MOLTEN METALS AND OTHER MATERIALS

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1.0 SCOPE

This data sheet contains property loss prevention guidance unique to facilities processing and handling molten materials, which includes metals and metalloids (e.g., silicon and boron) as well as minerals and slags. Guidance contained herein applies to the molten occupancy, which may extend from raw material handling (receiving, staging and charge preparation) to molten processing (charging, smelting, melting, refining or alloying), molten transfer or transport, or casting for forming intermediate or finished shapes.

Additional property loss prevention guidance is contained in the following FM Property Loss Prevention Data Sheets for specific molten occupancies:

- 7-25, *Blast Furnace Ironmaking and Basic Oxygen Steelmaking,* for guidance on traditional crude iron and steel production using blast furnace (BF) and basic oxygen furnace (BOF) technologies
- 7-26, *Glass Manufacturing,* for guidance on primary and secondary glass production
- 7-64, *Aluminum Smelting*, for guidance on primary aluminum production using the Hall-Heroult or Soderberg processes
- 7-85, *Combustible and Reactive Metals*, for guidance processing and handling combustible and reactive metals, as well as any molten metal processing, including specialty steel alloys within a chamber (i.e., vacuum induction melting, vacuum arc remelting, electroslag remelting, or other specialty furnaces)

Application

This data sheet contains general guidance for molten hazards and is the “core” standard for all molten occupancies. The data sheets listed above supplement this general guidance for specific molten occupancies and their unique hazards and exposures. When encountering common hazards and exposures not specifically addressed in this data sheet nor unique to the molten occupancy, apply the relevant data sheet. Examples include the following:

- Construction data sheets (1-series) for the design and construction of buildings enclosing a molten occupancy
- Data Sheet 5-4, *Transformers*, for fire protection and maintenance of arc furnace transformers and induction furnace transformers
- Data Sheet 7-98, *Hydraulic Fluid*, for hydraulic oil supplies cutoff from the molten occupancy
- Data Sheet 7-110, *Industrial Control Systems*, for control equipment rooms and operator control rooms

1.1 Hazards

By default, all molten occupancies are subject to a molten material release hazard capable of causing thermal damage and ensuing damage from fire. However, other unique hazards and exposures are associated with molten handling and processing.

1.1.1 Molten Material Release

The unintentional release of molten material is a leading loss driver in the industry. A molten release, also referred to as a breakout, runout, froth-over or splash occurs when:

1. High-temperature resistant refractory or water-cooled surfaces containing the molten material fail
2. During upsets in molten processing such as spill/overtop, frothing, wild tap or a failure/loss of motion control during transfer or transportation

Depending on the circumstances, the molten release may involve some or all molten held in the equipment. The molten spreads across the floor similar to water, potentially exposing unprotected load-bearing members and equipment to thermal damage due to immersion within hot molten material, or the convective heat plume or thermal radiation from the molten pool. In addition to thermal damage, a molten release can also cause ensuing events such as fire or molten-water explosion that can exacerbate damage and hamper recovery efforts.

1.1.2 Molten-Water Explosion

Most molten materials explode violently when mixed with water. At a minimum, a steam explosion results when the two fluids come into contact. Depending on the molten material, quantities of each fluid and mixing, greater energy releases can occur. Molten and water can come together when: water, ice, snow or moisture is charged into the molten equipment (equipment explosion); pressurized water leaks into the molten equipment (equipment explosion); or a molten release from equipment encounters stray water or compromises process water piping (room explosion).

1.1.3 Mechanical Breakdown

The refractory lining or water-cooled crucible is responsible for containing the hot molten material within the equipment. If these materials wear (thin) or are damaged (crack), a molten breakout can result. If these conditions are detected prior to a molten release, the release can be prevented and damage limited to a lining repair or reline. Unfortunately, these repairs can still result in a lengthy recovery duration.

Additionally, mechanical breakdown of unique, custom equipment such as a tilting gear box or slew bearing can render equipment inoperable until repairs are made or replacement occurs, ideally expedited by having a contingency plan or equipment breakdown spare.

1.1.4 Electrical Breakdown

Melting and processing molten materials often requires significant energy input. When electrically powered, furnaces require complex circuitry with large equipment. Failure of insulation, dielectric fluid or mechanical restraint can lead to powerful arcing events. Much of the power supply equipment is unique or custom; thus, damage can render equipment inoperable until repairs are made or replacement occurs, ideally expedited by having a contingency plan or equipment breakdown spare.

Electrical breakdown incidents have also been the initiator of fires. An ensuing fire can further increase damage and delay recovery efforts. These fires can be fueled by plastic insulation or oil released from oil-containing equipment such as transformers, capacitors or switchgear.

1.1.5 Fire

Molten occupancies routinely contain ignition sources including a molten release, sparks/embers and hot surfaces. Typical fire mitigation solutions such as automatic sprinklers are often less viable in these occupancies given the molten-water explosion hazard. If ignition sources are present, the remaining element that can be leveraged to prevent an intense, large fire is fuel and controlling that fuel. Combustible construction, combustible packaging and waste, and staged combustible process materials can be minimized, if not eliminated, from the melt shop or foundry. When essential ignitable liquids and oil-containing equipment are used, fluid selection can reduce or eliminate the hazard. When these options are not available, ignitable liquid safeguards such as fire interlocks can be employed to reduce or manage the risk.

1.1.6 Combustion Explosion (Dust or Gas/Vapor)

Metal dusts generated during processing and handling, fuel, gas, oxygen, flammable off-gases and combustible dust (raw materials) can all present a combustion explosion hazard in equipment and the surrounding room. Understanding how and when these materials may be created and released during normal operating and upset conditions, and/or mix with sufficient air/oxygen to create a flammable atmosphere, is a critical component of the hazard analysis in a site’s process safety program. Preventing a flammable atmosphere from forming is key protection against a combustion explosion within the equipment, the exhaust and pollution control system, and the surrounding area. When necessary, explosion mitigation may be necessary per the process hazard analysis.

1.1.7 Radioactive Contamination

Radiation contamination is a potential exposure in any location where scrap metal is handled and remelted. Scrap monitoring is the most effective method to prevent radioactive material from entering the site and being introduced to production equipment. If a radioactive source or radiation contaminated materials can be detected before being charged into the equipment, these materials can be disposed of properly. If melted, the product, slag, dust, equipment and exhaust system may become contaminated, requiring a costly and lengthy cleanup.

1.2 Changes

April 2025. This document has been revised. Significant changes include the following:

A. Revised radiation detection and testing.

B. Clarified molten equipment cooling system guidance and aligned with other molten standards

C. Updated loss history.

2.0 LOSS PREVENTION RECOMMENDATIONS

2.1 Introduction

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* or Roof*Nav*, online resources of FM Approvals, as appropriate.

A. Use a nonignitable liquid or FM Approved industrial fluid within hydraulic systems located in the molten occupancy (e.g., molten equipment, and surrounding areas exposed to a molten release), or where the surrounding occupancy does not warrant automatic sprinkler protection given limited combustible loading. Alternatively, provide fire protection in accordance with FM Property Loss Prevention Data Sheet 7-98, *Hydraulic Fluids*, which often entails automatic fire interlock and sprinklers. Hydraulic systems may be found in overhead cranes and mobile pot carriers, tilting and other furnace equipment movements, or vertical direct chill (VDC) casting, among other molten operations.

B. Use dry electrical equipment or electrical equipment containing an FM Approved industrial fluid (dielectric fluid). Alternatively, for ignitable fluid (oil)-containing equipment, provide fire protection guidance in accordance with the respective FM data sheet. Fire protection may consist of location, construction, fire protection system and ventilation guidance. The following data sheets provide fire protection guidance for oil-filled electrical equipment:

- Data Sheet 5-4, *Transformers*, for oil-filled transformers
- Data Sheet 5-19, *Switchgear and Circuit Breakers*, for oil circuit breakers
- Data Sheet 5-30, *Power Factor Correction and Static Reactive Compensator Systems*, for oil-filled capacitors (Apply the fire protection guidance regardless of the quantity of oil present.)

C. Use a nonignitable liquid or FM Approved industrial fluid within heat transfer fluid (HTF) systems in accordance with Data Sheet 7-99, *Heat Transfer Fluid Systems*.

