ALUMINUM SMELTING

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1.0 SCOPE

This data sheet contains property loss prevention guidance unique to aluminum smelters and addresses hazards and exposures associated with reduction pots (potline), the potroom, electrical distribution and rectifiers supplying power to the potline, other critical potline utility services and ancillary support systems, and anode production.

This data sheet does not cover operations upstream or downstream of aluminum smelting. Refer to the applicable data sheets for loss prevention guidance for these operations, which may include 7-12, *Mining and Ore Processing Facilities*, for bauxite mining and alumina refining; and 7-33, *Molten Metals and Other Materials*, for molten aluminum refining and alloying, and casting.

This data sheet is intended as a supplement to other data sheets. When evaluating hazards and exposures not addressed in this data sheet (i.e., not unique to aluminum smelting), apply the applicable data sheet. These may include the following:

- 5-4, *Transformers*
- 5-19, *Switchgear and Circuit Breakers*
- 5-31, *Cables and Bus Bars*
- 7-110, *Industry Control Systems, for control equipment and operator control rooms*
- 1-62, *Cranes*
- 7-11, *Conveyors, for bulk material handling*
- 7-78, *Industrial Exhaust Systems, for fume or gas treatment centers*
- 7-99, *Heat Transfer by Organic and Synthetic Fluids, for heated anode production equipment*

Appendix C contains a more comprehensive list of data sheets that may be applicable at aluminum smelters and anode plants.

1.1 Hazards

1.1.1 Aluminum Smelter

Potline freeze is the primary hazard at an aluminum smelter. Loss of line current for several hours can be disastrous for the potline as the cryolite bath and molten aluminum solidify, damaging pots that take months to recover. Electrical interruptions may occur anywhere in the power supply path from offsite generating station to transmission to onsite generation to onsite distribution to rectifier groups due to equipment breakdown or natural hazard events. In addition to electrical power, loss of other utility services or ancillary support systems such as compressed air, alumina supply or handling, pot controls, anode supply, or gas treatment for hours to days can also force a potline to shut down. Given the extreme sensitivity of pots to loss of critical services and support systems, potlines warrant N-1 redundancy, while operator training, procedures, and recovery planning aid in responding to abnormal or emergency conditions, and expedite potline recovery efforts.

1.1.2 Carbon Plant

Fire and mechanical breakdown hazards tend to be the more significant in a carbon plant. Fuel loading in a carbon plant can include heat transfer fluid (HTF), process materials (petroleum coke and pitch), and hydraulic fluid, which when combined can support a large fire. Abnormal operation of anode baking furnaces can lead to combustible residues forming in the downstream exhaust ductwork and emission-control equipment. From a mechanical breakdown perspective, replacement parts for specialized process equipment, such as the preheater and kneader, often have long lead times. A fire in the carbon plant or critical equipment failure has the potential to disrupt carbon plant production for up to several months.

1.2 Changes

April 2025. Interim revision. Minor changes were made to process safety guidance to align with FM Property Loss Prevention Data Sheet 7-33, *Molten Metals and Other Materials*.

2.0 LOSS PREVENTION RECOMMENDATIONS

2.1 General

2.1.1 Use FM Approved equipment, building materials, and services whenever applicable and available. Select and install FM Approved products and services in accordance with their 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 Implement a process safety program for the following areas of the facility:

- Electrical power supply and onsite distribution to potline rectifying groups whether fed by offsite utility substations and transmission lines, offsite captive generation and transmission lines, or onsite captive generation with local grid inter-ties
- Carbon and anode plants
- Potline(s) including often critical support systems such as: rectifying and auxiliary electrical power; anode supply; alumina receiving, storage, and transfer; fume treatment; pot and potline controls; pneumatic air; pot-tending assemblies; tapping; and casting
- Downstream molten processing and casting (refer to FM Data Sheet 7-33, *Molten Metal and Other Materials)*

2.1.2.1 Align the process safety program with FM Data Sheet 7-43, *Process Safety*, and when molten metal is present, Data Sheet 7-33, *Molten Metal and Other Materials*, as well. The process safety program should at a minimum evaluate for and assess the following hazards: loss of utility power (service interruption); electrical breakdown (loss of power generation and distribution); fire; combustible dust explosion; flammable gas explosion; molten-water equipment explosion; molten-water equipment room; and molten release with thermal damage.

2.2 Potline

2.2.1 Location and Construction

2.2.1.1 Route electrical power cabling and control wiring so redundant cable/wire runs to critical electrical equipment are outside of a common fire area or otherwise not subject to a common exposure or failure mode. Similarly, route cable and wire runs to critical equipment through areas not subject to fire or other exposures.

2.2.1.2 Construct buildings or rooms containing the following using noncombustible construction: potrooms, critical ancillary support system or utility service equipment, and wherever a molten aluminum-water explosion hazard exists. If combustible or plastic building materials are required, use FM Approved building materials. Combustible building construction may include insulated metal panels, insulated steel deck roof assemblies, and interior plastic facings. Install FM Approved building materials in accordance with the manufacturer's guidelines and the FM Approval listing.

2.2.1.3 If claustra panels are used in potrooms, use noncombustible materials and assemblies.

2.2.1.4 Design the potroom building envelope in a manner that limits the potential for water ingress onto the potline operating floor. Install exteriorly routed roof drains. If exterior drains are not feasible, construct interiorly routed drains in a manner to prevent a leak or rupture from exposing pots (e.g., use high-strength materials and pipe joints, heat trace exposed portions, and limit pipe bends).

2.2.1.5 Design potroom basements (i.e., areas beneath the potline operating floor) to prevent storm water, ground water, and wind-blown snow from entering or collecting beneath pots.

2.2.2 Protection

2.2.2.1 Provide automatic fire protection in rooms that house critical equipment and are exposed by fire. Critical equipment may be part of the electrical distribution system, or ancillary support systems. Critical equipment may also include operator control rooms, and control equipment rooms. Design and install protection in accordance with Data Sheet 7-110, *Industrial Control Systems*. Additionally, provide automatic fire protection throughout buildings containing fire hazards that expose rooms with critical equipment.

