rubber-lined tank

Fig. 8. Label warning of rubber-lined equipment including piping

2.4.4.3 Implement an emergency response plan for a rubber-lined equipment or plastic equipment fire in accordance with section 2.1.5.5. Consider the following actions when responding to the various fire scenarios:

• Verifying actuation and assessing effectiveness of automatic protection systems.

• Maintaining fire protection systems operational (e.g., managing water or foam supplies).

• Isolating ignitable liquid or flammable gas supplies.

• Activating wash/slurry pumps to circulate water through equipment with combustible internals.

• Evaluating the fuel burning and potential secondary fuel packages.

• Launching a manual firefighting attack, and apparatus and/or equipment to be used.

2.4.4.4 Implement an asset integrity program for production critical grinding mill and their drive train based on section 2.1.5.6 and the following guidelines. Within the asset integrity program, develop an ITM program with the assistance of the OEM, relevant data sheets (e.g., 13-7, *Gears*, for ring gears and 5-17, *Motors and Adjustable Speed Drives*, for gearless mill drives-GMD), and/or other expertise to monitor for and manage the various damage mechanisms exposing the mill shell, liner, feed-in and discharge heads, trunnions, bearings, pedestal/foundation, and drive train (GMD or ring gear). Damage mechanisms may include: slurry racing; wear/erosion due to inadequate clamping force on bolted attachments or media impact; fatigue cracking due to operating history or misalignment; stress cracking due to frozen load or misalignment; and arcing due to insulation breakdown or misalignment. At a minimum, include the following activities in the ITM plan.

A. Routine operator walkdowns during mill operation

B. Bearing lubrication analysis

C. Vibration monitoring

Fig. 9. Signage indicating a rubber-lined vessel below

D. Alignment verification

E. Nondestructive examination (NDE) including thickness monitoring and/or surveying for surface or volumetric indications on the trunnions, heads, and shell.

Update the asset integrity and associated ITM program based on changes in operating conditions or maintenance results. Increase the frequency or scope of the ITM when results reveal unexpected or increasing trends in wastage or crack indications, vibration/noise, or lubrication contamination.

2.4.4.4.1 Implement a program to monitor for slurry-racing in wet grinding mills. Evaluate shell, heads, trunnions, and bearings in accordance with OEM guidance.

2.4.5 For ring gear equipment contingency planning guidance, see 2.1.6.2.

2.5 Metallurgical Processing

2.5.1 Pressure Leaching

2.5.1.1 Locate control rooms, and critical utility and support system equipment in areas where the exposure to a pressure vessel rupture (explosion) is minimized.

2.5.1.2 Locate power distribution equipment such as transformers, switchgear, and motor control centers in areas not exposed to corrosive process materials. When switchgear must be installed in or adjacent to areas containing corrosive substances, design and construct buildings and/or enclosures to prevent the ingress of corrosive substances.

2.5.1.3 Locate power distribution equipment such as transformers, switchgear, and motor control centers in areas not exposed to dust particulates (i.e., ore, alumina, or other dusts). Alternatively, provide ventilation systems to maintain positive pressure in rooms or enclosures to prevent particulate from entering.

2.5.1.4 Apply guidance provided in Data Sheet 12-3, *Continuous Digesters and Related Process Vessels* and 12-6 *Batch Digesters and Related Process Vessels* to metallurgical autoclaves and alumina digesters.

2.5.1.5 Protect unfired pressure vessels against overpressure in accordance with Data Sheet 7-49, *Emergency Venting of Vessels*, and 12-43, *Pressure Relief Devices*. Design process relief systems for both superheated liquid and vapor (i.e., two phase flow) that may enter and accumulate in a vessel as a result of the worst possible case over pressure upset condition.

2.5.1.6 Ensure elongated horizontal autoclaves on concrete pedestal supports have been positioned and designed to slide or move lengthwise due to thermal expansion and contraction forces.

2.5.1.7 Design vessels to minimize the potential for unoxidized titanium (or other metal) to come into contact with an oxygen-enriched atmosphere.

2.5.1.8 Use tell-tale leak detection when liners such as explosion bonded titanium (or other metal) or acid brick are used to protect an outer carbon steel shell. Tell-tales may be electronic devices, thermography (to detect hot liquid entering the annular space), or small diameter tubes that penetrate the annular space and allow escaped liquid to collect in visual indicators.

2.5.1.9 At alumina refineries, design process equipment arranged in series allowing individual pieces of equipment to be bypassed and isolated without significantly affecting upstream or downstream operations. Install permanent piping and valving to facilitate bypassing and isolation. Isolation and bypassing may be applicable to the following process trains:

A. Continuous alumina digesters and associated flash tanks

B. Clarification and decantation tanks for the separation of red mud

C. Red mud washing tanks

D. Continuous decomposition tanks for the precipitation of alumina trihydrated crystals

2.5.1.10 Provide critical utility services and support systems with a high degree of reliability and availability. Identify critical services and support systems in the process safety program using an appropriate process hazard analysis (PHA). Examples of undesirable outcomes to consider in the PHA include: hazardous conditions such as overpressure; damage to long lead-time equipment such as titanium lined pressure parts; and extended production downtime while recovery efforts are taken (e.g., at alumina refineries, solidification in precipitators). When assessing reliability, not only consider equipment breakdown hazards, but also external hazards in the surrounding areas that may expose the identified critical equipment to fire, corrosive substances, and equipment or building collapse due to material accumulation. A high-degree of reliability may take the form of viable N+1 redundant equipment or N-1 operating capacity (i.e., hot, redundant capacity). The following guidance is specific to precipitator agitation reliability.

2.5.1.10.1 For precipitators at alumina refineries, provide N+1 for utilities and support systems to prevent solidification within equipment. Arrange N+1 reliability as follows along with a provision for emergency agitation.

A. When agitators are electrically-powered, provide N+1 reliability as follows.

   1. Arrange for agitators to be fed from two independent electrical substations (preferably on different electrical busses), or a combination of substation and reliable onsite power generation such as an internal combustion engine driven generator (i.e., diesel generator), steam turbine generator, or gas turbine generator.

   2. Route independent power feeders from both power supplies to each agitator.

   3. Physically separate N+1 electrical substations and feeders to prevent a single point of failure from compromising both supplies. When evaluating single point of failures, consider equipment breakdown scenarios such as transformer failure as well as external exposures such as fire (e.g., fire following transformer failure or cable fire) or mechanical impact.

   4. Monitor precipitators for loss of agitation. Sound an alarm upon loss of agitation (e.g., agitator shaft rotational speed).

5. Install air injection ports on precipitators to allow for emergency agitation via compressed air.

B. When agitation is fluid-driven (i.e., hydraulic or pneumatic), provide agitators with a N+1 reliability as follows.

1. Power agitators from two independent pneumatic or hydraulic supply stations.

2. Route independent fluid-power feeds from both stations to each agitator.

3. Physically separate N+1 fluid-power stations to prevent a single point of failure from compromising both supplies. When evaluating single point of failures, consider equipment breakdown scenarios such as transformer failure as well as external exposures such as fire (e.g., fire following transformer failure or cable fire) or mechanical impact.

4. Designed the electrical power supplies to each fluid-power supply station in accordance with sections 2.5.1.10.1.A.1 through 2.5.1.10.1.A.3. Alternatively, provide sufficient supply capacity driven by different motive force (e.g., internal combustion engine or turbine).

5. Monitor precipitators for loss of agitation. Sound an alarm upon loss of agitation (e.g., agitator shaft rotational speed).

6. Install air injection ports on precipitators to allow for emergency agitation via compressed air.

2.5.1.11 At alumina refineries, develop an emergency operating procedure for loss of precipitator agitation. Address the following aspects within the procedure.

A. Determine the duration before the onset of solidification upon loss of agitation. Consider various process conditions and equipment arrangements to identify the shortest duration.

B. Unless the affected precipitator can be scuttled (drained) to a disposal site such as a lagoon or pond before solidifying, provide a means of emergency agitation.

C. Inspect, test, and maintain (ITM) emergency response equipment (e.g., internal combustion engine-driven compressors) per OEM guidelines along with the relevant FM data sheets.

2.5.1.12 For pressure leaching utility and support equipment contingency planning guidance, see 2.1.6.3.

2.5.2 Heap Leaching

2.5.2.1 Design and install heap leach pads (piles or stacks) in accordance with the local jurisdiction, a certified geotechnical engineer, and when in a seismically active area, a certified specialist in earthquake dynamics.

2.5.2.2 Design heap leach pads to withstand the subsidence, earthquake and seismic, flood, and stormwater erosion hazards when the exposures are present.

2.5.2.3 Develop an asset integrity progam for heap leach pads in accordance with section 2.1.5.6 and the following guidelines.

A. Develop standard operating procedures to govern heap leaching activities including pad operations and alterations, and liner repairs or alterations. Include a provision for a leach pad specialist to be present when altering the pad, or altering or repairing the liner to prevent undetected liner damage.

B. Conduct inspection, testing, and maintenance (ITM) activities to monitor the health and stability of the pad. Activities should cover monitoring embankment faces for slope movement or slippage, and documenting instrumentation readings such as from piezometers, if installed. Document ITM records along with any corrective actions taken for management review and audits.

C. Conduct an independent heap leach pad audit annually by a third-party certified geotechnical specialist to evaluate the solution collection system, and pad stability and potential for failure from natural hazard exposures including but not limited to stormwater erosion and inundation, earthquake and seismic, and/or flood. Document the results of the audit along with any corrective actions completed to address audit findings.

D. Develop an emergency operating procedure to respond to a pad slope failure or a liner leak.

2.5.3 Mineral Solvent Extraction (SX)

The following loss prevention guidance applies only to mineral solvent extraction (SX) plants using ignitable liquid solvents such as organic kerosene and alcohols. Do not apply the following guidance at plants using solvents that are not an ignitable liquid such as water, or to agricultural (i.e., soy beans, palm oil) solvent extraction using hexane and similar low flash point solvents.

2.5.3.1 Conduct a facility siting study to determine appropriate separation distances between solvent extraction cells, solvent processing, solvent storage, adjacent mine operations, and other adjacent buildings. Refer to Data Sheet 7-14, *Fire Protection for Chemical Plants* and 7-88, *Ignitable Liquid Storage Tanks* for a first approximation for separation distances. Base separation distances on a formal, documented hazard analysis conducted as part of the facility's process safety program. The siting study should account for thermal radiation from pool fires, solvent drainage patterns, wind effects, and the emergency fire response plan.

2.5.3.2 Avoid below-grade spaces, pits or pipe trenches in or near areas containing ignitable solvent.

2.5.3.3 Locate all solvent extraction equipment and processes at the same elevation.

2.5.3.4 Provide ignitable liquid spill containment around mixer-settlers, transfer piping, and in solvent processing areas to contain the spilled solvent in the area of origin. Install curbs at least 6 in. (150 mm) tall and limit curbed areas to 5,000 sq. ft (460 m^2).

2.5.3.5 Provide ignitable liquid emergency drainage for all areas afforded with spill containment (i.e., solvent extraction cells and transfer piping, and in solvent processing areas). Direct spilled solvent to a remote catch basin or pond. Accomplish drainage via gravity (i.e., do not rely on pumps), and design drainage in accordance with Data Sheet 7-83, *Drainage and Containment Systems for Ignitable Liquid*.

2.5.3.6 Install an automatic scuttling (rapid drain) system for equipment containing large volumes of solvent. Direct scuttled solvent to a remote catch basin or pond. Accomplish scuttling via gravity (i.e., do not rely on pumps). An example diagram of a scuttling system is shown in Figure 10.