2.1.2 Implement a process safety program, commensurate with hazards and exposures present in the molten occupancy. The molten occupancy may involve the molten operations as well as upstream operations such as raw material preparation, support and utility systems as defined in the process safety program. Within the program, implement the following core process safety elements.

A. Management commitment consisting of at least the following components:

1. A formal process safety policy endorsed by management.
2. The policy outlines the process as well as any internal compliance reviews and audits.
3. The appointed process safety coordinator has sufficient resources to administer the program and make productive use of the findings.

Additional guidance on this process safety element and components is provided in FM Property Loss Prevention Data Sheet 7-43, *Process Safety*.

B. Process knowledge consisting of at least the following components:

1. The necessary documentation is maintained and kept up-to-date (e.g., equipment drawings and specifications, site and production equipment layout, and piping and instrumentation diagrams [P&IDs]).
2. Process piping, instrumentation, and control elements are clearly field labeled per Section 2.5.13 of this data sheet.

3. Safe operating limits (SOL) are defined.
4. Equipment nameplate data and integrity operating window (IOW) are documented.

Additional guidance on this process safety element and components is provided in Data Sheet 7-43.

C. Process hazard awareness and analysis consisting of at least the following components:

1. A process hazard analysis (PHA) has been conducted and is kept up-to-date as part of the management of change program and as part of an annual review. At a minimum, PHAs should address molten release, molten-water explosion hazards, and when relevant, combustion explosion (flammable gas or combustible dust atmosphere) hazards in melting, transport, and casting operations. Additionally, the PHA should explore the following scenarios.
   - Loss of utility power (service interruption)
   - Equipment breakdowns in onsite utility or support systems
   - Hazards introduced with the raw materials and material charging
   - Failure of the refractory lining, crucible, and within any associated cooling systems
   - Failure of the structural support components of the molten equipment
   - Loss of exhaust ventilation
   - Loss of critical operational or safety instrumentation (e.g., operating an EAF without a slag analyzer, or loss of cooling water monitoring)
2. Awareness of industry losses, lessons learned, and equipment history (damage mechanisms and failure modes), as well as site-specific events and lessons learned
3. Hazard statements are incorporated into emergency operating procedures (EOPs).

Additional guidance on this process safety element and components is provided in Data Sheet 7-43.

D. Asset integrity consisting of at least the following components:

1. A maintenance manager or equivalent to oversee the asset integrity program
2. A maintenance program is in place in accordance with OEM guidance, industry standards and best practices, service agreements, site experience, and this and other relevant FM data sheets. The program is commensurate with the level of exposure present.
3. The program addresses equipment service aging and remaining useful life, deficiency management, root cause analysis, documentation requirements and trending, and equipment contingency planning. (Section 2.6)
4. A work order system is in place for managing maintenance activities, capturing results/findings and documenting any corrective actions taken.

Additional guidance on this process safety element and components is provided in Data Sheets 7-43, *Process Safety* and 9-0, *Asset Integrity*.

E. Management of change consisting of at least the following components:

1. A formal management of change (MOC) procedure is in place.
2. The procedure differentiates between temporary and permanent changes.
3. A system is in place for managing open MOCs and preserving closed MOCs

Additional guidance on this process safety element and components is provided in Data Sheet 7-43.

F. Incident investigation consisting of at least the following components:

1. A formal policy and procedure is in place to investigate incidents and near misses.
2. A system is in place for managing active investigations and preserving completed investigations.
3. Incident reports contain a root cause analysis (RCA), any recommendations for corrective action and sufficient supporting detail.

4. Open recommendations are tracked.

Additional guidance on this process safety element and components is provided in Data Sheets 7-43 and 9-0.

G. Contractor Management comprised of at least the following components:

1. A formal contractor management policy is in place.

2. Contractor access to the site is regulated, and supervised or audited as needed.

3. Contractor training is required for site-specific hazards and policies.

4. Prior to the start of work, a job work plan is completed with the appropriate site personnel.

Additional guidance on this process safety element and components is provided in Data Sheets 7-43 and 10-4, *Contractor Management*.

H. Operator program consisting of at least the following components:

1. Operator mentorship and qualification programs are in place. (Section 2.5.5)

2. Standard operating procedures (SOPs) and EOPs are in place commensurate with the hazards. (Section 2.5.7)

3. Initial and refresher training is provided on SOPs and EOPs. (Section 2.5.6)

4. An administrative program is in place to track operator qualifications.

Additional guidance on this process safety element and components is provided in Data Sheets 7-43 and 10-8, *Operators*.

2.2 Location and Construction

Location

2.2.1 Locate critical production and support system equipment outside the molten occupancy in areas not exposed to routine corrosive off gases, spatter/sparks and heat, or upset conditions such as a molten release and the associated radiant or convective heat, or overpressure from a molten-water explosion. When unavoidable, as the equipment is intrinsic to the subject molten operation, protect the equipment from the molten occupancy hazards by limiting the exposure through engineering design, such as installing thermal and/or pressure-resistant barriers. Equipment is considered critical if the repair or replacement of just the damaged equipment is expected to delay the recovery effort following a molten release or explosion.

2.2.2 Route concentrations of power cabling and control wiring in a manner that limits their exposure from sparks released during normal operations or a molten release. For example, to reduce the likelihood of damage during routine operation (i.e., from embers) or upset condition such as a molten release (i.e., associated thermal radiation and convective heat plume), route concentrations of cabling and wiring entering/exiting electrical or control equipment rooms outside of and distant from the breakout containment footprint. For grouped or individual cable or wire runs to molten equipment connections, ideally route from above the molten level and drop down to connection points.

2.2.3 Locate the operator control room outside areas exposed to a molten release and the associated radiant heat or convective heat transfer, or overpressure from a molten-water explosion. When unavoidable, protect the control room from molten occupancy hazards (e.g., thermal- and pressure-resistant construction with protected egress path from the operator control room).

2.2.4 Locate supplies of ignitable liquid (e.g., hydraulic oil) or flammable gas (e.g., natural gas or oxygen) outside the molten occupancy, preferably in exterior cutoff rooms. If exposed to molten occupancy hazards, enclose the rooms in protective construction designed to withstand these hazards (e.g., thermal- and pressure-resistant construction).

2.2.5 Locate slag pits a safe distance from structures to prevent steam explosions from damaging the molten occupancy, as well as other buildings and equipment (e.g., power lines).

2.2.6 Locate the flux gas supply, such as chlorine, outside of the molten occupancy, preferably in an outdoor location but at least isolated in an exterior cutoff room (i.e., along an exterior wall).

2.2.7 Route roof drainage piping outside the molten occupancy building, preferably using an exterior roof drainage system. If an exterior drainage system is not feasible, route and construct interior roof drainage piping in a manner to prevent a leak or rupture from exposing the molten occupancy such as: using high-strength materials and pipe joints; heat trace piping possibly exposed to cold; and limit pipe bends elevated above the molten occupancy).

Construction

2.2.8. Design and construct buildings and rooms containing a molten occupancy using noncombustible construction (e.g., corrugated metal, concrete and mineral wool insulated metal panels). If plastic building materials are required, use FM Approved building materials. Install FM Approved building materials in accordance with the manufacturer's guidelines and the FM Approval listing. Plastic building materials may be found in insulated metal panels, fiberglass reinforced panel wall and ceiling coverings, and insulated steel deck roof assemblies.

2.2.9 When corrosive gases are used or produced in molten operations (e.g., chlorine gas injection to flux molten aluminum), provide the following protection features for structural members and building assemblies:

A. Install a fume exhaust system to control corrosive fumes at release points, which may include furnace doors, burner ports and other furnace penetrations above the metal line.

B. Provide a protective coating on structural members and non-load-bearing building assemblies exposed to corrosive fumes.

2.2.10 Design and maintain the building containing the molten occupancy in accordance with FM Property Loss Prevention Data Sheet 1-28, *Wind Design*, to prevent damage to the building envelop from stormwater entering the molten occupancy.

2.2.11 Design and maintain the building roof over the molten occupancy in accordance with FM Property Loss Prevention Data Sheet 1-54, *Roof Loads and Drainage*, to prevent roof ponding and snow induced collapse, allowing water to enter the molten occupancy.