2.2.2.2 Conduct a fire risk analysis to determine the appropriate fire protection features for potline rectiforming groups. Rectiforming groups may consist of regulating and rectifying transformers, DC converter, control equipment, and associated power cabling and control wiring along with any magnetic compensation loop equipment. The fire protection goal is to (a) limit fire damage to one rectiformer group of origin without exposing adjacent groups, collector bus, or other critical equipment; and (b) allow personnel to deenergize the collector bus, deenergize the subject group, and reenergize the collector bus prior to risking a potline freeze. To achieve this performance goal, consider the following fire protection features for potline rectiforming groups.

A. Install fire-resistive separations around individual potline rectiforming groups and the potline collector bus in accordance with Data Sheet 5-4, *Transformers*. Given the limited space available in a typical potline substation, separation distance between rectiformer groups is often not feasible.

B. Install ignitable liquid spill containment and/or emergency drainage around transformers in potline rectiforming groups in accordance with Data Sheet 5-4, *Transformers*. Design the containment to prevent transformer oil from spreading to expose adjacent potline rectiforming groups and the collector bus, and when appropriate install emergency drainage to minimize fire duration. An example of transformer containment and drainage may include a concrete pit surrounding each transformer filled with rock arranged to gravity drain to a remote oil-water separation pit.

C. Install operational controls and fire protection features to enable prompt manual isolation of the subject rectiformer group during a fire (e.g., the incoming AC supply and the DC feed to the potline collector bus). Arrange operational controls for remote manual operation (e.g., from the control room). Ensure isolation switches, power cabling, control wiring, and controls for remote isolation of the rectiformer group are not exposed by the subject fire.

D. If automatic water spray/deluge is provided over the potline rectiforming group to minimize fire duration thus recovery time, design the automatic fire protection system in accordance with Data Sheet 5-4, *Transformers*. Lack of automatic fire protection is acceptable if the rectiformer group fire is properly isolated from adjacent rectiformer groups and the bus re-energized as discussed in section 2.2.2.2 A through C.

2.2.2.3 Use nonignitable hydraulic fluid or FM Approved industrial fluid in hydraulic systems located in areas that process or handle molten aluminum.

2.2.2.4 Separate multi-cell/compartment reactors/baghouses in gas treatment centers (GTC) with fire-resistive construction, rather than providing automatic fire protection, in accordance with data sheet 7-76, *Combustible Dusts*.

2.2.2.5 Provide automatic fire protection within fume treatment center (FTC) baghouses in accordance with Data Sheet 7-76, *Combustible Dusts*, for design guidance.

2.2.3 Equipment and Processes

2.2.3.1 Electrical Supply

2.2.3.1.1 When supplied by an offsite utility, arrange offsite power transmission to the smelter as follows:

A. Connect the smelter to the utility grid using a double-ended arrangement fed by different substations. Connect the feeders directly to the utility grid or generating station independent of power transmission to other customers.

B. Install at least N+1 feeders (i.e., minimum of two feeders each capable of supporting total smelter demand).

C. When run aboveground, physically separate multiple feeders and redundant feeders on independent towers (i.e., pylons) without cross-overs to prevent a single point of failure from exposing both feeders (e.g., avalanche from damaging towers of multiple feeders). Additionally, provide sufficient space separation between towers to prevent collapse of one tower damaging adjacent feeders.

D. With aboveground feeders, design power transmission lines and towers to resist maximum natural hazard-related loads (e.g., ice, wind, avalanche, or earthquake) in accordance with local jurisdictions.

E. When run underground, separate multiple or redundant feeders within independent conduit or tunnels to prevent a single point of failure from exposing both feeders.

F. If underground feeders are installed, identify the underground runs with placards to prevent damage during excavation.

2.2.3.1.2 When the smelter is supplied by onsite power generation (captive), or a combination of onsite and offsite power generation, design the electrical supply to resist transients and N-1 contingency events. In the design, consider all possible operational configurations and include the following.

A. Develop N-1 scenarios and provide sufficient availability in the onsite power generation (and utility supply) to accommodate the combination of planned outages for turbine-generator maintenance, and fluctuations in seasonal generating efficiencies along with forced outages (trips) such as loss of primary fuel source.

B. Provide an automated power-swing management system to handle trips of generation (captive), interties (utility), or loads (potlines) accounting for the transients associated with these trips.

C. Provide an onsite black-start power generation system.

D. Design the electrical system to ease recovery efforts in the event of a cascading failure to allow a black start.

2.2.3.1.3 Provide the electrical feed supplying potline rectiforming groups with N+1 consisting of redundant power feeds and main incoming transformers (e.g., double-ended arrangement). Physically separate N+1 electrical equipment to prevent a single point of failure from exposing redundant or multiple feeds. When evaluating single points of failure, consider both equipment breakdown scenarios such as arcing or arc-flash due to electrical insulation breakdown as well as fire following equipment breakdown when oil-filled electrical equipment, concentrations of grouped power cabling, or other concentrations of combustibles are present.

The power feed from incoming transformers to potline rectiforming groups may consist of transformers, bus bars, power cables, and/or switchgear.

2.2.3.1.4 Provide critical potline electrical loads, other than rectiforming groups, with N+1 consisting of redundant power feeds from independent substations (e.g., double-ended arrangement). Physically separate N+1 electrical equipment to prevent a single point of failure from exposing redundant power feeds. When evaluating single points of failure, consider both equipment breakdown scenarios such as arcing or arc-flash due to electrical insulation breakdown as well as fire following equipment breakdown when oil-filled electrical equipment, concentrations of grouped power cabling, or other concentrations of combustibles are present.

Critical electrical loads are those potline utility services or ancillary support systems that if lost may result in a potline freeze or a forced potline shutdown before repairs are completed and power can be restored. Critical loads may be found in pot tending controls (e.g., anode bridge adjustment), power controls (e.g., power regulation and rectiformer groups), compressed air stations, material handling (e.g., cranes and conveyors), and gas treatment centers.