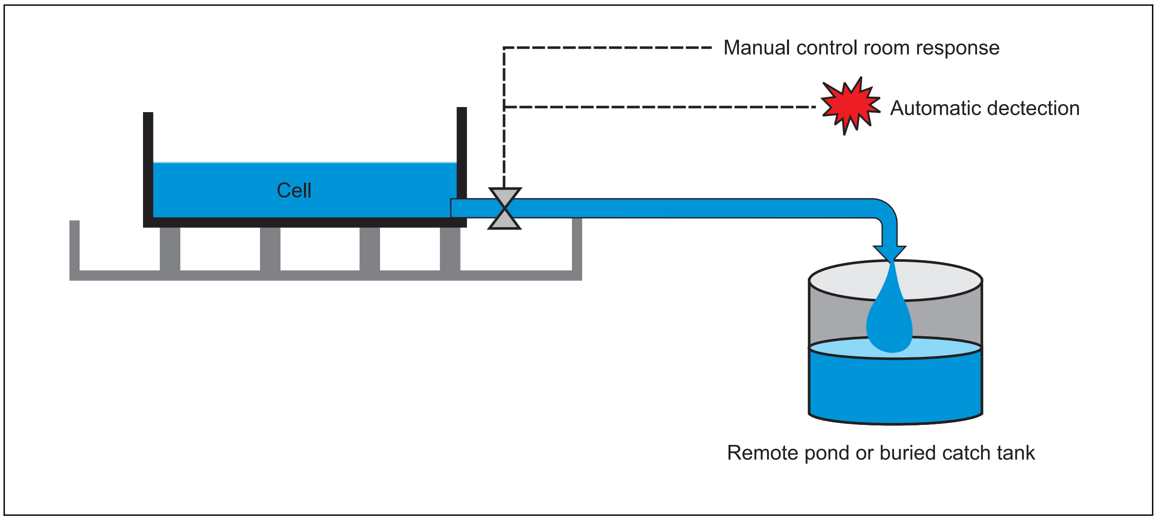

Fig. 10. Diagram illustrating a scuttling (rapid drain) system for mixer-settler

2.5.3.7 Provide fire protection for solvent extraction (SX) mixer-settler complexes as follows.

A. Larger (outdoor) mixer-settler complexes (see section 2.5.3.7.1)

B. Smaller (outdoor or indoor) mixer-settler complexes (see section 2.5.3.7.2)

C. Pulsed columns (see section 2.5.3.7.3)

D. Manual fire protection (see section 2.5.3.7.4)

2.5.3.7.1 For larger mixer-settler complexes, provide the following automatic fire protection.

2.5.3.7.1.1 Provide automatic low-expansion foam, foam-water sprinkler, or compressed-air foam (CAF) protection in the following mixer-settlers, solvent processing, and solvent storage areas.

A. Mixer-settler buildings or cells protecting the solvent pool surface. If the mixer-settler roof is greater than 10 ft (3 m) above the solvent pool surface or the mixer-settler is uncovered, use foam distribution chambers at the perimeter. Ensure a foam blanket will promptly cover the entire solvent surface including around obstructions such as weirs and fences.

B. Along launders and open solvent weirs outside of mixer-settlers.

C. Inside below-grade pipe trenches that may contain solvent if emergency drainage is inadequate.

D. Inside all storage tanks containing solvent or other ignitable liquid.

E. Above solvent pumps.

F. Inside spill containment areas around solvent storage tanks located in proximity to solvent process areas.

2.5.3.7.1.1.1 Design and install automatic low expansion foam systems in accordance with the respective Data Sheets depending on the application which may include: 4-7N, *Low Expansion Foam Systems*; and/or 7-88, *Ignitable Liquid Storage Tanks*. However, design protection to deliver the density specified in the Approval Guide listing for the foam concentrate over the cell surface area, containment area, or surface area of the equipment. Example locations of foam protection nozzles are shown in Figures 11 to 14.

2.5.3.7.1.1.2 Design and install automatic foam-water sprinkler systems in accordance with the respective Data Sheets depending on the application, which may include: 4-12, *Foam-Water Sprinkler Systems*; 7-88, *Ignitable Liquid Storage Tanks*; and/or 7-14, *Fire Protection for Chemical Plants*. However, design protection to deliver the density specified in the *Approval Guide* listing for the foam concentrate over the cell surface area, containment area, or surface area of the equipment. Example locations of foam nozzles are shown in, Figures 11 to 14.

2.5.3.7.1.1.3 Design and install automatic compressed-air foam (CAF) systems in accordance with the respective Data Sheets depending on the application, which may include: 4-12, *Foam-Water Sprinkler Systems*; 7-88, *Ignitable Liquid Storage Tanks*; and 7-14, *Fire Protection for Chemical Plants*. However, design protection to deliver the density specified in *Approval Guide* listing for the foam concentrate over the cell surface area, containment area, or surface area of the equipment. Example locations of foam nozzles are shown in, Figures 11 to 14.

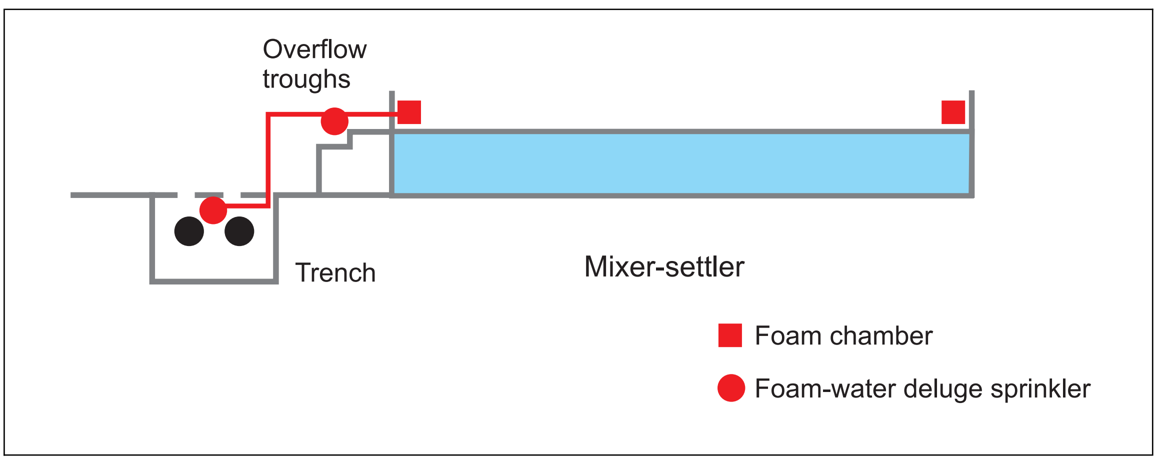

Fig. 11. Protection for large mixer-settler without a roof (elevation)

2.5.3.7.1.1.4 Base the water demand on the largest number of automatic fire protection systems expected to operate plus manual fire protection demands and duration, which should all be as specified in the process safety program discussed in section 2.1.5.2. However at a minimum, size the foam concentrate supply for a foam discharge within the expected fire area for the greatest of the following scenarios: 10 minutes with adequate emergency drainage; 20 minutes in areas with limited or no emergency drainage; and where the potential exists for a three-dimensional spill fire, the ignitable liquid release duration or 20 minutes.

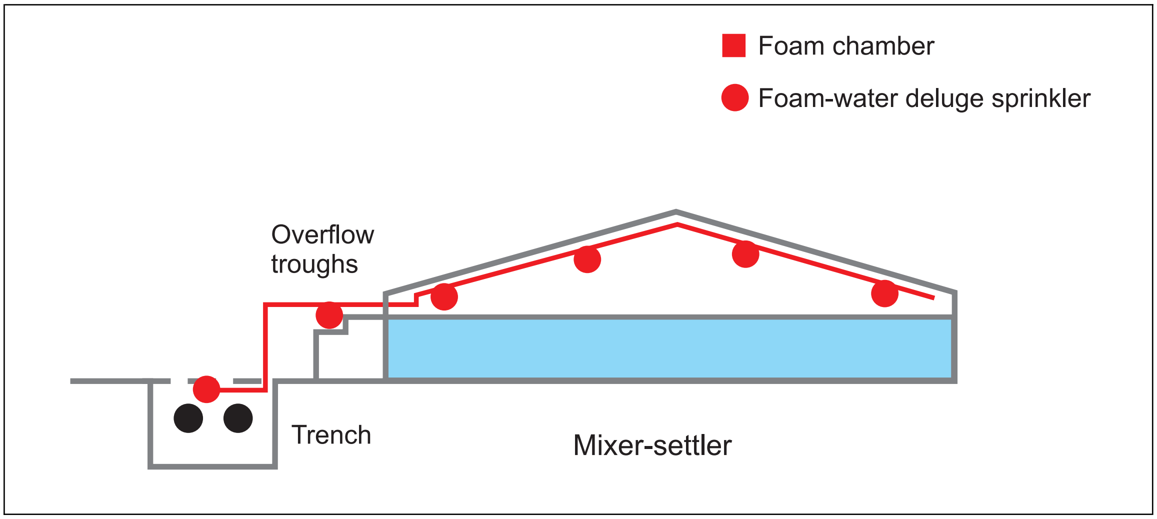

Fig. 12. Protection for large mixer-settler with low roof (elevation)

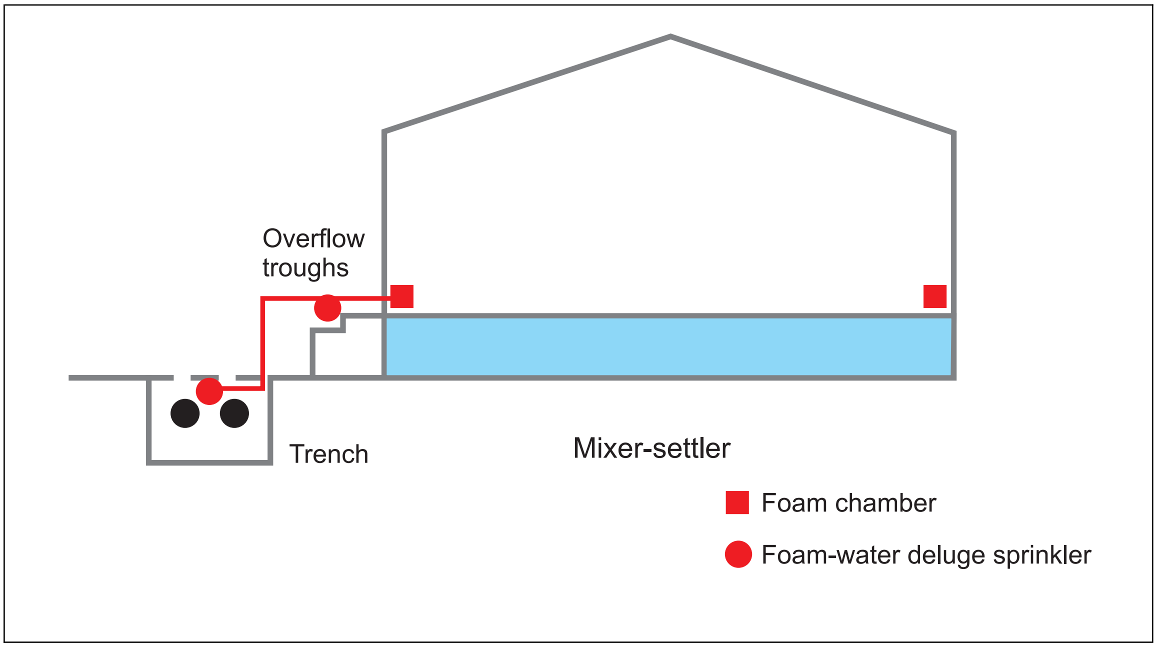

Fig. 13. Protection for large mixer-settler with high roof (elevation)

2.5.3.7.1.2 Provide automatic fixed water spray or sprinkler deluge protection in the following mixer-settlers, solvent processing, and solvent storage areas.

A. Over below-grade pipe trenches that may contain solvent but are provided with sufficient emergency drainage.

B. When an equipment breakdown with fire following presents an ignition source for the solvent (e.g., oil filled transformer).