2.2.12 Design buildings containing a molten occupancy in accordance FM Property Loss Prevention Data Sheet 1-40, *Flood*, to prevent flood water or storm water runoff from entering the molten occupancy and any associated below grade spaces such as molten breakout containment pits.

2.2.13 When the molten occupancy extends below grade, conduct a groundwater study, and (if necessary) install groundwater mitigation (barriers/drainage) around and/or under below-grade spaces to keep them dry.

2.2.14 Provide molten breakout containment (emergency containment) around stationary molten equipment. Breakout containment should corral the largest potential molten release while allowing it to cool in a controlled manner limiting thermal damage beyond the equipment of origin as well as the potential for the molten release to encounter stray water (ensuing room explosion) or combustibles (ensuing fire). Design and install molten breakout containment in accordance with the following:

A. Design molten breakout containment to be liquid tight and hold the contents of the vessel plus 4 in. (100 mm) of freeboard. Extend the containment beyond the footprint of the vessel to capture: (1) a sidewall molten release, or a molten stream deflected beyond the equipment footprint by surfaces along the equipment; and/or (2) a molten release from the equipment during pouring, or failure of the receiving ladle, launder or trough.

B. Within the molten breakout containment area, limit openings in the floor and containment walls, such as trench drains and weep holes, that may allow molten material to escape the containment area.

2.2.14 Provide thermal protection for structural members within the molten breakout containment area that could be immersed within a molten pool or impinged upon by a molten stream extending from a sidewall release. Extend thermal protection at least 1 ft (0.3 m) above the highest expected level of molten contact. Thermal barrier design should consider molten temperature, quantity of metal, thermal expansion and mechanical impact potential.

For example, when the molten material temperature is above 2000°F (1095°C), a minimum 3 in. (75 mm) covering of concrete having a 28-day compressive strength no less than 3,000 psi (21 MPa) with steel straps or reinforcing ties to hold the concrete on the structural members may be sufficient.

2.2.15 Provide molten breakout containment and thermal protection for structural members around stationary molten transfer (troughs) and casting stations in accordance with Sections 2.2.13 and 2.2.14. Design containment to hold the largest cast load or ladle load.

2.2.16 When molten material is transported through the facility (e.g., by vehicle or overhead crane), provide thermal protection for structural members along the molten travel path. Extend thermal protection at least 18 in. (0.5 m) above the floor. Use reinforced concrete as discussed in Section 2.2.14 or materials affording similar impact resistance.

2.2.17 When molten material is transported through the facility, assess the travel path for potential exposures during a molten release such as:

- Critical in-service production, utility and support system equipment
- Stored critical equipment breakdown spares such as an arc furnace transformer (AFT)
- Combustible or ignitable materials such as hydraulic oil or other ignitable liquids

If present, either alter the travel path or relocate the exposure.

Alternately, provide thermal protection against a spreading molten pool at floor level per Section 2.2.14; or molten release described above using thermal barriers and liquid-tight, thermally resistive-construction.

2.3 Protection

2.3.1 Provide ignitable liquid protection in areas containing lubrication oil and grease systems (i.e., supply and use points) in accordance with Data Sheet 7-32, *Ignitable Liquid Operations*.

2.3.2 Provide fire protection for concentrations of power cabling and control wiring in accordance with Data Sheet 5-31, *Cables and Bus Bars*. In the molten occupancy, avoid the use of automatic sprinklers whenever possible. Alternative solutions may include FM Approved cable coatings or wraps.

2.3.3 Provide automatic fire protection within control equipment rooms and operator control rooms in accordance with Data Sheet 7-110, *Industrial Control Systems*.

2.3.4 Refer to Data Sheet 7-40, *Heavy Duty Mobile Equipment*, for fire protection guidance of mobile ladle or pot carrier vehicles. If protected, the fire extinguishing agent should be compatible with the molten material.

2.4 Equipment and Processes

2.4.1 Provide two levels of radiation detection for facilities processing recycled scrap or reclaim/revert steel, aluminum or lead. Scan all incoming scrap at points of entry (e.g., scale houses), and at a second level within the scrap processing stream where the scrap is in an alternate configuration (e.g., once the scrap has been unloaded from the shipping container, truck trailer, or railcar; and the scrap material arrangement has been altered). Common second level detector positions include on scrap handling equipment such as grapples, along the underside of cranes, over scrap conveyors and at charging bucket stations.

2.4.2 At facilities processing recycled scrap or reclaim/revert metal other than steel, aluminum, and lead, provide one level of radiation detection. Refer to Section 2.4.1 for guidance on common the detection positions within the onsite scrap handling sequence. Ensure that 100% scanning is achieved prior to scrap entering the melting process (e.g. by scanning at the truck/rail scales or charging bucket).

2.4.3 When scrap metal or other charge materials are stored outdoors and a wet charge hazard exists, provide the following:

A. A canopy to cover staged charge materials, including scrap.

B. A preheating system to remove moisture that may be trapped within charge materials. Preheating is particularly important during the wet or cold seasons.

2.4.4 Provide onsite emergency power generation capable of supporting a molten equipment hot-hold or a controlled shutdown during a service interruption (e.g., loss of utility power).

2.4.5 When an operator control room arranged as described in Section 2.2.1.3 is not provided, provide remote emergency controls that allow molten equipment operators to drive equipment to a safe state and initiate a controlled equipment shutdown. Locate controls in at least one remote location that will remain accessible under anticipated emergency conditions. Preferably, install the emergency controls within the egress path of operators or where emergency responders are likely to enter the building.

2.4.6 Design fuel supplies and fuel-fired burners in accordance with applicable data sheets, using fail-safe design and safeguards, as applicable.

2.4.7 Design oxygen supply, burners or lances in accordance with applicable data sheets, using failsafe design and safeguards, as applicable.

2.4.8 When molten equipment is water cooled, use an enclosed, low-pressure spray cooling system when possible. Do not use open, low-pressure spray cooling systems. When use of a high-pressure water-cooling system is unavoidable, provide a leak detection system; and maintain the water-cooling systems in accordance with this data sheet. Use of an enclosed low-pressure water spray cooling system minimizes the likelihood of a pressurized water stream entering the molten-containing hearth.

2.4.9 Provide redundancy in the primary cooling media supply serving the molten equipment where loss of cooling can result in refractory or crucible damage and the potential for a molten release. Cooling media applications include: cooling water for refractory or crucible, exhaust system tubing, and/or other internal cooled components; cooling air (wind) passing across a furnace shell; and compressed gases for burners or mixers/bubblers. Consider the following failure scenarios when evaluating redundancy options: loss of utility power; electrical breakdown involving a motor, power cable or switchgear, with damage to adjacent equipment (i.e., cabinets with common busbar and cabling); or a mechanical breakdown of a pump, blower/fan or compressor. Examples of common redundancy arrangements include the following:

A. For cooling water, back-up pumping with electric motors supplied from an independent onsite substation as shown in Figure 2.4.9-1.

B. For cooling air (wind), a back-up blower/fan and motor with power supplied by an independent onsite substation.

C. For compressed gas, a back-up compressor with motor supplied by an independent onsite substation, or a compressed gas tank back-up.