2.2.3.1.5 In potline current creep projects and changes in power and generation and distribution, ensure the following aspects are considered:

A. Maintain N-1 during and after project completion for all critical ancillary support systems and utility services (e.g., electrical service, compressed air service, cranes, and gas treatment centers)

B. Update power swing management and tripping schemes.

C. Update standard operating and emergency procedures

D. Update recovery and equipment contingency plans.

E. Update operator training.

2.2.3.2 Rectiforming Groups

2.2.3.2.1 Design the direct current (DC) electrical supply for a potline using N-1.

The intent is to: (a) allow one rectiforming group to be out-of-service for a planned outage (maintenance) yet maintain full line current; and (b) accommodate a second forced outage of a rectiforming group yet support stable potline operation, possibly at reduced line current, to prevent a potline freeze (i.e., a maintenance outage and forced outage). The potline rectiforming group may consist of a regulating transformer, rectifying transformer, rectifier unit (diode or thyristor), and rectiformer group local control cabinet. Consider direct current (DC) electrical supplies serving a magnetic compensation loop as part of the rectiforming group.

2.2.3.2.2 Provide leak detection for water-cooled rectifier units to first sound an alarm at a constant attended location upon reaching an abnormal condition, then interlock-trip the unit upon reaching a hazardous condition. Leak detection methods may include low water level, or low return water pressure or flow.

2.2.3.2.3 Provide arc protection within rectifier unit cubicles (diode or thyrister) interlocked to automatically trip the unit. Arrange detectors to automatically isolate the cubicle of origin.

2.2.3.2.4 Route the direct current (DC) collector and distribution bus in a manner that minimizes exposures from fire, molten aluminum (pot tapout), and mechanical impact damage. Additionally, arrange the bus to be inspected by maintenance personnel and accessed for emergency repairs.

2.2.3.3 Compressed Air Supply

2.2.3.3.1 Provide critical potline compressed air loads with N+1 consisting of redundant distribution paths from independent, redundant compressor stations. Physically separate independent compressor stations and distribution piping to prevent a single point of failure from exposing redundant compressed air feeds. When evaluating single points of failures, consider both equipment breakdown scenarios such as rupture of an oil-separator as well as fire following equipment breakdown when lubrication oil systems are present and mechanical impact.

Critical compressed air loads are in potline utility services or ancillary support systems that if lost may result in a potline freeze before repairs are completed and power restored. Critical loads may be found in pot tending controls (e.g., crust breaking, pot charging, and/or pot tapping), material handling (e.g., cranes and conveyors), and gas treatment centers.

2.2.3.4 Ancillary Support Systems

2.2.3.4.1 Design potroom crane systems (i.e., cranes, pot tending assemblies, and crane ways and cross-over paths) fulfilling critical potline functions to ensure maximum reliability and availability (e.g., pot tapping, pot tending, and pot rebuild). Apply the N-1 for the potroom crane systems to allow for continued potline operation during both a scheduled crane outage (maintenance) and a forced crane outage (breakdown).

2.2.3.4.2 Use noncombustible materials in the construction of ancillary support systems such as pot gas treatment centers. If combustible or plastic materials are required, use FM Approved materials. Install FM Approved building materials in accordance with the manufacturer’s guidelines and the FM Approval listing.

2.2.3.4.3 Design gas treatment centers to ensure maximum reliability and availability for processing reduction cell exhaust gases. Apply the N-1 to gas treatment centers.

2.2.3.4.4 Maintain a sufficient quantity of emergency bus-bar sections, wedges, and jumpers to allow for bypassing of individual pots or groups of pots during a potline emergency (e.g., extended power outage where pots become unstable).

2.2.3.5 Downstream Aluminum Processing

2.2.3.5.1 Design onsite casting facilities to ensure maximum reliability and availability for processing primary aluminum production. Apply the N-1 for casting operations to prevent an interruption of a casting machine from affecting primary aluminum production (i.e., the smelter). Interruptions may be caused by damage from fire, molten metal-water reactions, or equipment breakdown. For the various exposures, use creditable scenarios to assess damage to the machine of origin along with damage to surrounding machines. For example, a molten metal-water explosion in a vertical direct-chill casting pit destroying the machine of origin and damaging the machines immediately adjacent as well as holding furnaces.

2.2.4 Operation and Maintenance

2.2.4.1 Operation

2.2.4.1.1 Implement a standard operating procedure for the following routine potline activities:

A. Startup of a new pot.

B. Response to open circuit events.

C. Response to pot low/high voltage.

D. Operating at slightly reduced line current.

E. Managing anode effects.

F. Monitoring pots at end of life.

G. Operating without N-1 reliability for scheduled maintenance (i.e., typically a shorter duration outage).

H. Cutting out a pot or groups of pots due to instabilities. Ensure the following aspects are covered:

1. Decision-making process for cutting out a pot.

2. Procedural steps to cut out a pot.

3. Have the procedure endorsed by senior management granting authority to remove pots from production.

4. Location of bypass and equalizer wedges, bus sections, and ancillary hardware and tools needed to cut out a pot.

Develop, maintain, and train operators on the procedures in accordance with Data Sheet 10-8, *Operators*.

2.2.4.1.2 Implement abnormal and/or emergency operating procedures for the following potline scenarios:

A. Loss of AC electrical power to the smelter (offsite service interruption at power distribution and generating station)

B. Loss of or reduced AC power to a potline (onsite electrical breakdown)

C. Loss of or reduced DC power to a potline

D. Loss of auxiliary power to potline ancillary support systems such as cranes (pot tending or transportation of hot crucibles), pot controllers, or anode jacking.

E. Loss of or reduced compressed air for a potline

F. Interruption in onsite alumina supply for a potline

G. Interruption of baked anode and rodded anode production

H. Loss of gas treatment or reduced gas treatment capacity for a potline.

I. Loss of DCS control requiring manual operation using pot controllers.

J. Operating without N-1 reliability due to a forced outage (i.e., typically a longer duration outage).

K. Wash-out of potline bus bar (temporary bus repairs).

Develop, maintain, and train operators on the procedures in accordance with Data Sheet 10-8, *Operators*. Focus the procedures on the potline operations for managing pot instabilities and maintaining pots warm to prevent an uncontrolled potline shutdown (i.e., potline freeze). Procedures should contain details with regards to anode changing, metal tapping, pot voltage control, anode covering material, bath level control, bath temperature and acidity control, operation of gas treatment centers, impact on cast house operations, and manpower and equipment requirements to complete tasks. Also, consider decision-making processes for load-shedding of non-critical potline operations, reducing line current, cutting out pots, and/or conducting a controlled potline shutdown as part of the emergency operating procedure.