2.5.3.7.1.2.1 Design and install automatic fixed water spray or sprinkler deluge protection in accordance with Data Sheet 7-14, *Fire Protection for Chemical Plants*. Example locations of deluge nozzles are shown in Figure 16.

2.5.3.7.1.2.2 Base the water demand on the largest number of automatic fire protection systems expected to operate plus manual fire protection demands and duration, which should all be as specified in the process safety program discussed in section 2.1.5.2. However at a minimum, size the water supply for a discharge

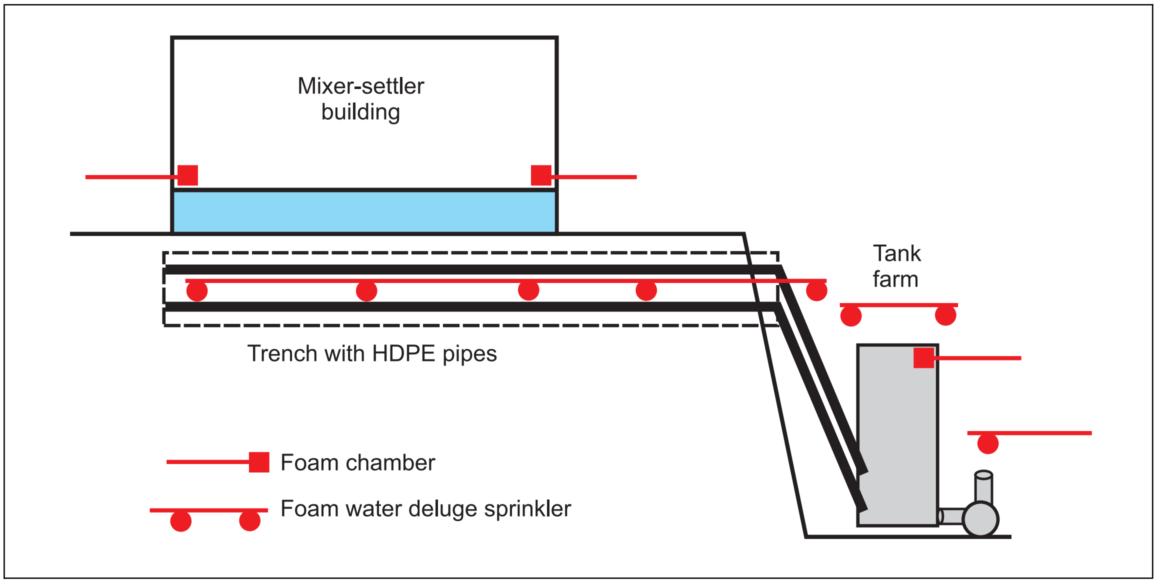

Fig. 14. Protection for large mixer-settler, trenches, and tank farm (elevation)

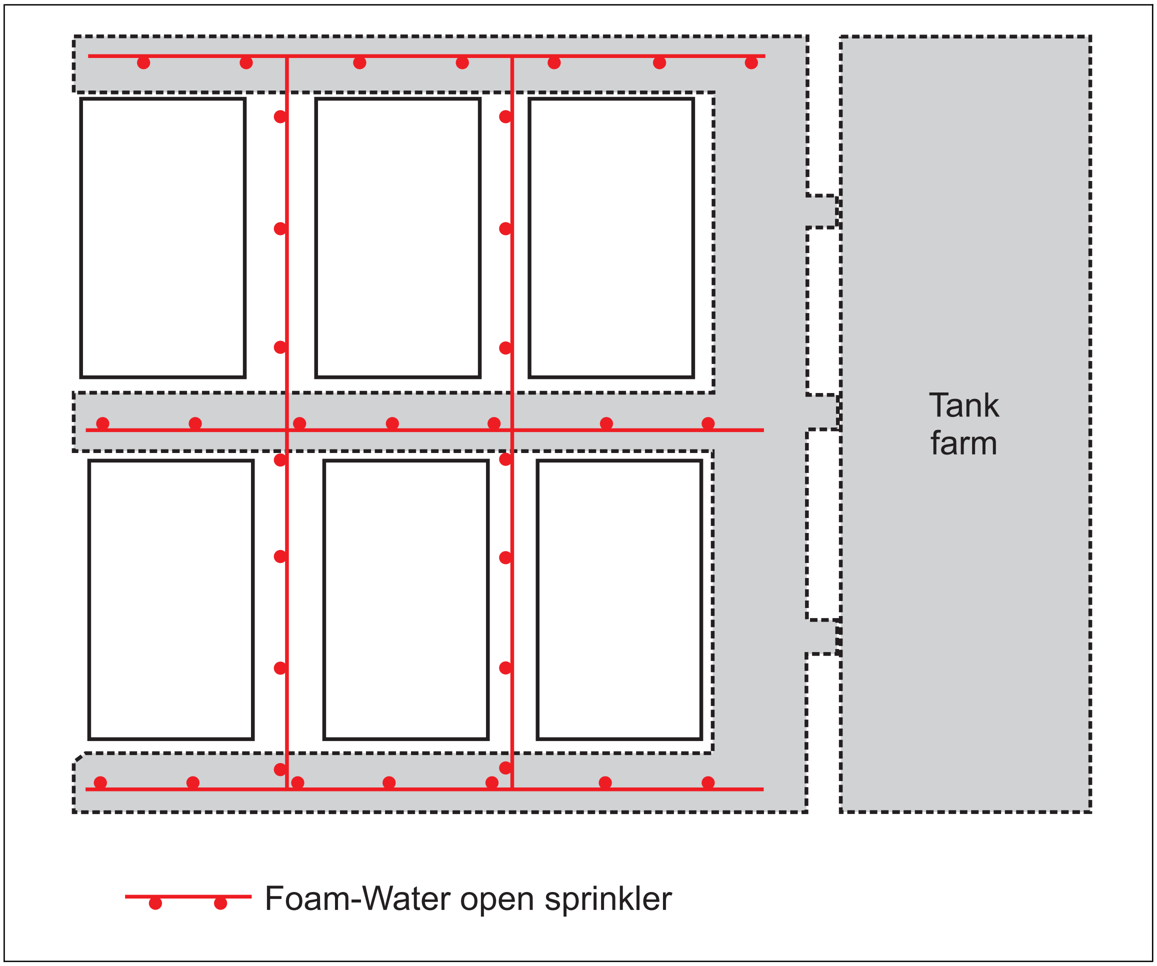

Fig. 15. Protection over trenches around large mixer-settlers (plan)

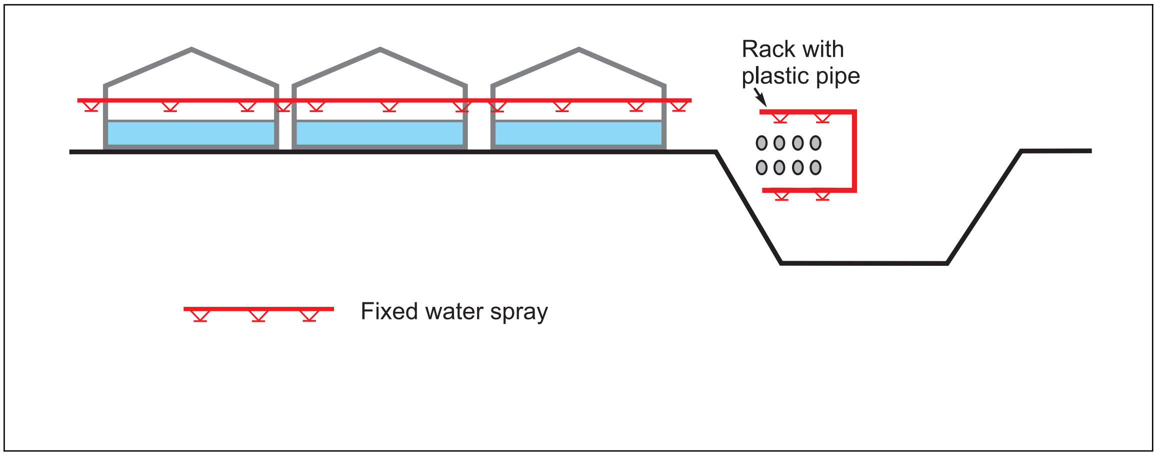

Fig. 16. Protection around large mixer-settlers and tank farm (elevation)

within the expected fire area for the greatest of the following scenarios: the duration of the ignitable liquid release and that required to drain the released liquid; the fire to consume the released ignitable liquid; or a minimum of 120 minutes.

2.5.3.7.1.3 Provide automatic fixed water spray protection in the following mixer-settlers, solvent processing, and solvent storage areas.

A. Along the exterior sides of tanks and mixer-settlers located in proximity to adjacent tanks and mixer-settlers.

B. Over elevated pipe racks containing solvent in plastic piping, which may be subjected to an external fire exposure.

C. Over plastic or rubber flexible connections in solvent piping, which may be subjected to an external fire exposure.

2.5.3.7.1.3.1 Design and install fixed water spray protection in accordance with Data Sheet 7-14, *Fire Protection for Chemical Plants*.

2.5.3.7.1.3.2 Base the water demand on the largest number of automatic fire protection systems expected to operate plus manual fire protection demands and duration, which should be all as specified in the process safety program discussed in section 2.1.5.2. However at a minimum, size the water supply for a discharge duration as discussed in section 2.5.3.7.1.2.2.

2.5.3.7.1.4 Use corrosion-resistant fire protection equipment such as nozzles, piping, and pipe supports when located in proximity to corrosive environments (e.g., acid mists).

2.5.3.7.1.5 Use optical fire detectors to promptly actuate fire protection systems within larger, outdoor mixer-settler, containment around process equipment, and containment around solvent storage tanks. Other forms of fire detection such as spot or linear heat detection are acceptable to actuate fire protection systems in other areas of the mixer-settler complex. For example, linear heat detection may be more effective in pipe-racks or cable trays. Design and install fire detection in accordance with Data Sheet 5-48, *Automatic Fire Detection*, and the *Approval Guide* listing of the automatic fire protection system equipment.

2.5.3.7.2 For smaller outdoor or indoor mixer-settler complexes with banks of cells, provide the following automatic fire protection.

2.5.3.7.2.1 Provide automatic low-expansion foam, foam-water sprinkler, and/or compressed-air foam (CAF) protection within the mixer-settler cells over the solvent pool surface when there is an avenue for internal fire spread from cell to cell. Example locations of foam nozzles is shown in Figure 17.

2.5.3.7.2.2 Provide automatic low-expansion foam, foam-water sprinkler, and/or compressed-air foam (CAF) protection over the entire cell bank, under large equipment such as raised solvent tanks, and under grated or solid mezzanines. Example locations of foam nozzles are shown in Figure 18

2.5.3.7.2.3 Design and install automatic foam protection in accordance with sections 2.5.3.7.1.1.1 through 2.5.3.7.1.1.4.