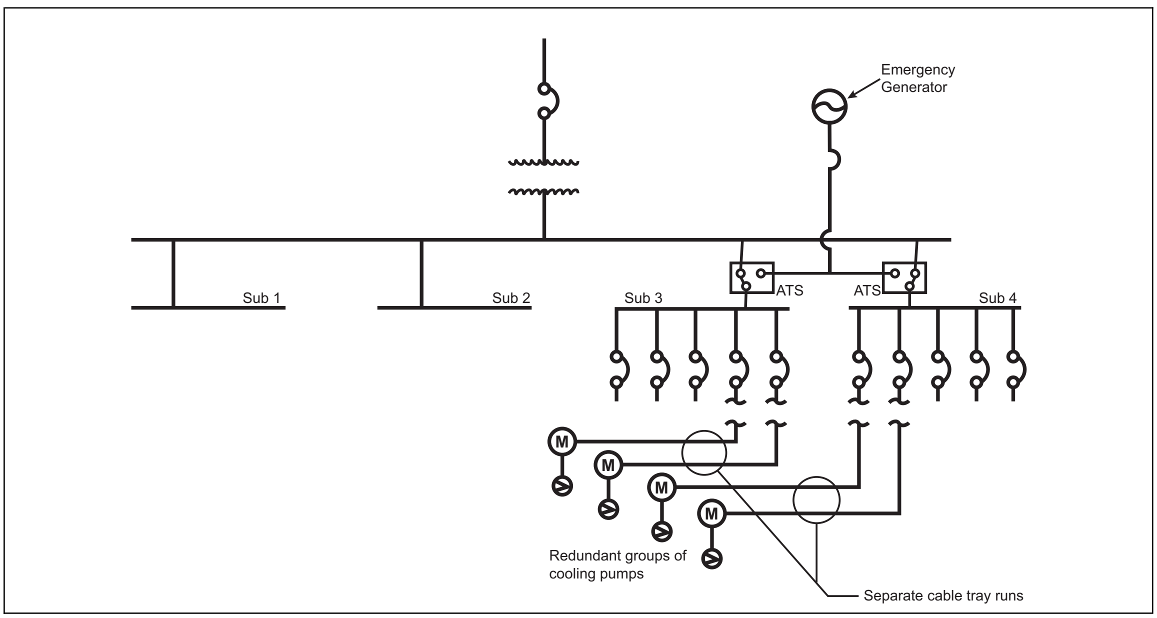

Fig. 2.4.9-1. Separate power supply feeds to redundant cooling water pumps

2.4.10 Provide an emergency cooling water supply independent of the primary cooling water supply and sized to allow the safe shutdown of molten and associated water-cooled equipment. Configure the emergency cooling water supply to sense loss of cooling water and automatically backfill or transfer from the primary supply. Ensure the primary and emergency water supplies do not share a single point of failure. Common emergency cooling water supply configurations include but are not limited to:

- A gravity water tank
- A dedicated water tank or other source with diesel engine or direct current (DC) electric water pump
- A connection to a reliable public or industrial water supply
- A connection to a reliable onsite fire water supply as described in Data Sheet 3-29, *Reliability of Fire Protection Water Supplies*

2.4.11 Arrange the emergency cooling water supply piping to connect as closely as practical to the water-cooled molten equipment to minimize any common failure points with the primary cooling water supply. Ensure the emergency cooling water connection point has a means to prevent cooling water back flow through the primary system (e.g., install a reliable series of check valves, a backflow preventer or automated control valves).

2.4.12 Arrange supply and/or return mains containing pressurized cooling water, oxygen, or flammable gas and hydraulic oil in a manner that limits their exposure during a molten release. For example, route main piping outside of the molten breakout containment footprint and (when approaching the equipment) from above the molten level; and/or sufficiently offset to limit contact during a molten release through the sidewall. When possible, also minimize the exposure of rigid pipe or flexible hose connections at use points below the molten level.

2.4.13 When enclosed low-pressure spray cooling systems are used, route cooling water collection troughs and gravity drain piping in a manner that limits their exposure during a molten release as described in Section 2.4.12.

2.4.14 Design the cooling water supply and distribution to water-cooled elements (e.g., spouts, tuyeres, staves/panels, tapholes) within molten equipment in a manner that allows operators access to final control elements (i.e., manual isolation valves) from a location that will remain accessible under anticipated emergency conditions. Alternately, provide the capability for remote operation of those control elements, with power cabling and control wiring arranged to remain in-service during an emergency (e.g., protected from molten release).

2.4.15 Implement a failsafe design philosophy for cooling water system final control elements serving molten or electrical equipment to prevent overheating of cooled equipment upon loss of power, control media or other support system failure or upset. For example, remotely actuated control valves supplying cooling water should fail to the open position, assuming this is the safe condition as defined in the PHA or industry best practices.

2.4.16 Design tiltable molten equipment to be inherently failsafe, such that loss of motion control results in a gravity return of the tilted equipment to a safe condition to prevent uncontrolled movement and a molten release. For example, the tilting pivot on a ladle is located above the center of gravity; thus, the ladle returns to level upon loss of motion control.

2.4.17 Design final control elements of molten transfer (e.g., tapping or pouring) to be fail-safe, as defined by the PHA, to prevent a loss of motion control media resulting in an unsafe condition. For example, loss of compressed air to a taphole plug or slide gate causes the device to “fail” to the closed position, preventing an uncontrolled molten release. Assess failure during both routine and upset conditions to determine the failsafe position, which may vary based on state of operation (e.g., progression within the process cycle) or upset condition.

2.4.18 Provide thermal protection for final control elements and associated utility and support connections exposed to a molten release when they are identified in the EOP as necessary for critical response actions. For example, tilting and taphole equipment may be required to drain a furnace into a standby ladle or (in a controlled manner) into the containment below during a molten release from a furnace.

2.4.19 Install an online refractory monitoring system for molten equipment to continuously assess lining wear and inspect for molten penetration within the lining. Record data for trending and system validation during reline, and arrange the system to sound an alarm at a constantly attended location. Refer to Sections 2.7 and 2.8 for equipment specific guidance related to online refractory monitoring. Particularly important is monitoring lining areas defined by the OEM or PHA that may be prone to higher wear rates (e.g., slag line or transfer ports), mechanical impact damage (e.g., impacts during charging) or where high-pressure water cooling is provided. Refer to Section 3.1 for background discussions on refractory monitoring techniques.

2.4.20 Provide online leak detection for high-pressure water-cooled molten equipment to at least sound an alarm at a constantly attended location or, preferably, initiate an interlock to automatically drive molten equipment to a safe state (e.g., shut down heat input). Refer to Section 2.7 or 2.8 for equipment-specific guidance on cooling water leak detection. The objective is to detect a cooling water leak capable of entering the molten-containing hearth. At a minimum, design leak detection to identify large ruptures such as a burn/melt-through failure of a single cooling circuit (i.e., large leak detection). When technology and the application permit, design leak detection to identify smaller cooling water releases such as a tube pinhole or thru-wall tube crack (i.e., small leak detection).

2.4.21 Provide online leak detection for water-cooled electrical equipment in the equipment power supply to sound an alarm at a constantly attended location. Refer to Section 2.7 for furnace specific guidance on cooling water leak detection.

2.4.22 Avoid using an excess amount of water or a solid stream of water (i.e., use water spray) to cool slag.

2.5 Operation and Maintenance

Operation

2.5.1 Implement a housekeeping program to manage essential combustibles such as combustible alloying metals, and limit nonessential combustibles such as shipping or packaging materials from accumulating within the molten occupancy. Combustibles may include wood or plastic (e.g., shipping materials or trash bins), combustible metals for alloying (e.g., magnesium) or ignitable liquid (e.g., containers of hydraulic or lubricating oil). Include the following in the molten occupancy housekeeping program:

A. Store combustible process materials outside the molten occupancy, and limit staged materials within the molten occupancy.

B. Perform periodic inspections of the molten occupancy for essential and nonessential combustibles. Document inspections and communicate inspection findings.

C. Following planned outages and prior to resuming production, inspect and promptly remove any remaining combustibles (e.g., shipping materials).

2.5.2 Implement a housekeeping program to manage metal dust, batch or ore accumulations on elevated horizontal surfaces to prevent structural overloading and/or accelerated corrosion. Within the program, include periodic documented inspections with inspection frequency adjusted based on previous findings; and document any corrective actions such as accumulation removal results and methods. When these materials present combustible dust explosion hazards, refer to Data Sheet 7-76.

2.5.3 Implement a stray water prevention and detection program consisting of the following elements:

A. Regularly inspect the molten occupancy for stray water in accordance with the established operating procedures. Emphasize inspection of molten breakout containment or other below-grade areas of molten equipment, as well as areas where molten is transferred and transported through the facility.

B. When stray water is identified, implement an emergency operating procedure (EOP) to:

- Report the condition to site management
- Initiate actions to remove the water and initiate any process changes to manage molten operations in the wet area
- Investigate the cause
- Determine actions to prevent recurrence

C. Maintain the building envelope around the molten occupancy and any drainage systems to prevent ingress of stormwater, snow, flood water, stormwater runoff or ground water.