2.2.4.1.3 Implement emergency response plans in accordance with Data Sheet 10-1, *Pre-Incident Planning*, for combating the following exposures:

A. Fire involving a potline rectiformer group

B. Pot tapout to limit aluminum release and exposure posed

C. Fire involving plastic claustra panels within the potroom

D. Fire in a gas treatment center

E. Fire in alumina conveying equipment

2.2.4.1.4 Implement a potline recovery plan for the following scenarios. Include restart procedures that cover the restart method(s) along with materials, labor, and specialized resources and equipment required to restart a potline or multiple potlines. Develop an expected potline restart schedule with sourcing materials, equipment, and labor. Consider pot repair or rebuild rates, and expected pot restart rates.

A. Uncontrolled potline shutdown, where the pots are not prepared prior to freeze such as during a sudden loss of electrical power or compressed air.

B. Controlled potline shutdown, where the pots are “hibernated” or “put-to-sleep” to prevent or postpone freeze such as upon interruption in alumina or anode supply, or labor disruption.

2.2.4.2 Maintenance

2.2.4.2.1 Implement an asset integrity program for equipment associated with critical production equipment, and ancillary support systems and utility services in accordance with Data Sheet 9-0, *Asset Integrity*. Conduct remaining life assessments on aging equipment and establish asset replacement plans that include threshold criteria for specific actions (e.g., budgeting for or ordering a replacement), which may involve short-term budgeting for a rebuild or obtaining a replacement.

2.2.4.2.2 Implement a pot life monitoring program to prevent pot tapouts. Sample and test aluminum for iron content and bath for sodium content. Additionally, consider testing for silica, which is another indicator of molten aluminum penetration into refractory.

2.2.4.2.3 Inspect potline distribution bus bars for accumulations of alumina or other debris (conductive, insulating, or combustible), and for overheating at least weekly.

2.2.4.2.4 Inspect the potline collector and distribution bus bars for damage at least annually. Evaluate structural support and thermal stresses caused by current creep or fatigue cycling.

2.2.4.2.5 Inspect potline rectiforming groups in accordance with original equipment manufacturer’s guidelines. At a minimum, inspection of cooling water levels in the rectifying unit weekly (diode or thyrister cubicles).

2.2.4.2.6 Maintain rectifying units (diode or thyrister cubicles) in accordance with the original equipment manufacturer’s guidelines. At a minimum, inspect water-cooling hoses and connections, internal cleanliness (presence of dust that could lead to tracking), and tightness of electrical connections at least monthly.

2.2.5 Contingency Planning

2.2.5.1 Develop and maintain an equipment contingency plan for critical utility services and ancillary support systems that do not benefit from N-1 or N+1. Assess criticality based on the impact to potline operations in the event the service or system capacity is reduced or lost entirely for the expected recovery duration. Impacts may include reduced line current or possibly a controlled potline shutdown. Refer to Data Sheet 9-0, *Asset Integrity*, for mitigative strategies to limit business interruption along with information to document in the plan and specific actions to consider. The following services and systems may prove critical and warrant contingency plans:

A. Alumina ship unloading

B. Alumina conveying equipment such as belt conveyors and bucket elevators

C. Downstream molten aluminum refining (fluxing and degassing), alloying and casting operations

2.2.5.2 When required by the equipment contingency plan, properly store (either on or off site) and maintain spare parts/components and/or units to assure the viability of the units. Store spare parts in accordance with manufacturer’s instructions and protect them against physical damage, moisture, dirt and other contaminants. Inspect, test, and maintain spares per manufacturer’s instructions to maintain viability.

2.2.5.3 Review the equipment contingency plan annually and/or when there is a significant change onsite which could include the use of spares, spares not being stored/maintained as viable, changes in processes, change in revenue flows, etc. in order to manage change in exposures, maintain viability, and confirm effectiveness of the equipment contingency planning to mitigate the equipment breakdown exposure.

2.3 Carbon Plant

2.3.1 Location and Construction

2.3.1.1 Construct buildings or rooms containing the following using noncombustible construction: paste plants; bake oven areas; rodding shops; and other buildings containing equipment associated with critical services and ancillary support systems. If combustible or plastic building materials are required, use FM Approved building materials. FM Approved building materials include insulated metal panels, insulated steel deck roof assemblies, and interior plastic facings. Install FM Approved building materials in accordance with the manufacturer's guidelines and the FM Approval listing.

2.3.2 Protection

2.3.2.1 When heat transfer fluid (HTF) systems are used in the paste plant and for liquid pitch handling, provide fire protection features in accordance with Data Sheet 7-99, *Heat Transfer by Organic and Synthetic Fluids*. Of particular importance are the following recommendations:

A. Locate fluid heaters/vaporizers limiting the exposure to each other, adjacent process structures, other outdoor equipment and tanks, and buildings. When multiple heaters are installed in close proximity, consider fire-resistive construction (separations) along with spill containment and emergency drainage to prevent damage to an adjacent unit.

B. Provide ignitable liquid spill containment and emergency drainage in areas containing HTF. Of particular concerns are HTF use-points where either production critical equipment may be exposed to a long duration, intense fluid fire (e.g., preheater or mixer/kneader), or a three-dimensional spill fire may cause a large number of sprinkler operations and intense thermal damage (e.g., paste plant process structures with open grate flooring).

C. Provide automatic sprinkler protection in areas containing HTF.

D. Provide fire interlock-trips to automatically depressurize and isolate HTF circulation. Activate the interlock trip via FM Approved fire detection systems or upon automatic sprinkler activation. Arrange the trips to perform the appropriate interlock functionality to depressurize the fluid release and limit fluid hold-up available to gravity release. Actions may include shutting down pumps, isolating use-points and piping, and draining fluid to a safe location (e.g., dump tank).

2.3.2.2 Evaluate the potential for a dust explosion hazard when using green/petroleum coke (i.e., not calcined) or solid pitch.