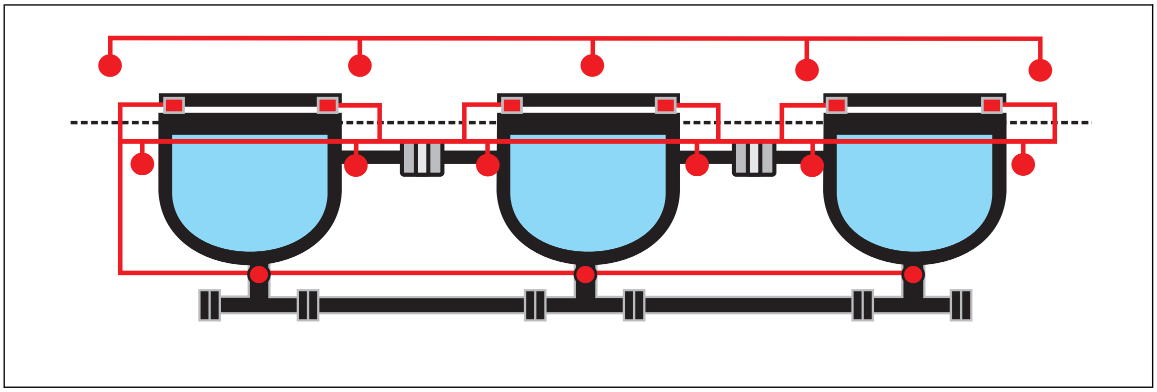

Fig. 17. Protection nozzle locations for smaller, outdoor SX complex (elevation)

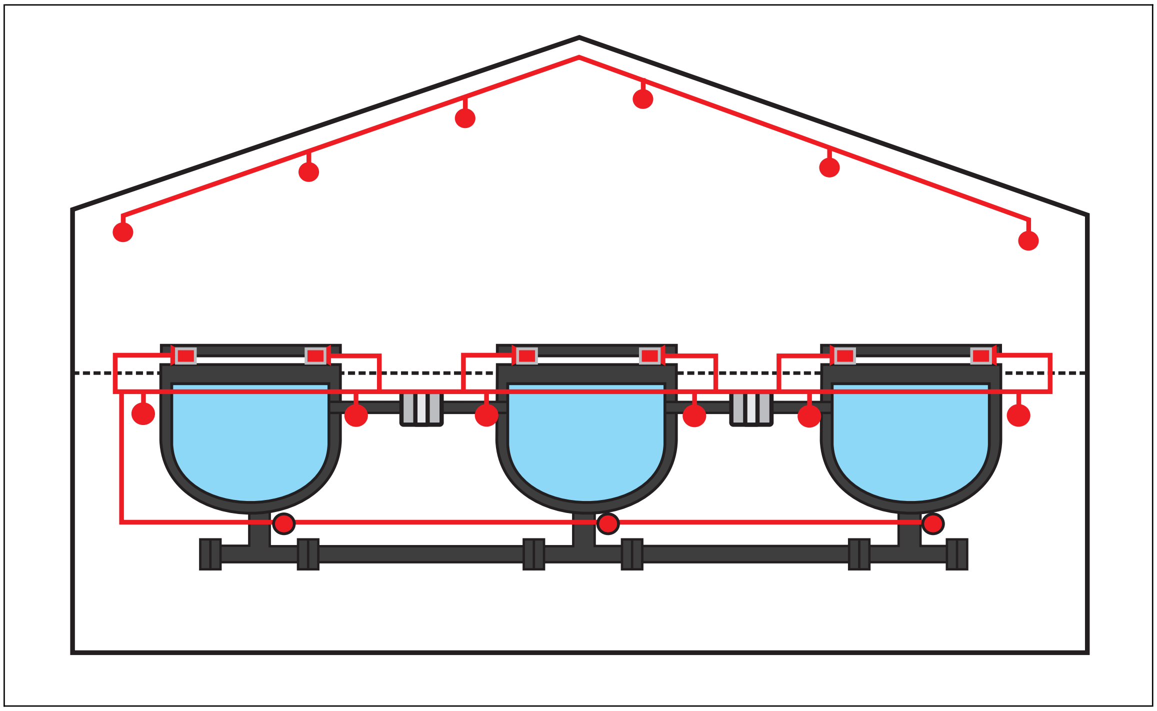

Fig. 18. Protection nozzle location for smaller, indoor SX complex (elevation)

2.5.3.7.2.4 Use corrosion-resistant fire protection equipment such as nozzles, piping, and pipe supports when located in proximity to corrosive environments (e.g., acid mists).

2.5.3.7.2.5 Use optical fire detectors to promptly actuate fire protection systems within larger, outdoor mixer-settler, containment around process equipment, and containment around solvent storage tanks. Other forms of fire detection such as spot or linear heat detection are acceptable to actuate fire protection systems in other areas of the mixer-settler complex. For example, linear heat detection may be more effective in pipe-racks or cable trays. Design and install fire detection in accordance with 5-48, *Automatic Fire Detection*, and the *Approval Guide* listing of the automatic fire protection system equipment.

2.5.3.7.3 For pulsed columns, provide exterior fire protection consisting of automatic foam, fixed water spray, and/or sprinkler deluge systems in accordance with the process safety program (i.e., process hazard analysis) and Data Sheet 7-14, *Fire Protection at Chemical Plants*.

2.5.3.7.4 Provide fire hydrants, hose valves, and monitors within the complex to supplement automatic fire protection systems. Design and install these manual fire protection systems in accordance with the process safety program (i.e. process hazard analysis), Data Sheet 3-10, *Installation and Maintenance of Private Service Mains and their Appurtenances*, and the following considerations.

A. Depending on the results of the facility siting study discussed in section 2.5.3.1, one or more monitors may warrant remote control and automatic foam concentrate injection via fixed piping if the exposure fire or thermal radiation will prevent safe access to the monitors. Elsewhere, arrange monitors for manual foam concentrate injection using portable concentrate tanks.

B. Design the manual firefighting water supply based on the expected demand and duration specified in the process safety program but at a minimum of a 500 gpm (1,900 l/min) demand.

C. Design the manual firefighting foam concentrate supply based on the expected demand and duration specified in the process safety program.

2.5.3.8 Construct piping systems, process tanks, and other solvent-containing equipment and piping in accordance with the facility siting study, and Data Sheet 7-32, *Ignitable Liquid Operations* and 7-14, *Fire Protection at Chemical Plants*. Use noncombustible or fire-resistive materials such as steel or concrete, when possible. Do not use plastic, rubber, or glass. Where flexibility is required, use steel slip joints or convoluted/ corrugated hose with steel braided cover as shown in Figure 19 and Figure 20.

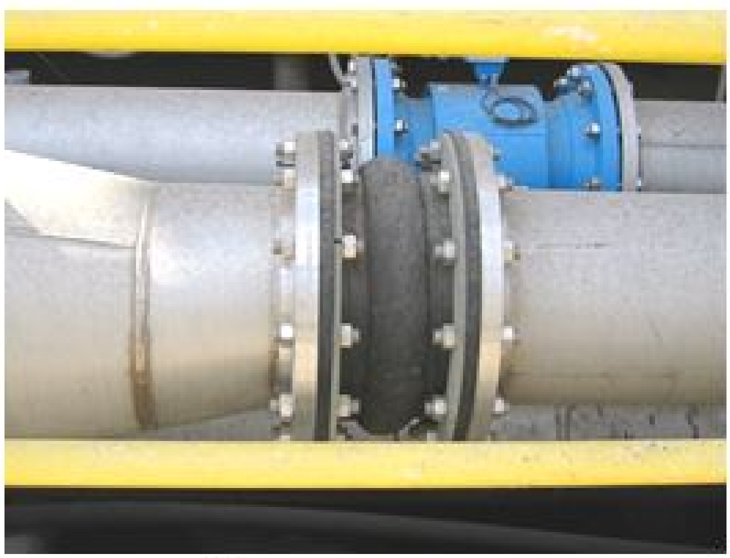

Fig. 19. Flexible rubber connection

Fig. 20. Flexible steel connection

Note: If plastic tanks, vessels, or piping are unavoidable, a structural plastic, such as fiber reinforced plastic (FRP), is preferred instead of a thermoplastic such as polyethylene or polypropylene, which is subject to softening and premature failure under fire exposure.

2.5.3.9 Use seal-less or mechanical double-sealed pumps to transfer ignitable solvent.

2.5.3.10 Minimize electrostatic charge generation and accumulation in equipment near or containing ignitable solvent as follows.

A. Ensure pipes carrying ignitable solvents are full, with no head space to prevent solvent mist from generating static discharge

B. Submerge or lower solvent pipe nozzle discharge below the liquid surface (e.g., install dip pipes that extend towards the bottom of the tank).

C. Minimize changes in direction, orifice restrictions in piping, and flow velocities. For combustible piping systems, limit velocities to less than 3.2 ft/sec (1 m/sec).

D. Use pumps with lower turbulence designs.

E. Install equipment and piping with electrostatically conductive surfaces. If liners are required, use graphite or similar materials with a low electrostatic resistivity.

F. Conduct internal inspections of solvent transfer piping for gypsum (jarosite) buildup, or other non-conductive inorganic deposits that may impede electrostatic charge dissipation from solvent to conductive liners or piping. If identified, determine the thickness the deposits that may pose a hazard, and implement an inspection and removal program. Document inspections and any associated corrective actions.

G. Ground and bond conductive equipment. Of importance, bond across flexible connections made of electrostatically insulating materials (i.e., plastic and rubber materials) as shown in Figure 21 and Figure 22.

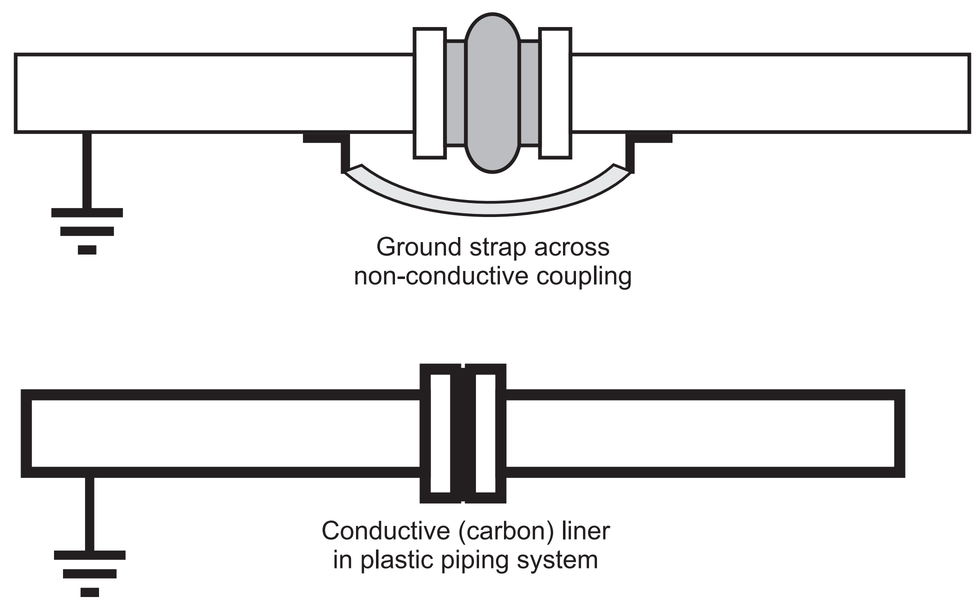

Fig. 21. Bonded pipe segments and conductive liner on plastic piping

2.5.3.11 Design the solvent flow through the SX plant to automatically depressurize and isolate upon fire detection or actuation of fire protection system. Depending on the systems affected and the severity of the specific fire hazard/exposure involved, initiating a controlled, sequential shutdown of the plant may be appropriate (i.e., shutting down transfer pumps and closing emergency safety shutoff valves). In either case, evaluate the potential to overflow the plant with continued gravity flow for pregnant liquor supply (PLS) feed lines.

2.5.3.12 Route critical safety control wiring and power cabling needed to respond to a fire emergency outside solvent fire areas. Alternatively, provide exposed wiring and cabling with a sufficient fire-resistive barrier (i.e., thermal barrier).

2.5.3.13 Provide a ventilation system for enclosed process buildings containing solvent in accordance with Data Sheet 7-32, *Ignitable Liquid Operations*.

2.5.3.14 Provide lightning protection for buildings and process equipment in accordance with one of the following standards and/or local jurisdiction requirements.

• NFPA 780, *Standard for Installation of Lightning Protection Systems*

• IEC 62305, *Protection of Lightning*

• IEEE 142, *Recommended Practice for Grounding of Industrial and Commercial Systems*

2.5.3.15 Conduct grounding and bonding inspections and testing. Document inspection and testing results along with any corrective actions.

2.5.3.16 Restrict hot work in SX complex areas when solvent is present or may be present, and where plastic or plastic/rubber-lined equipment (RLE) are present. Follow special required precautions in accordance with Data Sheet 10-3, *Hot Work Management*.