D. Where recurring stray water issues are related to process equipment/pipework leakage problems, pursue process and equipment improvements to reduce/eliminate the leakages.

E. Document all program activities including images, findings and recommended corrective actions. Retain documentation for review, trending and auditing.

2.5.4 Implement an emergency response plan for fire, explosion and molten material release incidents in accordance with Data Sheet 10-1, *Pre-Incident and Emergence Response Planning*. Integrate elements of the equipment EOPs into these response plans as needed.

2.5.5 Implement an operator program for molten equipment in accordance with Data Sheet 10-8, *Operators* and the following guidance. Within the program, include initial and refresher training, operator development path, required operator qualifications and role-specific competencies, audits and corrective actions. Additionally, as part of the operator program, maintain a staffing plan to ensure qualified operators are available on all shifts to meet present and future needs.

2.5.6 Train molten equipment operators on standard operating procedures (SOPs) and emergency operating procedures (EOPs). In addition to the operating procedures, include the following in the training curriculum:

A. Hazards present within molten occupancy, which may include molten release, molten-water explosion, electrical breakdown, fire and combustion explosion

B. Drills or what-if scenarios to recognize trends that can lead to upset conditions and emergencies, and how to respond to them

C. Alarm management, permissive and corrective (trip) interlock initiation, and actions taken

D. Ensuring molten equipment controls are never left unattended during operation and/or when molten material is present

E. Jumper and force management, MOC, and levels of authority in control and safety systems

F. Shift change communications

2.5.7 Implement standard operating procedures (SOPs) and emergency operating procedures (EOPs) for molten operations. Develop procedures based upon OEM operations and maintenance manuals, industry best practice guidelines, site experience and the process safety program. Update the procedures per the Management of Change (MOC) program. The following are examples of common operations and upset conditions that may be addressed in SOPs and EOPs, depending on site operations and equipment.

SOP

- Charge preparation and dewatering
- Furnace charging
- Relining commissioning and first heat (including refractory sintering where applicable)
- Cold-start, hot-restart and shut down
- Restart following trip, loss of support system (cooling water) or service interruption
- Melting and refining activities
- Molten handling including tapping, transfer and transport
- Casting start and stop
- Departure from established refractory monitoring and water-cooling conditions
- Radioactive contamination monitoring
- Operator walkdowns of molten equipment
- Jumper/force management

EOP

- Loss of heating (electric, fuel, oxygen or exothermic reaction)
- Loss of exhaust ventilation
- Loss of primary cooling water or media
- Service interruption (site-wide loss of power)
- Suspected or known refractory lining or crucible damage

- Suspected or known pressurized water release into molten equipment
- Identification of, and response to, stray water accumulation
- Inability to tap (continuous furnace) or wild tap (unintended release)
- Uncontrolled molten release
- Suspected or known detection of radioactive source
- Suspected or known “bridging” condition in induction or submerged arc furnace

2.5.8 Implement a wet-charge prevention program for scrap, ingots and other raw materials stored outdoors in which moisture can accumulate, form a thin layer on, or be absorbed by charge materials. Include the following in the program, as appropriate:

A. A standard operating procedure on storage and pre-charge activities to dry and inspect charge/batch ingredients for moisture.

B. Any additional precautions to be taken during the wet (rain) or cold (ice) seasons including but not limited to a drying or preheating furnace, or staging charge materials within a heated building space.

C. Document all program activities including images, findings, and recommended corrective actions. Retain documentation for review, trending, and auditing.

2.5.9 Implement charge preparation procedures and avoid loading contaminates or hazardous materials into a furnace. Include the following, as appropriate.

A. When preparing a charge, layer light materials to cushion the impact of large pieces against the refractory lining.

B. Inspect charge/batch ingredients for any of the following:

1. Oxygen-containing contaminants such as salts (e.g., sulfates, nitrates, or phosphates) or significant quantities of metal oxides
2. Coatings on metal not compatible with the furnace (i.e., varnish, lacquer or epoxy coatings may require special considerations if not removed prior to melting)
3. Combustibles such as oils (e.g., cutting oil on turnings or chips) that have accumulated on metal or at the bottom of the hopper
4. Sealed containers such as cans, cylinders or tanks that may explode when heated
5. Composite materials consisting of multiple metals with different thermal expansion rates or melting points, such as centrifugal cast rolls

C. Document all program activities including images, findings and recommended corrective actions. Retain documentation for review, trending and auditing.

2.5.10 When processing scrap metal, develop a standard operating procedure for scanning scrap metal for radioactive sources and contaminated materials. Address the following in the procedure:

A. On-site methods for detecting radioactive materials and limitations of the employed detection methods

B. Identify what materials require scanning. Include all raw materials, and either intermediate products during metallurgical sample analysis or outgoing materials such as melt shop waste, by-products and finished product

C. Confirming the radioactive contamination alarm, usually by conducting another test, possibly with a different detector.

D. List actions in response to a confirmed hot load at a gate

E. List actions in response to detection of a radioactive source or contaminated material in the scrap yard

F. Onsite communication protocols as well as those with local authorities

2.5.11 Require scrap metal suppliers to perform radiation monitoring of any loads destined for the facility prior to departure.

2.5.12 Position an empty, in-service ladle to capture as much escaping molten material as possible in an emergency if tapping spouts cannot be shut off or when another ladle develops an uncontrolled leak.

2.5.13 Implement a program to label process piping (type of media and flow direction). Additionally, devise and implement an identification ("tagging") system for critical field instruments and final control elements.

Maintenance

2.5.14 Maintain radiation detection systems in accordance with the OEM guidelines. Maintain a log of all maintenance activities and alarms. At a minimum, perform the following maintenance activities:

A. Visually inspect the system control panel each shift for in-service conditions.

B. Functionally test detectors quarterly, using a radioactive source, to verify proper operation.

C. Functionally test any speed sensing alarms per OEM but at least annually.

2.5.15 Implement a structural integrity program to manage damage to structural members supporting building and elevated equipment caused by corrosive off-gases, moisture laden dusts or other damage mechanisms such as mechanical impact. Within the program, include periodic documented inspections with inspection frequency adjusted based on previous findings; and document any corrective actions such as repair or replacement of damaged structural members.

2.5.16 Establish and implement an inspection, testing and maintenance (ITM) program for molten equipment. Refer to Data Sheet 9-0, *Asset Integrity*, for guidance on developing and structuring this component of the asset integrity program.

2.5.17 Implement a refractory/lining management program in accordance with OEM guidelines and industry standards, but at a minimum include the following:

A. Maintain the lining design documentation, including drawings, specifications and anticipated operating conditions.

B. Use quality refractory and other lining materials from a reputable supplier.

C. Where refractory materials are stored on site for significant periods, take measures to ensure that exposure to water and/or humidity is limited and controlled.

D. Prior to the campaign, establish an expected lining useful (service) life based on operating conditions and refractory design.

E. Conduct routine online visual inspections of lining surfaces for any physical damage or other abnormal conditions (e.g., dark spots that may be a cooling water leak or build-up on lining). For batch furnaces, inspect regularly (e.g., after each heat) when the furnace has been opened and the hearth and side-walls are visible. On continuous furnaces or holding furnaces, utilize inspection ports/openings or other means to monitor visible areas of the refractory. Inspection frequency depends on operating conditions and schedule, but the preferred frequency is prior to every heat (for batch operations) and every scheduled furnace outage (for continuous operations).

F. Perform thermographic inspections of online molten equipment where the shell or lining are visible (i.e., not water cooled or jacketed) as follows:

1. Following repairs, weekly for the first month
2. Following a reline, weekly during the first quarter of the anticipated campaign
3. After the first quarter, monthly as a part of the normal maintenance inspection
4. When the molten equipment approaches the final quarter of the campaign, twice a month
5. If a weakness is suspected or detected (i.e., determining a stable weakness vs. deteriorating weakness), increase thermographic survey frequency as appropriate until the equipment is shut down for lining repair or replacement. Appropriate frequencies may range from weekly to every shift, depending on the engineering assessment of the refractory and consequences of a molten release or a cooling water release and molten-water explosion.