2.3.2.3 Provide automatic sprinkler protection in areas where combustibles or ignitable liquids are present (e.g., heat transfer fluid, liquid or solid pitch, green coke, ignitable hydraulic fluid that is not FM Approved, belt conveyors, or bucket elevators). Design and install automatic sprinkler protection in accordance with the applicable data sheets. When possible, wet sprinkler protection is preferred.

Do not install automatic sprinkler protection over areas containing molten metal (e.g., iron casting area of the rodding shop). Provide alternative fire protection features in areas containing molten metal, which may include use of FM Approved industrial fluids in hydraulic systems or fire interlock-trips for hydraulic systems, or operating procedures and emergency response plans for belt conveyors.

2.3.2.4 Use FM Approved industrial fluid within rodding shop hydraulic systems such as butt strippers, thimble presses, and rod straighteners.

2.3.2.5 Provide automatic fire protection in anode baking oven fume exhaust systems extending from the ring main outlet to the fume treatment center inlet in accordance with Data Sheet 7-78, *Industrial Exhaust Systems*. Extend protection upstream to the ring main if housekeeping inspections reveal combustible deposit formation.

2.3.2.6 Design and protect anode baking baghouses in accordance with Data Sheet 7-76, *Combustible Dusts*.

2.3.3 Equipment and Processes

2.3.3.1 Monitor anode baking oven fume exhaust temperatures and maintain temperatures above the dew point throughout the ductwork to minimize condensation of combustible vapor and formation of combustible residues.

2.3.3.2 Provide a fume exhaust bypass downstream of anode baking ovens but upstream of the fume treatment equipment (e.g., baghouse or scrubber) with vent to atmosphere.

2.3.3.3 Provide an alternative means to drive anode baking oven exhaust fans upon loss of electric power in order to allow for a controlled, safe shutdown. Potential options include installing drivers of different motive force (e.g., diesel-engines) or a local power supply (e.g., diesel-driven generators).

2.3.3.3.4 Implement a management of change program. Of particular concern are changes in anode furnace operating or control limits, types of burner fuels, and raw materials used in green anode production.

2.3.4 Operation and Maintenance

2.3.4.1 Operation

2.3.4.1.1 Implement a standard operating procedure (SOP) to manage the ignition hazard posed by hot spent anodes on a conveyor belt. Alternatively, add points of emphasis to existing SOPs regarding the importance of managing hot anode butts on conveyor belts. During a forced or planned shutdown of conveyor belts, ensure all hot anode butts or bath material has been removed.

2.3.4.1.2 Implement emergency response plans in accordance with Data Sheet 10-1, *Pre-Incident Planning*. Involve operators and maintenance personnel when developing the response plans, and include them as members of the emergency response team. Document the response plans, and audit them at least annually (e.g., review the plans to ensure facility changes were addressed). Develop responses to the following scenarios as appropriate:

A. Fire in paste plant (e.g., involving HTF, hydraulic fluid, and/or combustible process materials)

B. Fire in the anode baking oven fume exhaust system

C. Fire in the liquid pitch storage and handling areas

D. Fire in the rodding shop (e.g., involving a belt conveyor or hydraulic fluid)

2.3.4.2 Maintenance

2.3.4.2.1 Visually inspect the internals of the preheater and kneader in accordance with OEM guidelines. Adjust the inspection scope and frequency to monitor the active damage mechanism (i.e., erosion or abrasion).

2.3.4.2.2 Develop a nondestructive examination (NDE) program for the preheater screw and kneader barrel in accordance with OEM guidelines. Conduct full examinations starting at a minimum of annually. Document examination results along with any requests for corrective action. Adjust the examination scope and frequency based on site-specific conditions such as operating history, current operating conditions, equipment upgrades or changes, and the results of the previous examinations.

2.3.4.2.3 Maintain preheater and kneader gears in accordance with Data Sheet 13-7, *Gears*.

2.3.4.2.4 Implement a housekeeping program to inspect for and remove combustible dust accumulations in areas processing green/petroleum coke or solid pitch. Of particular concern are dust accumulations on cable and wire trays, sprinklers or deluge nozzles, and elevated horizontal surfaces including piping, structural members, and exhaust ductwork. Base the frequencies for inspection and accumulation removal (cleaning) based on trended inspection results. Often weekly cleanings are considered sufficient to minimize dust accumulations; however, ensure cleanings are conducted immediately following any sudden, large dust releases. When possible, install a central vacuum system to be used for regular cleaning with ports and tools installed at common release points. During inspections, identify combustible dust release points, and generate a corrective action to address the release point. Document inspections and cleaning activities for review by management.

2.3.4.2.5 Implement a housekeeping program to inspect for and remove combustible deposits/residues in areas handling liquid pitch or using HTF. Arrange the program similarly to the combustible dust inspections (section 2.4.4.2.4), but concentrating on liquid release points including flanged connections, pumps, flexible hoses, and rotary joints.

2.3.5 Contingency Planning

2.3.5.1 Develop and maintain an equipment contingency plan for critical production equipment, and ancillary support systems and utility services that do not benefit from N-1 or N+1. Assess criticality based on the impact to potline operations in the event anode and rodded anode production capacity is reduced or lost entirely for the expected recovery duration. Impacts may include reduced line current or possibly a controlled potline shutdown. Consider the breakdown scenario when determining the expected recovery duration. Equipment breakdown scenarios should be derived based on the exposing damage mechanisms and failure modes as well as potential damage to interconnected or adjacent equipment. Of particular concern at a carbon plant are the following operations and equipment:

- Coke unloading station (ship unloader)
- Calciner (e.g., ring gear)
- Grinding/ball mill (e.g., gear set or other drive components)
- Liquid pitch supply
- Heat transfer fluid (HTF) heater/vaporizer
- Preheater (e.g., gear box and screw)
- Kneader (e.g., gear box and screw)
- Anode press or vibratory compactor
- Anode baking furnace crane systems
- Spent anode processing (e.g., carbon jaw press and iron thimble jaw press)
- Rodding shop molten iron casting process equipment including spent anode processing

2.3.5.2 When required by the equipment contingency plan, properly store (either on or off site) and maintain spare parts, components, and/or units to ensure the viability of the units. Store spare parts in accordance with manufacturer's instructions and protect them against physical damage, moisture, dirt and other contaminants. Inspect, test, and maintain spares per manufacturer's instructions to maintain viability.