2.5.3.17 Implement a process safety program in accordance with section 2.1.5.2.

Fig. 22. Flexible steel connection

2.5.3.18 Implement a standard operating procedure for draining and temporarily storing solvent when large process equipment or storage tanks are repaired or altered. Do not temporarily drain solvent into spill containment areas in the SX complex, solvent processing areas, or solvent storage tanks.

2.5.3.19 Implement emergency operating procedures and emergency response plan for various solvent release and fire scenarios in accordance with the process safety program and process hazard analysis (PHA).

2.5.4 Electrowinning and Electro-Refining

2.5.4.1 Construct electrowinning and electro-refining cells/tanks along with associated piping and equipment of noncombustible materials such as stainless steel or concrete. When noncombustible construction is not feasible, provide fire protection over combustible equipment per this Data Sheet.

2.5.4.2 Locate power distribution and rectiforming equipment such as transformers, and switchgear in areas not exposed to corrosive materials. When switchgear must be installed in or adjacent to areas containing corrosive substances, design and construct buildings and/or enclosures to prevent the ingress of corrosive substances.

2.5.4.3 When combustible cells/tanks are present, provide ceiling-level automatic sprinkler protection in accordance with Data Sheet 3-26, *Fire Protection for Nonstorage Occupancies* depending on the combustible loading within the process area.

A. Hazard Category No. 2 when the combustible loading is essentially limited to the combustible cells/tanks and/or lids/covers.

B. Hazard Category No. 3 when the combustible loading in Part A also includes plastic grating and/or piping.

2.5.4.4 Design and install automatic sprinkler protection in accordance with Data Sheet 2-0, *Installation Guidelines for Automatic Sprinklers*.

2.5.4.5 Institute a program to document and label/sign plastic/rubber-lined equipment (RLE), and/or other equipment containing external or hidden internal combustible parts in accordance with section 2.4.4.2. Cells/tanks may be of constructed of combustible materials or contain combustibles.

2.5.4.6 Develop and maintain an equipment contingency plan (ECP) for critical utility and support system equipment that do not benefit from a high-reliability design such as that discussed in section 2.5.1.10 (e.g., N+1 or N-1). Rectiforming transformers and rectifiers (e.g., diodes or thyristors) are often custom equipment with long lead times. See 2.1.6 for ECP guidance.

2.6 Floating Equipment Platforms

2.6.1 Provide automatic fire protection for combustibles on a floating platform in accordance with the guidance for land-based fire exposures.

2.6.2 Provide a means for firefighting via onboard and/or remote manual fire protection systems.

2.6.3 Design and construction the flotation system and operating deck structure in accordance with local maritime jurisdictional requirements. Ensure the flotation system is designed by a maritime engineer or maritime architect based on the anticipated operating conditions on deck including static and dynamic loading.

2.6.4 Provide a flotation system monitoring system to supervise for list, trim, and freeboard/draft set to alarm at a constantly attended location (e.g., control room).

2.6.5 Operate the flotation system within the original equipment manufacturer's load charts

2.6.6 Develop standard operating procedures for the flotation system and system/equipment operating aboard the floating platform. Within the procedures address the following flotation system aspects.

A. Maximum list and trim at rated capacity plus various wind conditions.

B. Minimum freeboard at rated capacity plus various wind conditions.

C. Load charts based on applicable to water conditions (e.g., wind, wave action).

D. Towing/relocation within areas of the pond.

E. Concentrator operations including established perimeters for mass flow onto and off of the floating platform.

2.6.7 Develop emergency operating procedures for the flotation system and system/equipment operating aboard the floating platform.

A. High wind

B. High list/trim

C. Low freeboard (high draft)

2.6.8 Implement an emergency response procedure for the following events.

A. Fire aboard the floating platform

B. Refloating after sinking or capsizing (partial or completely)

2.6.9 Inspect the flotation system every shift for appropriate system conditions including hatch securement, four corner freeboard readings (draft), list/trim, not taking on water, and cleats and other components restraining the floating platform in position.

2.6.10 Inspect the equipment platform deck every shift for fixed load securement and unnecessary accumulations of heavy process material (e.g., sand or water).

2.6.11 Inspect, test, and maintain the flotation monitoring system in accordance with the original equipment manufacturer's guidelines but at least annually.

2.6.12 Conduct non-destructive examinations of the flotation device internals and externals (e.g., barge or pontoons) in accordance with local maritime jurisdictional requirements. Examine for general thinning as well as damage mechanisms including stress, corrosion, wear, and/or impact.

2.6.13 Conduct an audit of the flotation system (e.g., barge or pontoon) and above deck operating conditions by a competent third-party marine engineer, marine architect, or other qualified or licensed person at least annually but in accordance with local maritime jurisdictional requirements. At a minimum, cover the following topics in the audit.

A. Visual inspection of flotation system condition including flotation devices, ballast/bilge system, and position securement

B. Securement of fixed loads aboard the floating platform

C. Comparison between rated capacity (design), and past and current operating capacity

D. Flotation system operating records and inspection reports

E. Inspection of cathode protection system

2.7 Tailings Disposal Facilities (TDF)

2.7.1 Avoid constructing a TDF at an elevation higher than or near mineentrances, ore processing buildings or outdoor equipment except if an engineering evaluation has determined an impoundment failure will not impact these downstream production activities.

2.7.2 Avoid constructing a TDF where flood, stormwater runoff, sudden ice melt (i.e., caused by volcanic or ground heating activity), or avalanche runoff potentials present exposures to the facility. If unavoidable, provide protection against these exposures such as diversion chutes, barriers, or interceptors such as upstream ponds or dikes.

2.7.3 Do not allow utility or production structures to be constructed on the face of the impoundment or the impoundment foundation.

2.7.4 Install piezometer or inclinometer sensors in embankments to measure ground water levels and pore pressures, and to detect stack movement and stability changes.

2.7.5 Retain a certified third-party geotechnical engineering firm to design TDF and sequential raises (lifts). In earthquake prone areas, retain a registered specialist in earthquake dynamics and soils liquefaction. The design should include: underground water and soil analysis; foundation and soils investigations to include grain size and distribution, density, permeability, shear strength, moisture content, and plasticity; foundation subsidence and stability of surrounding slopes; and measures to prevent wave and wind erosion.

2.7.6 Develop TDF standard and emergency operating procedures. Within the procedures, specify operating conditions when further investigation and corrective action is warranted. Written procedures should address failure modes such as slope instability, overtopping, and internal erosion (piping) along with proper TDF operating conditions of the beach, embankment face, decanting of free water, and sensor readings (e.g., piezometers).

2.7.7 Train employees operating or maintaining the TDF or associated systems on relevant procedures and proper operating conditions.

2.7.8 Inspect the TDF for proper conditions of the beach, embankment face, decanting of free water, and sensor readings (e.g., piezometers) in accordance with the TDF management and operating procedures. The appropriate inspection frequency will vary but consider starting at monthly and adjust based on site conditions and previous inspection results. Formally document inspection findings including corrective actions taken for trending and management review.

2.7.9 Retain third-party professional geotechnical specialists to audit and evaluate the current condition of the TDF at least annually. The audit and evaluation should determine TDF stability and potential for failure due to slope instability, overtopping, and internal erosion (piping) along with natural hazard exposures posed by earthquake and sonic-induced liquefaction, and erosion/overtopping due to abnormal snowmelt, stormwater, or flood. Document audit findings and taken appropriate corrective actions when appropriate.

2.8 Overland Transportation

2.8.1 Implement an asset integrity program for privately owned and operated rail lines that extend from mineral processing to shipping terminals or offsite processing facilities in accordance with section 2.1.5.6.

2.8.2 Implement an asset integrity program for overland conveyors that extend from the mine or mineral processing facility to shipping terminals or offsite processing facilities in accordance with section 2.1.5.6.

2.8.3 Implement an asset integrity program for slurry pipelines that extend from mineral processing to shipping terminals in accordance with section 2.1.5.6. Within the program, develop an ITM program with the assistance of the pipeline design team and/or other consulting expertise to monitor for and manage the various damage mechanisms exposing the pipeline. Damage mechanisms may include: wear and thinning due to erosion and corrosion; cracking due to mechanical stresses from support failure or displacement; and overpressurization due to pressure-reducing valve failure. Consider including the following activities in the ITM plan.

A. Perform routine visual inspection while in operation (spot-check walkdown).

B. Nondestructive examination (thickness, and/or survey for surface or volumetric indications)

C. Pressure-reducing valve testing

D. Cathode protection inspection

E. Pigging to monitor internal geometry and/or lining.

Update the program based on changes in operating conditions or maintenance results. Increase frequency or scope of the ITM when negative results are reported including conditions approaching the limits of the integrity operating window or overall negative trends.

2.8.4 Develop and maintain an equipment contingency plan for overland transportation which may include a slurry pipeline, railway, or belt conveyor in accordance with section 2.1.6. Damage and/or interruption of conveying operations may occur due to equipment breakdown or by a natural hazard exposure such as wild fires, flooding, landslides, avalanche, or soil subsidence. The plan should address all aspects of expedited recovery efforts and/or alternate temporary conveying methods. See Data Sheet 7-11, *Conveyors*, for additional ECP guidance.

2.9 Coal Preparation and Drying

2.9.1 Locate coal screening, crushing, cleaning, and other operations that release coal dust into process areas outdoors or in open process structures in accordance with Data Sheet 7-76, *Combustible Dusts*. Alternatively, provide damage-limiting construction (DLC) for coal processing areas exposed to a room coal dust explosion hazard in accordance with Data Sheet 1-44, *Damage Limiting Construction*, and Data Sheet 7-76.

2.9.2 Provide automatic sprinkler protection in coal storage and processing areas and equipment where either combustible construction or occupancy is present. Often full or local automatic sprinkler protection is warranted in coal reclaim tunnels, loading galleries, and silo galleries.

2.9.2.1 Provide automatic sprinkler protection over combustible spiral separators (i.e., often constructed of fiberglass) in accordance with section 2.4.2.

2.9.3 Provide an automatic deluge system inside fluidized bed and screen-type thermal coal dryers to protect the constriction or screen deck against thermal damage. Locate discharge nozzles so that they will effectively cover all portions of the top surface of the deck. Design the system to provide a minimum density of 0.3 gpm/ft^2 (12 mm/min) over the area of the deck. Actuate the system using heat detection located inside the dryer set at 50 F (10 C) above the maximum operating temperature of the dryer. Design and install the protection system in accordance with Data Sheet 4-1N, *Fixed Water Spray System for Fire Protection*.

2.9.4 Provide automatic deluge water spray within ductwork, dust collectors, and other emissions control equipment downstream of thermal dryers when appropriate. Of particular concern are ducts susceptible to coal dust accumulations. Design the protection system to provide 0.3 gpm/ft^2(12 mm/min) density over the internal surface area. Design and install the protection system in accordance with Data Sheet 2-0, *Installation Guidelines for Automatic Sprinklers* for nonstorage sprinklers (and Data Sheet 7-78, *Industrial Exhaust Systems* for ductwork protection).

2.9.5 Provide dust explosion mitigation for process equipment exposed to coal dust explosion hazards in accordance with Data Sheet 7-76.

2.9.6 Install properly rated electrical equipment in coal processing buildings in accordance with Data Sheet 5-1, *Electrical Equipment in Hazardous Locations (Classified)* when coal dust and flammable gases (e.g., methane) hazards are present.

2.9.7 Provide a reliable water supply for scrubbers downstream of thermal dryers consisting of the following:

A. Provide an emergency water supply such as a reliable gravity tank water supply, or secondary pump and water source both of which are independent of the primary water supply (e.g., fire protection water supply).

B. Arrange the control system to automatically switch to the emergency water supply and sound an alarm in a constantly attended area upon loss of the primary water supply.

2.9.8 Provide process interlocks to interrupt heat input to the dryer when the following abnormal operating or emergency conditions occur.