G. Conduct routine cold (offline), internal inspection of the lining for any physical damage or other abnormal conditions (i.e., oxide or corundum build-up on aluminum reverb).

H. Document all program activities, including images, findings and recommended corrective actions. Retain documentation for review, trending and auditing.

2.5.18 Implement an inspection, testing and maintenance program to ensure the integrity of water-cooled circuits near and within molten equipment. Water-cooled equipment may include staves, water cooled panels, burner ports, submerged circulation pumps, tap holes and slag doors, upper wall panels, roof panels, exhaust ports and ducts, etc. Establish the program in accordance with OEM guidelines, industry standards and the following:

A. When replacing water-cooled components, evaluate vendor quality assurance practices and specifications.

B. Inspect water-cooled components upon receipt, or at a minimum, prior to installation.

C. Hydrostatically test water-cooled components following installation and prior to placing the equipment back into service. Additionally, hydrostatically test the cooling circuits following refractory repairs or replacements.

D. Inspect rigid piping and flexible hose connections for damage or deterioration at least monthly. More frequent inspections may be warranted based on history, motion frequency and length, and vibration levels.

E. As part of internal lining inspections, visually inspect exposed surfaces of refractory abutting water-cooled components and water-cooled components with thin protective coatings.

F. In response to refractory damage and repairs near cooling water components, evaluate the surrounding refractory for hydration; and hydrostatically test nearby water-cooled components.

G. Track and document water-cooled components to manage age; heating cycles; incidents/events which initiate or cause damage, shortening the remaining service life of the component; and maintenance findings.

2.5.19 Implement an inspection, testing and maintenance program for molten equipment cooling water supplies per OEM guidelines, industry practices and the following:

A. Lock or seal manual isolation valves in cooling water supplies and distribution supply points in the appropriate position.

B. Inspect manual isolation valves in cooling water supplies and distribution supply points at least monthly for the appropriate position (open/closed) and locked or sealed condition.

C. Exercise valves at least annually to ensure the valve moves freely, full travel.

D. Test alarms and interlocks associated with the primary or emergency cooling water supply at least semiannually.

E. Condition and monitor the primary or emergency cooling water source based on industry standards to prevent introducing contaminants that could damage heat transfer surfaces and supply and return piping (e.g., erode, corrode, scale internal high-heat surfaces and biological growth within open systems).

F. Inspect, test and maintain emergency cooling water pump drive systems in accordance with FM data sheets. The maintenance activities are governed by the emergency pump drive system installed.

G. Functionally test the emergency cooling water supply, including automatic transfer from primary to emergency, at least semi-annually.

2.5.20 Implement an inspection, testing and maintenance program for water cooled electrical equipment in accordance with OEM guidelines and industry practices. At a minimum, include the following:

A. Install flexible hoses and connections in accordance with OEM guidelines.

B. Inspect flexible hoses and connections for condition and cleanliness that could lead to tracking.

C. Check connection tightness at least monthly.

D. If possible, check the cooling water reservoir level system for changes that may indicate a leak (e.g., decreasing tank level or increasing need to top-off).

2.5.21 Inspect structural and mechanical components used for supporting and moving molten equipment for deterioration and damage. This includes the following:

- Concrete pedestals and restraints
- Equipment structural members and welds
- Pivot points and rockers
- Hydraulic or pneumatic cylinders and attachments
- Fastener tightness
- Perform inspections per OEM specifications, but at least annually.

2.5.22 Inspect molten breakout containment and thermal protection for unacceptable conditions such as excessive solidified slag or metal, deteriorating thermal barrier, or cracks/spalling in curbs or walls. Escalate negative findings to site management. Document all program activities, including images, findings and recommended corrective actions. Retain documentation for review, trending and auditing.

2.5.23 Maintain molten equipment safety devices in accordance with the OEM, along with a functional test of alarms and interlocks at least semiannually.

2.5.24 Ensure tools in contact with molten material are in good working condition, (i.e., dry, contaminant free, and any protective coatings intact). Tools may be used for alloying, skimming, stirring or sampling.

2.5.25 Operate and maintain cranes used to transport and lift molten equipment in accordance with Data Sheet 1-62, *Cranes*.

2.6 Contingency Planning

2.6.1 General

2.6.1.1 When molten equipment breakdowns would result in an unplanned outage to site processes and systems considered key to the continuity of operations, develop and maintain a documented, viable 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, consider the following hazards and their associated exposures in the contingency planning process within the molten occupancy.

A. Molten material release

B. Electrical breakdown (electrically heated molten equipment)

2.6.1.2 Sparing can be a mitigation strategy to reduce the downtime caused by a molten equipment breakdown, depending on the type, compatibility, availability, fitness for the intended service and viability of the sparing. For general sparing guidance, see Data Sheet 9-0.

2.6.2 Equipment Breakdown Spares

2.6.2.1 Equipment breakdown spares for molten equipment are intended to be used in the event of an unplanned molten equipment outage to reduce downtime and restore operations. Refer to furnace- or casting-specific sections (Section 2.7 and 2.8) for additional information on equipment breakdown sparing.

2.6.2.2 Maintain molten equipment breakdown spares viable per Data Sheet 9-0, *Asset Integrity*.

2.6.3 Routine Spares

2.6.3.1 Routine molten equipment spares are consumables. They are expected to be put into service under normal operating conditions over the lifetime of the molten equipment but not reduce equipment downtime in the event of a breakdown. Routine spares can include sparing recommended by the original equipment manufacturer. See Section 3.1.4 for routine spare guidance.

2.7 Furnace Specific

Apply the guidance in Sections 2.1 to 2.6 in addition to the following furnace specific guidance.

2.7.1 Induction Furnaces

2.7.1.1 Provide reinforced concrete isolation walls around each coreless induction furnace on a minimum of three sides. Isolation is not applicable to channel induction furnaces.

2.7.1.2 Provide ignitable liquid safeguards for oil-filled capacitor banks as follows.

A. Isolate the capacitor bank from other furnace capacitor banks and power supply equipment along with the surrounding occupancy using fire-resistant construction designed and installed per Data Sheet 1-21, *Fire Resistance of Building Assemblies*.

B. Install ignitable liquid spill containment around each oil-filled capacitor bank (each furnace) per Data Sheet 7-83, *Drainage and Containment Systems for Ignitable Liquids*.

C. Provide automatic sprinkler protection over capacitor banks (regardless of oil volume) designed and installed in accordance with Data Sheet 5-30, *Power Factor Correction*.

2.7.1.3 Provide lightning and surge protection per Data Sheet 5-11, *Lighting and Surge Protection for Electrical Systems*. The adequacy of the surge protection should be checked. Low sparkover lightning arresters should be provided for dry-type transformers. Resistance of the ground connections should not exceed 5 ohms. Preferably, it should be as near 1 ohm as possible.

2.7.1.4 Avoid installing furnace operating controls in multiple locations. If unavoidable, arrange system logic to default to the lowest power setting at furnace start.

Table 2.7.1. Alarms and Interlocks for Induction Furnaces

Equipment Parameter or Upset Condition	*Permissive*	*Alarm*	*Trip*	*Action*	*Reference*
Furnace refractory thinning/metal penetration	-	X	X	De-energize coils	2.4.19
Furnace cooling water/air, flow	X	-	-	Allow energizing coils	2.7.1.5
Furnace cooling water/air, low flow	-	X	X	De-energize coils	2.7.1.6
Furnace cooling water/air, return/ inductor high temperature	-	X	X	De-energize coils	2.7.1.7
Furnace cooling water, circuit leak	-	X	-	-	2.7.1.8
Furnace cooling water, body leak	-	X	-	-	2.7.1.9
Furnace bath/contents, ground fault(coreless only)	-	X	X	De-energize coils	2.7.1.10
Power supply cooling water/air, flow	X	-	-	Allow energizingcoils	2.7.1.11
Power supply cooling water/ air,low flow	-	X	X	De-energizecoils	2.7.1.12
Power supply cooling water/ air,return/equipment high temp	-	X	X	De-energizecoils	2.7.1.13
Power supply cooling water, leak	-	X	-	-	2.7.1.14

2.7.1.5 Configure furnace controls for a start-up permissive requiring proof of furnace cooling water or air flow.

2.7.1.6 Where cooling water or forced ventilation is provided for the furnace, initiate an alarm; and interlock the power supply to de-energize on low cooling water or air flow.