2.3.5.3 Review the equipment contingency plan annually and/or when there is a significant change onsite which could include the use of spares, spares not being stored / maintained as viable, changes in processes, change in revenue flows, etc. in order to manage change in exposures, maintain viability, and confirm effectiveness of the equipment contingency planning to mitigate the equipment breakdown exposure.

3.0 SUPPORT FOR RECOMMENDATIONS

3.1 Supplemental Information

3.1.1 Aluminum Smelter

3.1.1.1 Critical Utility Services and Potline Freeze

Unlike most other molten material processes, in which the material can be re-melted upon solidification, aluminum reduction pots do not have such capability. Smelters rely heavily on electrical power and compressed air to maintain pots operating and stable. Smelting pots use an electrical current passing between anodes and cathodes via the molten cryolite/alumina mixture and aluminum pad. Without line current, pots begin to cool. Newer technology pots are at risk of freeze in as little as 2 hours, while older potlines begin feeling the loss of line current in 4-8 hrs.

In addition to electricity, pots also rely on compressed air for pot-tending activities such as loading cryolite/additives and alumina, siphoning molten aluminum from the pad, and crust-breaking. Without these activities, pot instabilities may start surfacing in as little as 30 minutes, which if not addressed could lead to freeze.

As discussed previously, potlines are subject to freeze without DC power and compressed air in addition to auxiliary AC power for pot controls and other ancillary support systems.

During uncontrolled solidification (potline freeze), not only is production shut down but abrupt loss of these critical services may impede operators preparing warm pots for solidification, which may involve tapping out the metal pad, removing molten bath, or repositioning anodes (up or down). These actions can help expedite recovery following solidification.

After pot solidification, the potline cannot simply be re-energized to re-melt the cryolite bath like in other molten metal furnaces. When molten cryolite is allowed to cool, molten bath resistivity increases, and upon freezing, the solid bath is essentially nonconductive. Frozen pots need to be prepared for a cold restart, which is a lengthy manual labor-intensive process as solidified bath and aluminum need to be removed from most pots, while older pots may need to be rebuilt. Given the number of pots in a line, and the increasing pot size with new technologies, the potline may not be fully operational for many months.

3.1.1.2 Recovery Following a Service Interruption or Electrical Breakdown

Even at smelters with a more reliable electrical system, equipment breakdown incidents involving electrical infrastructure will occur, and inevitability power to potlines and/or the whole smelter may be interrupted. Such power interruptions can be shorter duration such as a circuit breaker operation to clear an upset condition or longer duration such as catastrophic failure of equipment. It is important that smelters develop operating procedures to ensure there is a prompt and effective response to any abnormal or emergency condition.

Standard operating and emergency operating procedures should contain sufficient detail on managing potline operations during various length power planned or forced outages. Accompanying procedures, operator training should be completed to ensure the abnormal or emergency operating procedures are promptly and effectively implemented. With effective procedures and operator training, there is a greater likelihood of a successful recovery following a power outage.

3.1.1.3 Fire Protection for Potline Rectiforming Groups

DC rectiforming groups contain a large amount of fuel from transformer oil to insulating plastics capable of supporting an intense, long duration fire (e.g., a rectiformer can contain over 45,000 gal or 170,000 L of oil). The risk posed by this fire hazard is exacerbated by the congested nature of potline equipment yards containing critical potline equipment, and the small recovery window available to restore line current and prevent a potline freeze. Given the sizable fire hazard and risk posed by a potline freeze, a comprehensive fire protection scheme is advised for rectiforming groups. The performance goal of the fire protection scheme should be to limit damage sustained to the subject rectiforming group (i.e., preventing damage to adjacent rectiforming group, collector bus, and DC isolators) and restoring line current within a reasonable period of time in order to minimize the potential for pot instability and/or potline freeze.

The starting point of the fire protection evaluation should be the assumption that a fault occurs in a transformer releasing a large quantity of oil producing a very intense pool fire that if not protected properly could burn for over 4 hours. To limit damage and allow for the restoration of line current, fire protection features may consist of not only fire-resistive construction (fire walls) but also fixed automatic fire protection, and emergency drainage and spill containment.

3.1.1.3.1 Adjacent Rectiforming Groups

Fire-resistive construction (i.e., fire walls) is preferred over space separation as a means of protecting adjacent rectiforming group. Relying on space separation alone (unless obviously extensive) may expose sensitive components of an adjacent rectiforming group to thermal and non-thermal damage as transformer oil is released, and the burning pool spreads in the equipment yard. Even minor damage to an adjacent rectiforming group may result in hours to days of downtime for that second unit, which in turn leads to a major reduction in line current with two rectiforming groups out of service. If unable to operate at the reduced line current, a forced potline shutdown or potline freeze may result.

When an equipment mezzanine is installed above the rectiforming groups, additional protection features may be warranted to prevent structural steel collapse and/or thermal damage to equipment, both of which may affect multiple rectiforming groups. Water-spray and emergency drainage, or foam-water and spill containment, may be options to protect overhead mezzanines.

3.1.1.3.2 Collector Bus

The design and layout of smelter DC power supplies can vary significantly such that no two are the same. The arrangement of aluminum bus bars with respect to the rectiforming groups varies significantly, where in some cases the bus bars pass directly over the transformers, nearby at grade level, or are located well away. Aluminum bus bars melt at temperatures of 1100°F-1200°F (600°C-650°C). These temperatures are quickly reached near a transformer oil fire. Location and/or fire-resistive construction (i.e., fire walls) are preferred to prevent thermal damage to the collector bus.

3.1.1.3.3 DC Isolators

Equally as important as limiting physical damage is being able to promptly isolate the damaged rectiforming group from the collector bus in order to re-energize the remaining rectiforming groups and restore line current. Typically, rectiforming groups have four DC isolators installed upstream of the collector bus. In some installations, the isolators are located just outside of transformer fire walls. Isolators may be remotely operable (powered devices) with manual override features; however, to manually open the isolators, an operator needs to be able to safely access the isolator, which may be while the subject transformer is still burning. Fire protection features should be provided to permit safe access either during the fire using fire-resistive construction or by promptly extinguishing the fire using water-spray and emergency drainage, or foam-water and spill containment.