A. High temperature above the constriction or screen deck (screen and fluidized bed dryers), in the drying chamber (flash dryers), in discharge ducts from the dryer, and in cyclones. Trip the dryer when temperatures reach 50 F (10 C) above the normal operating temperature for the subject zone.

B. Loss of primary and emergency water supply to wet scrubbers.

C. Actuation of any internal fire protection system.

D. Interruption in wet coal infeed into the dryer, or dry coal outfeed from the dryer.

E. Actuation of explosion protection systems.

2.9.9 At locations processing coal known to, or suspected of being, high in combustible gas content, provide the following protection for below grade or confined storage locations such as within silos.

A. Combustible gas detectors to sound an alarm in a constantly attended station when the concentration of methane in air exceeds 25% of the lower explosive limit

B. Continuous mechanical ventilation designed to exhaust liberated gases to atmosphere. Design ventilation rate to maintain the concentration below 25% of the lower explosive limit of the gas or gas mixture. Provide a ventilation failure alarm to sound in a constantly attended station.

2.9.10 Monitor carbon monoxide (CO) gas concentrations, which is an early indicator of internal heating which could lead to spontaneous combustion, using FM Approved combustible gas detectors inside long term coal storage silos, bins, and bunkers. Long term is defined here as storage in residence more than one month.

2.9.11 Develop standard operating procedures (SOP) for coal preparation and drying operations in accordance with the facility's process safety program (refer to section 2.1.5.2). Consider including responses to the following upset conditions within the SOPs.

A. High temperature within the drying circuit.

B. Loss of scrubber water.

C. Interruption of wet coal feed into the dryer or dry coal feed from the drying circuit.

D. Release of heat transfer fluid (thermal oil) when present.

2.9.12 Develop emergency response plans (a.k.a. emergency operating procedures) for thermal coal preparation and drying operations in accordance with Data Sheet 10-1, *Pre-Incident Planning* and the facility's process safety program. Involve operators and maintenance personnel in the development of the response plans and include them as members of the emergency response team. Document the response plans, and audit the response plan at least annually (e.g., review the plan to ensure that the plans were updated to address facility changes, which may include physical or personnel changes). Consider developing responses to the following emergency scenarios.

A. Fire within coal preparation equipment or process area.

B. Explosion within coal preparation equipment.

C. Fire within coal drying equipment or process area.

D. Explosion within coal drying equipment.

2.9.13 Provide initial along with regular refresher training for operators in accordance with Data Sheet 10-8, *Operators*. During the training, emphasis should be placed on standard operating procedures as well as emergency operating/response procedures.

3.0 SUPPORT FOR RECOMMENDATIONS

3.1 Supplemental Information

3.1.1 Underground Mining

3.1.1.1 Hoists

Hoists may contain large synchronous motors, gear sets and wire ropes for hoisting equipment, personnel, and ore to and from the mine. They are usually located at the surface and may be housed in combustible buildings in older facilities. Hoists may be located underground in some mines. This equipment is susceptible to fire involving lubrication and hydraulic oil systems and in some cases combustible fuels, but also mechanical impact, mechanical breakdown, or electrical breakdown. Mechanical breakdown of hoist drums, hubs, spokes, drive shafts, brakes, and gears have occurred. Large synchronous electric drive motors have failed. Resultant damage and production downtime can be extensive. Also wire ropes can sever and cause skips and cages to fall down the shaft either due to fire exposure or mechanical damage. Hoist and wheelhouse buildings may be susceptible to ground subsidence if over shallow underground workings, or be exposed to other natural exposures.

3.1.1.2 Crushers

Some mines have primary crushing equipment underground. The crushed ore is then sent via conveyors or hoist systems to surface secondary crushing circuits. Crushers are long lead time equipment exposed to fire (hydraulic and lubricating oil systems and grouped electrical cables). Crushers are designed to withstand harsh conditions but can have mechanical breakdown due to metal fatigue or abnormal operating conditions such as a mechanical impact.

3.1.1.3 Wood Lagging and Liners

Most modern mines use noncombustible shaft liners and steel infrastructure although wood/timber continues to be used in many countries or older mines. Plastic liners have been rare; however, new applications for plastic materials are constantly being introduced to the market and may be proposed for new mines.

Metal mines are often wet and wood shaft liners may be saturated with water. Some non-metal mines, while drier, may have inorganic materials (such as naturally fire-retardant potassium carbonate in potash mines) that have impregnated the wood lining over time. Either of these can affect potential for fire spread. When very wet liners (essentially saturated) are encountered and it is determined that this is normal and consistent throughout the shaft (for approximately 10 hydraulic diameters above shaft stations), fire protection may not be warranted.

3.1.1.4 Belt Conveyors

Shut control valves supplying sprinkler protection over conveyors are common within the industry. Sprinklers and piping are exposed to mechanical impact from the conveyor contents. Unfortunately, these sprinkler impairments are rarely handled with proper fire protection impairment program, thus control valves can remain unknowingly shut until tested or a fire occurs. Fairly common are conveyor fires ignited by belt slippage or misalignment. The combination of these two factors can lead to more frequent and significant conveyor fires.

3.1.1.5 High-Sulfide Content

Some underground metal or non-metal mines have concentrations of high sulfide-content (HSC) ore, or may have regions of coal or other combustible fossil materials. HSC ores are defined as having a sulfide content of more than 28%. HSC ores and coal seams are subject to spontaneous heating and their dusts, when released, can explode violently especially when disturbed and dispersed during production blasting or because of an incipient methane gas explosion.

3.1.1.6 Gassy or Fiery Mines

Some underground metal or non-metal mines may have concentrations of naturally occurring methane or other flammable gases such as carbon monoxide or hydrogen sulfide (caused by deep seated combustion processes) that may be present due to nearby coal deposits or other organic materials in the geologic structure being mined. Ignition of concentrations of such gases that are within their explosive limits can cause underground damage up to thousands of feet (meters). Even if in unmined deposits, gas can seep into working areas.

3.1.1.7 Rock Burst/Fall and Ground Control

The science and technology of minimizing or preventing collapse of mines, rock bursts or localized rock falls from mine backs is well established and dependent on the geology and structure of the mine and ore body and external effects such as vibrations from blasting or equipment and from seismic events. Experts determine the need for various roof and mine support systems. Roof support can vary from using mining techniques such as room and pillar to providing localized rock bolting, shotcrete or timber sets.

3.1.1.8 Use of Ventilation in Response to Underground Fires

Underground ventilation systems can be effectively used for fire control as well as environment conditioning. Ventilation can have an effect not only on oxygen content (and thus the potential for fire growth or suppression) but also on the ability of emergency teams to effectively access a fire source.

3.1.1.9 Flooding and Water Inundation

Serious hydrogeological (water-based) exposures are common underground. The term inundation is usually applied to underground water events to differentiate from common floods as envisioned on the surface involving storm water runoff or ravine overtopping.

Mines under surface bodies of water such as rivers, lakes or seas have been inundated when the water found an artificial pipe or pathway downwards or when the weight of the water body collapsed into the mine. Water and mud has also entered from failed tailings disposal facilities.

Water occurs naturally or incidentally in underground mines from several sources such as the following:

A. Natural aquifers: First and most common the mineral being mined may be located within or below an aquifer. The natural aquifer needs to be artificially lowered – usually by pumping (dewatering) - to keep mining zones relatively dry and to prevent high flow water in workings. Should pumps fail or be turned off for a long enough period water will naturally re-enter by gravity and eventually fill the mine up to its pre-dewatered aquifer (called the phreatic) level. Failure can be caused by loss of motive power such an electrical power failure, damage to pumps by roof fall, mechanical or electrical system failures, and flooding (water overtopping).

B. Hidden water pockets: Some mines – especially certain sedimentary salt formation mines like potash, rock salt, trona (soda ash) and in some uranium mines – may have hidden brine deposits, lakes or pockets (called anomalies) within or above the geological formation, and if one of these is accidentally penetrated sudden in-rushes of water can occur by gravity. Normal aquifer dewatering systems are not designed for sudden water inflows. If a water anomaly or brine deposit is penetrated, the mine can flood up to the level of the water body.

C. Process/production water: Water may be introduced into the mine as part of normal production processes. Water sprays may be used on equipment such as longwall mining machines, as dust mitigation sprays on production equipment or as part of a hydraulic mining process.

D. External: Water may enter the mine from aboveground natural hazard sources such as heavy rainfall or surface flooding which directly enters a shaft or portal or via faults, fractures or cracks from a surface sinkhole, lake or river.

3.1.2 Surface Mining

3.1.2.1 Heavy Duty Mobile Equipment Shops

High-bay shops used for servicing and repairing heavy-duty mobile equipment such as haul trucks and railroad locomotives are primarily a noncombustible occupancy by themselves except when mobile equipment is introduced with rubber tires, hydraulic oil, lubricating oil, cabling and wiring, and diesel fuel. With the potential for multiple pieces of equipment parked side-by-side, the potential for an intense fire with spread to multiple assets is possible capable of destroying the equipment as well as rendering service and repair infrastructure such as overhead cranes out-of-service due to the moderate to severe thermal damage expected during an equipment fire in a building. Automatic fire protection helps limit the exposure to adjacent equipment as well as service and repair operations.

3.1.3 Ore and Mineral Processing

3.1.3.1 Combustible Loading within Concentrators

From a fire protection standpoint, it cannot be overemphasized that combustible loading in concentrator facilities be quantified. These large, open facilities typically appear to have only a light, scattered combustible loading because they usually handle noncombustible products within noncombustible equipment and piping in noncombustible buildings. Historically in older facilities, unless the building was constructed of heavy-timber or wood frame ceiling-level sprinkler protection was rarely installed.

However, concentrators almost always have “hidden” combustibles that can contribute to intense, long duration fires. The principle “hidden” combustibles are internal rubber or plastic-lined equipment, or equipment constructed of or coated in rubber or plastic. Rubber and/or plastic linings are present in essentially all concentrators from inside tanks, pipes, cyclones, and pumps to inside mills and crushers. Trommel screens at the out-take of SAG and ball mills often are constructed entirely of plastic, and these are partially enclosed within a metal shroud and not readily visible or accessible for firefighting. Shaker screens, internal screens in flotation tanks, and filter presses are also commonly plastic. Localized external fire protection, labeling of combustible-lined equipment, and human element policies (hot work, combustible-lined equipment management, and management of change) go a long way to minimize these exposures.

Spiral separators represent one of the larger combustible loadings that are readily visible. Other recognizable and visible combustibles in a concentrator include conveyor belts, power cables, control wiring, flexible rubber pipes, and to some extent ignitable liquid such as lubrication and hydraulic oils, flotation reagents, and heat transfer fluid also referred to as thermal oil. Ignitable liquid supplies are often isolated in cutoff rooms or areas, and usually do not represent widespread combustible loading, but the ignitable liquid use points for these systems are at or near production equipment. When not properly protected, the combination of these fuel packages makes for a either an intense, long duration localized fire, or worse, a fire that spreads through most of the facility due to continuity of these combustibles. There have been several instances of both scenarios playing out world-wide in recent years.

In addition to the occupancy, combustible building construction consisting of plastic paneling or insulated metal panels with combustible cores has found favor in the industry to insulate and resist corrosion.

3.1.3.2 Equipment Breakdown in Concentrators

With production flow through concentrators being critical for downstream metallurgical operations, concentrators often pose significant production bottleneck. Harsh operating environment and/or conditions presents many damage mechanisms for mechanical and electrical equipment. Dust, moisture, corrosive agents, and dynamic loading can all lead to equipment breakdown if not managed properly by an asset integrity program. As a complement to the asset integrity program, equipment contingency planning is critical to recover from the unexpected breakdowns capable of causing long duration forced outages interrupting production. Relying on process knowledge and maintenance to detect and mitigate equipment breakdown may not be sufficient for equipment capable of causing months to over a year of production interruption if a failure were to occur. Of particular concern are SAG, ball, and rod mills and their associated equipment listed below given the long lead-times for replacement.