2.7.1.7 Where cooling water or forced ventilation is provided for the furnace, initiate an alarm; and interlock the power supply to de-energize on either high temperature in the return water flow or on water cooled-surfaces.

2.7.1.8 Provide cooling water leak detection (differential flow or pressure) on each induction coil circuit. An alternative to differential flow leak detection could be monitoring of make-up water on closed loop systems. Initiate an alarm upon detection of a leak.

2.7.1.9 Provide a cooling water leak detection device within the lower body cavity of coreless induction furnaces. Initiate an alarm on detection of water pooling below or within the furnace body.

2.7.1.10 Initiate an alarm and interlock the power supply to de-energize on ground-fault detection.

2.7.1.11 Configure furnace controls for a start-up permissive requiring power supply cooling water or air flow verification.

2.7.1.12 Where cooling water or forced ventilation is provided for power supply electrical equipment, initiate an alarm; and interlock the power supply to de-energize on low cooling water or air flow. Electrical equipment may include, but is not limited to, transformers, capacitors, conductors and bus bars, or rectifiers.

2.7.1.13 Where cooling water or forced ventilation is provided for power supply electrical equipment, initiate an alarm; and interlock the power supply to de-energize on high return water flow or equipment high temperature. Electrical equipment may include but is not limited to transformers, capacitors, conductors and bus bars, or rectifiers.

2.7.1.14 Where cooling water is provided for power supply electrical equipment, initiate an alarm on leak detection from electrical equipment cooling circuits per Section 2.4.21. Electrical equipment may include but is not limited to transformers, capacitors, conductors and bus bars, or rectifiers.

2.7.1.15 On tilting induction furnaces, inspect the joint between the top cap refractory and the crucible along with the furnace spout daily. Add to the backup sand or grout in the refractory frequently. Further compacting of the sand is caused by the electromagnetic vibrations, despite it having been well tamped initially. Voids can form between the top cap and the backup refractory. When the furnace is tilted, some of the backup material slides down to fill the void under the spout, thus creating an even larger void in the upper rear of the crucible. Unless additional backup material is provided, vertical cracks will develop in the rear of the crucible after ten to 20 heats.

2.7.1.16 After relining a coreless furnace, remove the top cap after the first 10 heats to inspect for and fill voids in the back-up material. Additionally, remove and inspect for the next 15 heats (heats 11-25) for voids.

2.7.1.17 Provide an emergency lifting point (hook) on the coreless induction furnace body for a tilting contingency.

2.7.2 Electric-Arc Furnace (EAF)

2.7.2.1 Locate each arc furnace transformer in a dedicated room designed in accordance with Data Sheet 5-4, *Transformers*.

2.7.2.2 Locate the furnace control panel outside the transformer room.

2.7.2.3 Provide thermal protection to limit the potential for a molten release contacting a rocker or tilt cylinder during a sidewall breakthrough. Refer to the PHA for possible mitigative solutions (i.e., deflecting shields).

2.7.2.4 Avoid the use of oil-filled circuit breakers as the primary switch for any type of furnace. Use air circuit breakers, air interrupters, or vacuum switches.

2.7.2.5 Construct new furnaces with an enclosed low-pressure spray cooling systems where possible.

Table 2.7.2. Alarms and Interlocks for Electric Arc Furnaces

Equipment Parameter or Upset Condition	*Permissive*	*Alarm*	*Interlock*	*Action*	*Reference*
Furnace, refractory thinning/metal penetration	-	X	X	De-energize electrodes	2.4.19
Furnace cooling water/air, flow	X	-	-	Allow energize electrodes	2.7.2.6
Furnace cooling water/air, low flow	-	X	X	De-energize electrodes	2.7.2.7
Furnace cooling water/air, cooling water return high temp high or high equipment temp	-	X	X	De-energize electrodes	2.7.2.8
Furnace cooling water, large leak	-	X	X	De-energize electrodes	2.7.2.9
Furnace cooling water, small leak	-	X	-	-	2.7.2.9
Furnace exhaust, low air flow	-	X	X	De-energize electrodes	2.7.2.13
Power supply cooling water/air, flow	X	-	-	Allow energize electrodes	2.7.2.6
Power supply cooling water/air,low flow	-	X	X	De-energize electrodes	2.7.2.10
Power supply cooling water, high return temp or high equipment temp	-	X	X	De-energize electrodes	2.7.2.11
Power supply cooling water, leak	-	X	-	-	2.7.2.12

2.7.2.6 Configure furnace controls for a start-up permissive requiring furnace and power supply cooling water or air flow verification.

2.7.2.7 Where cooling water or forced ventilation is provided for the furnace, initiate an alarm; and interlock the power supply to de-energize on furnace low cooling water or air flow.

2.7.2.8 Where cooling water or forced ventilation is provided for the furnace, initiate an alarm; and interlock the power supply to de-energize on furnace high return water, or equipment surface, temperature.

2.7.2.9 Initiate an alarm, and interlock the power supply to de-energize on detection of a large leak from a furnace cooling water circuit. Alarm on a small leak. A small leak and large leak are defined in Section 2.4.20.

2.7.2.10 Where cooling water or forced ventilation is provided for power supply equipment, initiate an alarm; and interlock the power supply to de-energize on low cooling water flow.

2.7.2.11 Where cooling water is provided for power supply equipment, initiate an alarm on power supply return water flow high temperature or equipment surface high temperature.

2.7.2.12 Where cooling water is provided for power supply equipment, initiate an alarm on leak detection from electrical equipment cooling circuits per Section 2.4.21. Electrical equipment may include but is not limited to transformers, capacitors, conductors and bus bars, or rectifiers.

2.7.2.13 Provide an alarm to sound at a constantly attended location and interlock to de-energize the power supply on furnace exhaust ventilation low flow.

2.7.2.14 Perform an overvoltage transient analysis of arc furnace transformer tap changes and primary switch operation in accordance with Data Sheet 5-11, *Lightning and Surge Protection*. Design the primary feed circuit based on the analysis findings. When the feeder circuit is altered or modified, update the transient analysis in accordance with the management of change (MOC) program.

2.7.2.15 Perform maintenance on an arc furnace transformer primary switch in accordance with the OEM.

2.7.2.16 Perform routine refractory thickness evaluation (gauging), particularly when using spray-applied cement-based coatings such as gunite. A common method for monitoring the wear and refractory thickness involves using chain gauges, while laser scanning may be another option.

2.7.2.17 Within the standard operating procedures, address whether raising the electrode(s) and verifying no current flow is necessary prior to opening and/or closing the primary switch. The need for raising electrodes to avoid overvoltage transients during switching is often driven by feeder circuit design.

2.7.2.18 Within the standard operating procedures, ensure a melt cycle/heat begins at low power prior to striking an arc, until electrodes bore into the scrap, to prevent arcs striking the furnace walls at full power.

2.7.2.19 Implement a mechanical inspection, testing and maintenance (ITM) program for key structural components of the furnace as discussed in Section 2.5.8. However, expand the program to include but not be limited to the tilting cylinder attachment points, rocker, and electrode mast and roof slewing system. Ensure particular attention is given to nondestructive examination of welds in these high-stress areas.

2.7.2.20 Provide the following equipment breakdown spares for an electric arc furnace (EAF):

A. Lower furnace (hearth): Sufficient spare shell plate for a weld repair following a molten release.

B. Upper furnace: Sidewall panels, top panels and roof panels

C. Mast: If present, slew bearing for the electrode and/or roof mast

D. Exhaust Ventilation: Fan and motor

E. Electrical Supply:

1. Arc furnace transformer (AFT) per Data Sheet 5-4, *Transformers*

2. Delta closure (secondary bus) that aligns with the existing transformer and electrode connections

3. Surge/overvoltage protective devices

Equipment breakdown spares for furnaces are intended to be used in the event of an unplanned furnace outage to reduce downtime and restore operations.