3.1.1.4 Combustible Claustra Panels in Potrooms

In recent years, “claustra panels” have become common place to improve cooling airflow in potrooms while also serving as a nonconductive barrier between the floating potroom floor and the grounded building structure. The panels are of plastic construction, which presents a new fuel package in an otherwise mostly noncombustible occupancy.

These panels are an open grid (80% to 90% open) structure, and have dimensions of 8 ft (2.4 m) high by several inches (several centimeters) deep and run the length of the room outer walls, with frequent breaks for columns. Local pot controllers will be inset in the claustra panel.

3.1.1.5 Fire Protection for Critical Power Cabling and Control Wiring

Upon loss of power to a potline, the smelter has roughly between 2 to 8 hours to restore power before being at risk of a potline freeze. The recovery time from a cable fire can exceed this timeframe depending on the extent of cable damage (i.e., number of cables damaged and repair methods). Automatic sprinklers will react to control a cable fire, but only after enough cable insulation is burning to generate sufficient heat to activate sprinklers. Sprinkler discharge will prevent fire spread down the cable run, but the fire still inflicts heavy localized damage in the fire origin. As the number of damaged cables increases, so does the recovery time. A sprinkler controlled cable fire can still result in a potline freeze, especially if redundant cables (N-1) are run in the same fire area.

FM Approved cable coatings, installed per their *Approval Guide* listing, limit damage to the surrounding cables. Thus, number of cables that need to be spliced or re-run is greatly reduced along with recovery time.

Although cable coatings limit fire damage, cable coatings are not a substitute for redundant cable runs to critical loads (N-1). Fire is not the only hazard cables are exposed to. Other hazards include mechanical impact and electrical breakdown.

3.1.1.6 Monitoring Pot Health to Prevent Tap-Outs

Smelter potline cells are typically sampled daily and tested for primarily two contaminants. One is sodium, which has a detrimental effect on current efficiency and changes based on bath height, while the other contaminant is iron. Iron impurities are an indication of wear or cracking of the cathode lining (seals) that allow molten aluminum to penetrate into the refractory towards the bottom of the shell. If allowed to continue, a pot tap-out would eventually occur. An operating pot cannot be easily surveyed for molten penetration into the refractory and cathodes, thus iron content in aluminum along with temperature of cradle bottom (>300°C), and one or more bus bars (> 300°C) are relied upon to determine when to cut out and rebuild a pot. Bottom leaks are not often fixed given the difficulty.

Some smelters also test for silica which comes from the refractory brick linings. This is used in a similar manner as testing for iron, as it indicates cracking or wear of the refractory and cathodes in either side wall or bottom.

3.1.1.7 Asset Integrity Program

Regulating and rectifying transformers are critical, long-lead time components in the potline DC power supply. Although N-1 reliability is often provided, loss of one unit would render the potline operating with N units for an extended period of time. The lack of redundancy and increased loading on the remaining units increases the potline freeze risk. A remaining life assessment evaluation should be conducted periodically based on inspection, testing, and maintenance results, manufacturer guidelines, and/or consultant recommendations. Budgeting for transformer rewind or replacement should be initiated at defined thresholds with the goal being prior to transformer breakdown.

Careful review of service aged regulating and rectifier transformers should be conducted to identify when replacement should be made in order to avoid potential cascading transformer failures. Often rectifying units will have the same history and operating conditions. If one unit fails and extra load is shifted to additional units, then the remaining units will be stressed increasing the likelihood of another failure. Reliance on the N-1 is acceptable until near end of life, at which time rewind or replacement should begin to be considered. While furan analysis of transformer oil has limitations, this testing is an indicator of when transformer insulation is near end of life, and could be used to trigger a more detailed remnant life assessment of the transformers to determine when rewind or replacement should be budgeted.

3.1.2 Carbon Plant

3.1.2.1 Use of FM Approved Hydraulic Fluids in Rodding Shops

Smelters typically maintain 1 to 3 days of rodded anodes available as buffer stock while they may only have 30 to 70 days of anodes. As a result, a disruption due to a fire in the rodding shop can quickly affect potline operation. The rodding shop operation is typically a single line process of bath removal, carbon removal, iron thimble removal, rod straightening, rod cleaning, and then resealing into a new anode at an iron casting station. Many of these steps involve the use of hydraulic systems, which may be the only combustibles elements in the rodding shop (except maybe conveyor belts).

Rodding shop operations often have limited redundancy to limit impact of a system heavily damaged by a fire. Temporary manual operations may be possible, but only for the short term as these operations are labor intensive. Automatic sprinkler protection may be an option outside of iron casting areas; however, sprinklers will not sufficiently limit fire damage to the equipment of origin to facilitate a quick recovery before the buffer stock is depleted. Given the lack of options and sensitivity of the potline to a rodding shop disruption, use of FM Approved less hazardous industrial fluids is the preferred protection feature within rodding shops.

3.2 Loss History

3.2.1 Loss Data

3.2.1.1 Aluminum Smelting

A group of aluminum smelter losses that occurred over a roughly 25-year period were reviewed. Table 1 contains a breakdown of the losses by initiating peril.

Table 1. Aluminum Smelter Losses by Initiating Peril

Peril	*No. of Losses*	*Total Loss*	*Property Damage*	*Time Element*
Electrical Breakdown	65%	30%	31%	29%
Service Interruption	14%	62%	63%	60%
Molten Breakout	11%	8%	5%	11%
Fire	7%	<1%	<1%	<1%
Explosion	2%	<1%	<1%	<1%
Other	<1%	<1%	<1%	<1%

3.2.1.1.1 Electrical Breakdown

Approximately 70% of the smelter losses were attributed to an electrical breakdown. The following conclusions were drawn from a review of these electrical breakdown losses.

A. The majority of the electrical losses involved the DC power supply equipment (rectiforming group) consisting of regulating, rectifying, or regulating-rectifying transformers. None of these failures resulted in a potline freeze due to N-1 reliability, or equipment contingency planning (e.g., onsite spare).