- Ring gear along with drive motors and reduction gears
- Gearless motor drives along with upstream power supplies

3.1.4 Metallurgical Processing

3.1.4.1 Pressure Leaching - Alumina Refining

3.1.4.1.1 Critical Service and Support Systems

Alumina refineries are mostly operated on a continuous basis. Several utility services and support systems (e.g., electrical supply, compressed air supply, steam supply) are essential to the process and continuity of operations. When a critical service or support system is restored after interruption, the process may be restarted promptly, or after a delay to repair or prepare equipment. The recovery time at a refinery after a service or support system interruption depends on the duration of the interruption as well as any actions taken by the refinery to prevent equipment fouling or damage.

In most cases, lack of agitation in a precipitator will result in uncontrolled alumina trihydrate crystal growth, and if allowed to be continue undisturbed, crystals will compact at the bottom of the precipitator. However, some sites may be able to dump the contents of a precipitator into a disposal pond, lake or lagoon (of the type used for red mud disposal) to avoid settling and compaction inside the precipitator.

3.1.4.1.2 Overpressure

At most alumina refineries, the high temperature mixture of caustic soda, water and dissolved alumina is continuously fed through a series of flash tanks associated with the continuous digesters. Here, the temperature and pressure are reduced stepwise, flashing off steam in each stage until reaching a blow tank at atmospheric pressure. In some cases, each flash tank in the train has a design pressure lower than the one preceding it. Therefore, each flash tank must be protected against an overpressure in excess of its maximum allowable working pressure. The primary source of overpressure would be an uncontrolled flow of high-pressure liquid from the upstream flash tanks and digester, or a downstream stoppage.

3.1.4.1.3 Process Bottlenecks

Loss of critical utility service or support system may result in reduced production or a production shutdown. Potential process bottlenecks that are exposed by hazards capable of causing significant property damage accompanied with a lengthy recovery time include onsite steam and power generation, alumina calcination, tailings disposal, and ore handling equipment.

The calcination stage in an alumina refinery is in line with the continuous hydrated alumina production process. Little or no in-process storage capacity is often available between the two. It is therefore particularly important to ensure availability of the rotary kilns. When no redundant capacity exists at this stage, any rotary kiln shutdown will force a reduction in hydrated alumina production.

Several thousand tons of ore are processed per day. Specialized cranes and ore handling systems are used, often in conjunction with rubber belt conveyor systems, to feed the process. In some instances, the entire process may rely on a single piece of ore handling equipment. Lengthy shutdown of such equipment would result in lengthy production interruption.

3.1.4.1.4 Harsh Equipment Environment

The environment of the alumina refinery is harsh for all equipment. Caustic solutions are corrosive, and corroded equipment requires more maintenance and has an increased potential for breakdown. Alumina is highly abrasive and a good insulator. Ingress into electrical equipment can rapidly erode moving parts, and the dust on electrical contacts could lead to malfunction. These harsh conditions require special design and protection of electrical equipment.

For on-site power distribution, buried cables installed in conduit, or cables in trays in tunnels are preferred. Overhead lines should be discouraged because they are susceptible to contamination, lightning and mechanical damage from cranes and vehicles.

3.1.4.2 Heap Leaching

Natural hazards and subsidence tend to be the culprits that damage piles and/or dilute process streams (impregnated liquor). Recent losses in these ore piles have occurred due to failure (sloughing) of the pile; rupture or penetration of the under-pile liner, and dilution due to flooding or storm water runoff.

3.1.4.3 Mineral Solvent Extraction (SX)

The traditional response to fire protection of an SX plant is to incorporate multiple layers of mostly active protection along with operational protection features, but only once the production facility design and layout has been determined. Fire protection design is often done months after initial design when little room is available to implement highly effective passive fire protection features such as fire-resistive barriers and spacing, spill containment and drainage, and using means other than gravity process flow such as pumps at certain stages in the process. These passive protection features should be the backbone of the fire protection methodology and only supplemented with high-volume water or foam-water deluge systems to control the less intense fires afforded by these passive protection features. While active protection features are effective, managing thermal radiation and release ignitable liquid are key for preventing secondary ignitable liquid releases capable of resulting very intense, long duration fires capable of exposing most of the plant and adjacent facilities.

Because low-flash point ignitable liquid poses a quick-spreading, very intense fire hazard, all protection systems must act together rapidly with very high reliability or the fire might gain control and overtax the protection system. If high-volume ignitable liquid storage, piping, or processing systems fail under fire exposure (such as at a rubber flexible fitting) and release additional fuel, the protection system's design capabilities may be exceeded. Once an ignitable liquid fire has grown beyond a controllable size, fixed protection systems may not be able to limit damage. Further, active suppression systems have a defined failure rate and may not be available upon demand over the life of a facility.

In chemical processing facilities, the widespread use of plastic equipment and piping has not become as common as in solvent extraction plants. Instead chemical plants tend to use strong corrosion-resistant metal alloys like stainless steel. This is an inherently safer approach preventing large secondary ignitable liquid releases due to direct flame impingement or thermal radiation imposed on plastic liquid-containing components. In early solvent extraction plants, stainless steel piping and equipment was the norm; however due to cost, these materials have been gradually replaced by plastics. In other instances, stainless steel alloys may not be able to withstand attack from chlorides commonly found in SX processes such as in copper extraction. In either case, use of plastic equipment and piping has become the norm.

Another common practice in solvent extraction plants that is not used in chemical processing is gravity flow through below grade trenches. Multiple pumping systems tend to cost more and are not as reliable as a single pump and gravity flow system. However, when an initial liquid release and large fire occurs, the quantity of liquid allowed to free flow (by gravity) can be an issue especially when manual firefighting is hindered by access to below grade spaces. Typically, the gravity flow systems and containment and drainage flow directly into the tank farms exposing any plastic piping and equipment along the way as well critical production equipment and ignitable liquid storage tanks. The combination of multiple pump systems, dedicated containment areas, and remote drainage impound area both limit fire size as well as reducing the potential for substantial secondary releases from plastic liquid containing components.

History has shown that fires at mineral processing solvent extraction plants can be severe given the quantity of ignitable liquid and common design practices. While often located in remote locations with a finite life expectancy, mineral processing solvent extraction presents similar fire likelihood and consequence as found in chemical processing facilities. A process safety culture and program should be in place to manage SX fire hazards from plant design through the entire life cycle of the plant.

3.2 Loss History

3.2.1 Loss Data

Other than the mineral solvent extraction loss discussion, the following loss review is based on 145 FM losses in mining and mineral processing over a recent 20-year period (1997 through 2017). Coal mining and preparation losses are not covered in this loss study.

Natural hazard perils were not reviewed, nor were rigging, transportation or similar perils. This loss review aligned with the scope of this standard focusing on fire, and boiler and machinery related perils.

Other than in the mineral SX discussion, loss amounts were indexed to 2017 values.

3.2.1.1 Industry Overview

As shown in Table 1, fire, impact, and equipment breakdown (electrical and mechanical) perils account for the majority of mining losses, while fire and breakdown perils constituted the majority of the total gross loss values as well. Although significant, the large total gross loss values for breach and earth movement (non-natural hazard) perils are attributed two catastrophic events consisting of a large TDF failure and sizable pit wall collapse.

Table 1. Mining Losses by Peril

Peril	*No. of Losses (% of total)*	*Total GrossLoss (% of total)*	*GrossProperty Damage (% of total)*	*GrossBusiness Interruption (% of total)*
Breach	2	25	14	27
Collapse (non-Natural Hazard)	3	0	1	0
Cyber	1	0	0	0
Earth Movement (non-Natural Hazard)	5	19	7	21
Electrical Breakdown	7	18	3	21
Explosion	1	0	0	0
Fire	19	12	26	10
Flood (non-Natural Hazard)	4	5	9	4
Impact (vehicle)	25	2	9	0
Mechanical Breakdown	25	14	18	14
Mechanical Impact	3	3	9	1
Miscellaneous	1	0	1	0
Overturning	2	0	1	0
Service Interruption	2	2	2	2

Table 2. Losses Grouped by Mining Operation

Mining Operation	*Activity*	*No. of Losses (% of total)*	*Total GrossLoss (% of total)*	*GrossProperty Damage (% of total)*	*GrossBusiness Interruption (% of total)*
Administration	Buildings	2	0	1	0
Site	Utility/Support Systems	4	4	3	3
Underground	Ore Excavation	28	2	10	0
	Material Handling	8	2	7	1
	Utility/Support Systems	6	5	11	4
	Subtotal(s)	42	9	28	5
Surface	Ore Excavation	3	17	4	20
	Material Handling	4	2	4	1
	Crushing	3	3	2	3
	Buildings	1	0	2	0
	Subtotal(s)	11	22	12	24
Concentrator	Separation	4	4	7	4
	Crushing	1	1	1	1
	Grinding	17	25	8	28
	Material Handling	1	0	1	0
	Utility/Support Systems	1	0	1	0
	Subtotal(s)	24	30	18	33
Metallurgical	Atmospheric Leaching	1	2	2	2
	Pyrometallurgical	5	1	2	1
	Subtotal(s)	6	3	4	3
Ancillary	TDF	2	25	16	27
	Acid Plant	1	2	1	2
	Wastewater	1	0	0	0
	Subtotal(s)	4	27	17	29
Transport	Storage	1	0	0	0
	Overland	4	1	9	0
	Sea	1	2	2	2
	Material Handling	1	2	6	1
	Subtotal(s)	7	5	17	3

3.2.1.2 Fire Losses in Mining and Mineral Processing

Table 3 contains fire losses at the various mining operations.

Table 3. Fire Losses by Mining Operation

Mining Operation	*No. of Losses (% of total)*	*Total GrossLoss (% of total)*	*GrossProperty Damage (% of total)*	*GrossBusiness Interruption (% of total)*
Administration	11	2	5	0
Underground	15	2	5	1
Surface	19	16	22	13
Concentrator	33	42	33	47
Metallurgical	15	20	10	26
Transport	7	18	25	13

3.2.1.2.1 Concentrator Fires and Ignition Sources

As presented in Table 3, a third of the mining fires occurred within concentrators with the majority of those fires ignited by poorly managed hot work, while frictional heating (hot surface) was the other more common source of ignition. Most fires were ignited in separation operations (screens and hydrocyclones), while those that weren't spread to separation operations involving plastic/rubber-lined equipment (RLE).

3.2.1.2.2 Fires at Solvent Extraction Plants

Losses in SX plants are primarily of fire origin. Seven large fires occurred within the last 45 years and are listed in Table 4. Three occurred in the 1970s. while four occurred between 1999 and 2003. From a review of available documentation, the following negative factors were prevalent in most incidents.

- Ignition by static electricity
- A small leak escalated to a large pool fire
- Plastic or glass piping failed
- Poor emergency drainage
- Inadequate fire protection
- Poor siting and location including sub-grade spaces
- Poor emergency response

Table 4. List of Large Mineral SX Fires

Date	*Location*	*Initial Fuel Package*
1972	Norway	Solvent release in mixer-settler area
1975	United States	Solvent release in mixer-settler area
1978	Namibia	Solvent leak in mixer-settler area
1999	Australia	Solvent release in mixer-settler area
2001	Australia	Solvent release in mixer-settler area
2003	United States	Solvent in mixer-settler
2003	Mexico	Solvent in mixer-settler

3.2.1.3 Flood Losses in Underground Mining

Flooding, as discussed in this section, refers to ground water inundation rather than surface induced flooding of the underground mine attributed to natural hazards such as stormwater or overflowing bodies of water. Underground inundation often is attributed to ground water levels, underground bodies of water, or aquifers.

As shown in Table 5 the majority of water inundation was attributed to loss of pumping rather than increased flow, while the overwhelming event resulted in larger losses. In one loss of pumping instance, striking of an underground body of water followed by loss of pumping was mitigated by executing emergency response procedures.

Table 5. Underground Mine Flooding

Cause	*No. of Losses(% of total)*	*Total GrossLoss(% of total)*	*GrossProperty Damage(% of total)*	*GrossBusiness Interruption(% of total)*
Loss of Pumping	83	37	52	30
Overwhelmed	17	63	48	70

3.2.1.4 Boiler & Machinery Losses in Mining and Mineral Processing

The overall boiler & machinery losses are shown in Table 6 listed by peril. Mechanical breakdown accounted for the greater number of losses and gross property damage, while electrical breakdowns lead to more business interruption; however, these statistics were skewed by a single electrical breakdown with substantial downtime.

Table 6. Boiler & Machinery Losses by Peril

Peril	*No. of Losses (% of total)*	*Total Gross Loss (% of total)*	*Gross Property Damage (% of total)*	*Gross Business Interruption (% of total)*
Mechanical Breakdown	77%	44%	88%	39%
Electrical Breakdown	23%	56%	12%	61%

3.2.1.4.1 Mechanical Breakdown Losses in Mining and Mineral Processing

As shown in Table 7, the majority of mechanical breakdown occurred within material handling equipment such as hoists and belt conveyors, and size-reduction equipment including crushers and grinding mills. Additionally, the group of losses also includes breakdowns of internal combustion engine driven generators, dredge pumps, and fans and blowers.

Table 7. Mechanical Breakdown in Mining by Operation and Activity

Mining Operation	*Activity*	*No. of Losses (% of total)*	*Total GrossLoss (% of total)*	*GrossProperty Damage (% of total)*	*GrossBusiness Interruption (% of total)*
Site	Utility/Support System	6	3	9	2
Underground	Material Handling	13	6	22	1
	Utility/Support System	5	0	1	0
Surface	Ore Exc	3	3	1	4
	Material Handling	5	2	5	1
	Crushing	8	16	3	20
Concentrator	Grinding	40	47	37	50
Metallurgical	Pyrometallurgical	8	5	7	4
Ancillary	Acid Plant	3	11	1	13
	Wastewater	3	2	1	2
Transportation	Overland	3	1	2	1
	Sea	3	4	11	2

3.2.1.4.2 Electrical Breakdown in Mining and Mineral Processing

As shown in Table 8, the vast majority of electrical breakdowns occurred within grinding mills (i.e., SAG and ball mills), while a few hoist motor failures occurred as well. The grinding mill breakdown losses are discussed in more detail in section 3.2.1.4.3.

Table 8. Electrical Breakdown in Mining by Operation and Activity

Mining Operation	*Activity*	*No. of Losses (% of total)*	*Total GrossLoss (% of total)Gross*	*Property Damage (% of total)*	*GrossBusiness Interruption (% of total)*
Underground	Material Handling	18	3	48	2
Concentrator	Grinding	82	97	52	98

3.2.1.4.3 Equipment Breakdown Losses Involving Crushers and Grinding Mills

An overview of size reduction equipment breakdowns is provided in Table 9. SAG mills accounted for the majority of breakdown losses as well as total gross loss, most likely due to long recovery durations and lack of spares and/or excess capacity for that grinding stage, which is often a production bottleneck.

Table 9. Equipment Breakdown of Size Reduction Equipment by Activity and Type

Activity	*Type*	*No. of Losses (% of total)*	*Total GrossLoss (% of total)*	*GrossProperty Damage (% of total)*	*GrossBusiness Interruption (% of total)*
Crushing	Primary	2	9	21	8
	Secondary	4	2	1	2
Grinding	SAG	51	80	60	81
	Ball	37	9	18	9

Table 10 provides an overview of mechanical breakdowns by mill type. As previously mentioned, SAG mills constitute a large portion of the gross TE loss likely due to being a production bottleneck.

Table 10. Mechanical Breakdown of Grinding Mills by Type

Mill Type	*No. of Losses (% of total)*	*Total GrossLoss (% of total)*	*GrossProperty Damage (% of total)*	*GrossBusiness Interruption (% of total)*
SAG	53	66	81	63
Ball	47	34	19	37

Table 11 provides an overview of electrical breakdowns by mill type. As mentioned previous, SAG mills constitute a large portion of the gross TE loss likely due to being a production bottleneck.

Table 11. Electrical Breakdown of Grinding Mills by Type

Mill Type	*Total Gross Loss US$ Million*	*Gross PD US$ Million*	*Gross TE US$ Million*	*Avg. Gross/Loss*
SAG	67	98	57	99
Ball	33	2	43	1

4.0 REFERENCES

4.1 FM

Data Sheet 1-44, *Damage-Limiting Construction*
Data Sheet 1-57, *Plastics in Construction*
Data Sheet 2-0, *Installation Guidelines for Automatic Sprinklers*
Data Sheet 3-10, *Installation and Maintenance of Private Service Mains and Their Appurtenances*
Data Sheet 3-26, *Fire Protection for Nonstorage Occupancies*
Data Sheet 4-1N, *Fixed Water Spray Systems for Fire Protection*
Data Sheet 4-4N, *Standpipe and Hose Systems*
Data Sheet 5-1, *Electrical Equipment for in Hazardous (Classified) Locations*
Data Sheet 5-17, *Motors and Adjustable Speed Drives*
Data Sheet 7-11, *Conveyors*
Data Sheet 7-14, *Fire Protection for Chemical Plants*
Data Sheet 7-29, *Ignitable Liquid Storage in Portable Containers*
Data Sheet 7-32, *Ignitable Liquid Operations*
Data Sheet 7-40, *Heavy Duty Mobile Equipment*
Data Sheet 7-43, *Process Safety*
Data Sheet 7-45, *Safety Controls, Alarms, and Interlocks*.
Data Sheet 7-76, *Combustible Dusts*
Data Sheet 7-78, *Industrial Exhaust systems*
Data Sheet 7-83, *Drainage and Containment Systems for Ignitable Liquids*
Data Sheet 7-88, *Ignitable Liquid Storage Tanks*
Data Sheet 7-98, *Hydraulic Fluids*
Data Sheet 7-99, *Heat Transfer by Organic and Synthetic Fluids*
Data Sheet 8-10, *Coal and Charcoal Storage*

Data Sheet 9-0, *Asset Integrity*
Data Sheet 10-3, *Hot Work Management*
Data Sheet 10-8, *Operators*
Data Sheet 13-7, *Gears*

APPENDIX A GLOSSARY OF TERMS

Gassy mine: A mine with known or potential flammable gas deposits.

Rock burst: Damage that occurs when a hydraulically or geologically stressed section of rock essentially "blows" out into the tunnel environment causing local damage and far ranging overpressure effects due to air pressure down tunnels.

Slurry racing: An erosion/corrosion phenomenon that occurs in wet milling (e.g., SAG or ball) where a mixture of water, chemicals, and pulp (i.e., slurry) leaks behind the shell, head, or trunnion liners causing gouges in these load bearing components typically in a circumferential orientation, and/or in bearing damage. Slurry racing is also known as "washing."

APPENDIX B DOCUMENT REVISION HISTORY

The purpose of this appendix is to capture the changes that were made to this document each time it was published. Please note that section numbers refer specifically to those in the version published on the date shown (i.e., the section numbers are not always the same from version to version).

July 2022. Interim revision. Minor editorial changes were made.

July 2020. Interim revision. Updated contingency planning and sparing guidance.

January 2020. This document has been completely revised. Major changes include the following:

A. Changed the title (from *Mining and Ore-Processing Facilities* to *Mining and Mineral Processing*).

B. Revised the scope to clearly define when the user should refer to another data sheet.

C. Revised recommendations for heavy-duty mobile equipment (HDME) shops with tall bays.

D. Added recommendations for fire hazards within mineral concentrators (e.g., screens, hydrocyclone clusters, spirals, and filter presses).

E. Revised and added recommendations for common boiler & machinery exposures (e.g., hoists, crushers, and mills).

F. Revised recommendations on pressure leaching.

G. Revised recommendations for mining-specific hazards such as TDF failures, collapse (underground), slope failure (surface), and de-watering (underground).

H. Added recommendations for floating equipment platforms.

January 2019. Interim Revision. Incorporated alumina refining content from Data Sheet 7-64, *Aluminum Smelting*, and made a few minor revisions. Added guidance on grinding mill ring gear contingency planning.

April 2016. Interim revision.

References to Data Sheet 5-7, *National Electrical Code* that was made obsolete, were deleted.

September 2010. Minor editorial changes were made.

May 2010. Minor editorial changes were made.

May 2007. Section 2.4.8 on solvent extraction plants was completely revised.

September 2004. References to FM Global earthquake zones have been modified for consistency with Data Sheet 1-2, *Earthquakes*.

January 2001. This document has been reorganized to provide a consistent format.

APPENDIX C RELEVANT FM DATA SHEET REFERENCES

This data sheet contains unique loss prevention guidance tailored specifically for mining and mineral processing along with their support systems. For brevity, general loss prevention guidance contained within other FM data sheets (i.e., not unique to a mine) was not duplicated within this data sheet, but may be applicable at a mine. For example, Data Sheet 5-4, Transformers, contains inspection, testing, and maintenance guidance that is applicable to step-down transformers and rectiformer group transformers. Below is a list of other FM data sheets that may be applicable at a mine or mineral processing facility. This list is not intended to be an all-inclusive.

Site Selection (Buildings and Utility Services)

1-2, *Earthquakes*
1-34, *Hail Damage*
1-40, *Flood*
1-27, *Windstorm*

Building Construction

1-11, *Fire Following Earthquake*
1-28, *Wind Design*
1-29, *Roof Deck Securement and Above-Deck Roof Components*
1-54, *Roof Loads for New Construction*
1-57, *Plastics in Construction*

Fire Protection

2-0, *Installation Guidelines for Automatic Sprinklers*
3-10, *Installation and Maintenance of Private Service Mains and Their Appurtenances*
3-26, *Fire Protection for Nonstorage Occupancies*

Systems and Equipment

1-6, *Cooling Towers*
1-62, *Cranes*
5-4, *Transformers*
5-11, *Lightning and Surge Protection for Electrical Systems*
5-17, *Motors and Adjustable Speed Drives*
5-19, *Switchgear and Circuit Breakers*
5-20, *Electrical Testing*
5-23, *Design and Protection for Emergency and Standby Power Systems*
5-30, *Power Factor Correction and Static Reactive Compensator System*
5-31, *Cables and Bus Bars*
5-32, *Data Centers and Related Facilities*
6-5, *Oil or Gas-Fired Multiple Burner Boilers*
6-17, *Rotary Kilns and Dryers*
6-23, *Watertube Boilers*
7-6, *Plastic and Plastic-Lined Tanks*
7-11, *Conveyors*
7-14, *Fire Protection for Chemical Plants*
7-29, *Ignitable Liquid in Portable Storage Containers*
7-32, *Ignitable Liquid Operations*
7-45, *Safety Controls, Alarms, and Interlocks*.
7-76, *Combustible Dusts*
7-78, *Industrial Exhaust Systems*
7-88, *Ignitable Liquid Storage Tanks*
7-95, *Compressors*
7-98, *Hydraulic Fluids*
7-99, *Heat Transfer by Organic and Synthetic Fluids*
7-101, *Fire Protection for Steam Turbines and Electric Generators*
7-110, *Industrial Control Systems*
12-2, *Vessels and Piping*

12-3, *Continuous Digesters and Related Process Vessels*
12-6, *Batch Digesters and Related Process Vessels*
13-3, *Steam Turbines*
13-7, *Gears*
13-17, *Gas Turbines*

Human Element

2-81, *Fire Protection System Inspection, Testing, and Maintenance*
7-43, *Process Safety*
9-0, *Asset Integrity*
9-18, *Prevention of Freeze-Ups*
10-1, *Pre-Incident Planning*
10-3, *Hot Work Management*
10-4, *Contractor Management*
10-8, *Operators*