B. The next largest group of equipment failures involved step-down transformers receiving or distributing power onsite. None of these failures resulted in a potline freeze due to N-1 reliability, or equipment contingency planning (e.g., onsite sparing).

C. Other equipment failures involved control equipment, switchgear, and cabling.

3.2.1.1.2 Service Interruption

Roughly 20% of the smelter losses were attributed to service interruption, which for the purposes of this study was considered a failure in the offsite power generation or distribution system (utility) or onsite power generating station (captive). The following conclusions were drawn from a review of these service interruption losses.

A. Half of the losses that occurred at utility-supplied smelters were the result of power transmission line damage by ice/wind, ice, and maintenance (utility conducted).

B. The other half of the losses occurred at captive power supplied smelters due to spurious operation of switchgear, generator tips (instabilities), and lightning voltage surge.

3.2.1.1.3 Molten Breakout

Roughly a tenth of the smelter losses involved a molten breakout. Nearly all breakouts occurred in the potroom, while a pot room truck struck a steel column tipping a ladle in the other molten metal release loss.

4.0 REFERENCES

4.1 FM

Data Sheet 1-57, *Plastics in Construction*
Data Sheet 1-62, *Cranes*
Data Sheet 5-4, *Transformers*
Data Sheet 5-19, *Switchgear and Circuit Breakers*
Data Sheet 5-31, *Cables and Bus Bars*
Data Sheet 7-11, *Conveyors*
Data Sheet 7-12, *Mining and Ore Processing Facilities*
Data Sheet 7-21, *Rolling Mills*
Data Sheet 7-32, *Ignitable Liquid Operations*
Data Sheet 7-33, *Molten Metals and Other Materials*
Data Sheet 7-43, *Process Safety*
Data Sheet 7-45, *Instrumentation and Control in Safety Applications*
Data Sheet 7-76, *Combustible Dusts*
Data Sheet 7-78, *Industrial Exhaust Systems*
Data Sheet 7-98, *Hydraulic Fluids*
Data Sheet 7-99, *Heat Transfer by Organic and Synthetic Fluids*
Data Sheet 7-110, *Industrial Control Systems*
Data Sheet 9-0, *Asset Integrity*
Data Sheet 10-1, *Pre-Incident Planning*
Data Sheet 10-8, *Operators*
Data Sheet 13-7, *Gears*

APPENDIX A GLOSSARY OF TERMS

Claustra panel: Wall partitions installed on the potroom floor serving as a nonconductive barrier between the floating potroom floor and the grounded building structure, while also allowing for cooling airflow through potrooms. Refer to Section 3.1.1.4 for additional information on claustra panels.

FM Approved: Products and services that have satisfied the criteria for FM Approval. Refer to the *Approval Guide* for a complete listing of products and services that are FM Approved.

N-1: A design concept that ensures continued acceptable system operation during a single creditable contingency event. The concept accounts for both system component reliability and availability.

At an aluminum smelter, a creditable N-1 contingency event involves an unplanned outage of a system component (i.e., unexpected failure or loss due to equipment breakdown, fire, or other peril) combined with a planned outage of a second system component (i.e., maintenance). Acceptable system operation is defined as preventing a potline freeze by maintaining potline conditions within the defined operating limits for the expected recovery duration. An example of N-1 would be stable potline operation, possibly at reduced line current, until power is restored when a forced outage occurs of one rectiforming group while a second rectiforming group is out-of-service for maintenance.

Although there are similarities between N+1 and N-1, there are fundamental differences. N+1 accounts for loss of one component or group of components in a system due to reliability. N-1 is a scenario-based concept where the system design takes into account both system component reliability and availability (e.g., maintenance outage) in response to an N-1 contingency event which is formally defined based on the system conditions and exposures.

N+1: A design concept that ensures continued acceptable system operation during the failure of any one system component (i.e., reliability only).

Potline rectiforming group: The series of electrical equipment responsible for converting the incoming AC electrical supply to DC line current. The set may consist of a voltage regulating transformer, rectifying transformer, and DC converter (e.g., thyristor or diode) along with their associated cooling system, controls, and cabling or bus bar.

Additionally, direct current (DC) electrical supplies serving a magnetic compensation loop should be considered as part of the rectiforming group warranting similar protection and contingency.

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).

April 2025. Interim revision. Minor changes were made to process safety guidance to align with FM Property Loss Prevention Data Sheet 7-33, *Molten Metals and Other Materials*.

January 2019. This document has been completely revised. The following major changes were made:

A. Changed the title from *Aluminum Industry* to *Aluminum Smelting*.

B. Reduced the scope to aluminum smelters and associated carbon plants.

C. Relocated the following subject content to other operating standards:

1. Alumina refining to OS 7-12, *Mining and Ore Processing Facilities*
2. Aluminum casting to OS 7-33, *High-Temperature Molten Materials*
3. Aluminum rolling mills to OS 7-21, *Rolling Mills*

D. Reorganized the document to align with current Operating Standard Development Guidelines.

E. Clarified the reliability recommendations for offsite electric power transmission, onsite generation, and onsite power distribution.

F. Clarified the reliability recommendations for potline rectiforming groups.

G. Revised fire protection recommendations for potline rectiforming groups. Added performance goals and mitigative options.

H. Added guidance on the fire hazard posed by plastic claustra panels in potrooms.

I. Revised guidance on fire protection for gas treatment and fume treatment.

J. Added a recommendation on asset management.

K. Added a recommendation on standard, abnormal, and emergency operating procedures for potlines.

L. Added a recommendation on emergency response planning.

M. Added a recommendation on recovery planning.

N. Clarified the reliability recommendations for compressed air, ancillary support systems, and downstream aluminum casting.

O. Revised guidance on fire protection of HTF systems in carbon plants.

P. Added ITM guidance on critical production equipment in carbon plants.

Q. Expanded guidance on equipment contingency planning for potlines and carbon plants.

May 2010. Minor editorial changes were made for this revision.

January 2007. The following changes were made for this revision:

- Added new recommendation for applying process safety management (PSM) in alumina refineries (section 2.1.2).

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

September 2000. This revision of the document has been reorganized to provide a consistent format.