2.7.3 Submerged-Arc Furnace (SAF) and Other Specialty Ferroalloy Topics

Apply EAF guidance in Section 2.7.2 in addition to the following:

2.7.3.1 Take appropriate measures to prevent static electricity from accumulating and discharging in the furnace exhaust gas handling system. Use metal ducting and equipment; bond and ground all conductive components. See Data Sheet 5-8, *Static Electricity*, for additional guidance.

2.7.3.2 Take appropriate measures to prevent foreign matter, such as tramp metal, from entering the exhaust gas handling system. Foreign matter can cause ignition.

2.7.3.3 Thoroughly purge furnace exhaust gas handling system with inert gas during system startup after a shutdown which may have allowed air to enter the system. Start-up and shutdown functions might allow air into the system. Refer to Data Sheet 7-59, *Inerting and Purging Vessels and Equipment*.

2.7.3.4 Ensure the entire furnace exhaust gas handling system is airtight.

A. If the system runs at a negative pressure, monitor the oxygen concentration. Provide an alarm to sound at a constantly-attended location if the oxygen concentration exceeds safe levels (e.g., 4.5% v/v oxygen when inerting with nitrogen). Provide a written plan that tells operators what corrective actions to take if a high-oxygen concentration alarm sounds.

B. If the gas handling system and furnace head space are operated at a positive pressure, ensure safe operating conditions by monitoring the internal pressure or by measuring oxygen concentration.

Table 2.7.3. Alarms and Interlocks for Submerged Arc Furnaces

Equipment Parameter Upset Condition	*Permissive*	*Alarm*	*Trip*	*Action*	*Reference*
Furnace, refractory thinning/ metal penetration	-	X	X	De-energize electrodes	2.4.19
Furnace cooling water/air, flow	X	-	-	Allow energizing electrodes	2.7.2.6
Furnace cooling water/air, low flow	-	X	X	De-energize electrodes	2.7.2.7
Furnace cooling water return high temp or high equipment temp	-	X	X	De-energize electrodes	2.7.2.8
Furnace cooling water, large leak	-	X	X	De-energize electrodes	2.7.2.9
Furnace cooling water, small leak	-	X	-	-	2.7.2.9
Furnace, rotation stopped	-	X	-	-	2.7.3.5
Power supply cooling water/air, flow	X	-	-	Allow energize electrodes	2.7.2.6
Power supply cooling water/ air,low flow	-	X	X	De-energize electrodes	2.7.2.10
Power supply cooling water, high return temp or high equipment temp	-	X	X	De-energize electrodes	2.7.2.11
Power supply cooling water, leak	-	X	-	-	2.7.2.12
Furnace exhaust, low air flow	-	X	X	De-energize electrodes	2.7.2.13
Exhaust air infiltration, high oxygen concentration or decreasing exhaust pressure	-	X	-	-	2.7.3.4.B

2.7.3.5 When the furnace rotates, sound an alarm upon loss of rotation.

2.7.3.6 When the furnace is stationary, cycle the furnace electrodes vertically at regular intervals to separate bridges when small raw materials sinter easily. Avoid the negative trend of longer pressure pulses by increasing electrode cycle frequency or by other equally effective correction method.

2.7.3.7 Ensure that SOPs and EOPs address investigating and taking corrective action whenever observable furnace conditions point to possible problems such as:

A. Increasing intensity and frequency of furnace charge cave-ins, which are typically evidenced by momentary increases in peak gas temperature or pressure

B. Significantly increases or decreases in power consumption

C. Rumble or popping noises

D. Increased hydrogen content in the furnace exhaust gases

2.7.3.8 Bring any significant change or trend in measured process parameters (e.g., furnace temperature, off-gas analysis) to the attention of plant technical/engineering staff.

2.7.3.9 Equipment breakdown spares for furnaces are intended to be used in the event of an unplanned outage of a furnace to reduce downtime and restore operations. Provide the following equipment breakdown spares for a submerged arc furnace (SAF):

A. Lower furnace (hearth): Sufficient spare shell plate for a weld repair and (for a rotating hearth) support bearing following a molten release.

B. Upper furnace: Sidewall panels, top panels, and roof panels

C. Exhaust ventilation: Fan and motor

D. Electrical supply:

1. Arc furnace transformer (AFT) per Data Sheet 5-4, *Transformers*

2. Delta closure (secondary bus) that aligns with the existing transformer and electrode connections

3. Surge/overvoltage protective devices

Ferroalloy Production and Storage

2.7.3.10 Store ferrosilicon in a dry, noncombustible room that is not exposed to flood water, storm water, ground water, or stray water from process or building systems.

2.7.3.11 If water might contact ferrosilicon, provide gas monitoring equipment to alarm at a constantly attended location if the flammable gas concentration (phosphine, hydrogen, acetylene) exceeds 50% of the lower explosive limit (LEL). This detection should also automatically actuate mechanical ventilation that provides an air exchange rate of 1 cfm/ft^2 (0.3 m^3/min per m^2).

2.7.3.12 Ensure that walls separating the ferrosilicon storage area from adjacent areas are as vapor-tight as practical to prevent evolved flammable gases from migrating into adjacent areas that might not be as well ventilated.

2.7.3.13 Ventilate ferrosilicon storage areas by installing fans or roof ventilators with louvers at floor level. Provide a minimum ventilation rate of 0.25 cfm/ft^2 (0.075 m^3/min per m^2).

2.7.3.14 Perform an engineering analysis to establish safe raw material grain size range at each plant.

2.7.3.15 Provide a written procedure to ensure raw material grain size will not be accidentally or purposely decreased before an adequate study is made.

2.7.3.16 Periodically verify the grain size of material to ensure it is within specifications. If practical, sample the grain size of every shipment of materials.

2.7.3.17 If raw material grain size smaller than the established safe minimum must be used, slowly introduce it into the furnace in progressively larger proportions, mixing it with the proper grain size material. Carefully monitor furnace operation during this period to detect any condition that could indicate later problems. If conditions become erratic, such as pressure puffs within the furnace increasing in magnitude or frequency, decrease the proportion of finer-than-normal raw materials until conditions become steady and safe. Do not try to compensate for erratic conditions by adjusting other process operating parameters.

2.7.3.18 Establish the safe moisture content of raw materials charged into the furnace. Provide written guidelines that cite the procedures needed to ensure raw material moisture content is not accidentally or purposely increased before an adequate study is made.

2.7.3.19 Periodically verify raw material moisture content to ensure it is within specifications. If practical, measure the moisture content of every shipment of materials. Remeasure the content before charging materials to the reactor if the material has been exposed to atmospheric precipitation after the initial moisture content has been assessed.

2.7.3.20 To prevent moisture content from rising above prescribed limits, shield raw materials from atmospheric precipitation during storage and handling.

2.7.3.21 If raw materials are unavoidably exposed to moisture, and moisture content rises to undesirable levels; arrange for drying the material. Consider waste heat from the furnace as an economical heat source.

2.7.3.22 If raw materials with a relatively high moisture content might routinely be used in a furnace, consider using non-hydrating refractory materials.

2.7.3.23 Measure the zinc content of incoming ore whenever the ore composition might have changed. The composition of the ore could change if it came from a different source. View any increase in zinc content as a possible reason to switch to a different ore. Written policies regarding analyzing incoming raw materials should specify zinc measurement and the appropriate follow-up action required if the zinc content increases.

2.7.3.24 If the safety of an existing level of zinc content in the ore is uncertain, consider conducting a study to find out if the zinc is accumulating in the furnace. This study will involve performing a careful chemical balance on the zinc, comparing how much comes in with the ores to how much leaves the furnace via the product alloy, slag and exhaust gases.

2.7.3.25 To ensure the proportion of coke added to the furnace charge is consistent, periodically verify the accuracy of the measuring instrument.

2.7.3.26 Measure coke quality and moisture content as needed to detect any significant variations promptly and compensate for the variations when setting the furnace charge.

2.7.3.27 Train operating personnel to understand the hazards of operating the ferroalloy furnace and the conditions which could lead to hazardous furnace conditions. Training helps personnel recognize problems quickly and react appropriately.

2.7.3.28 Implement standard operating procedures (SOPs) and emergency operating procedures (EOPs) for SAF smelting operations per Section 2.5.7 and the following upset conditions:

- Furnace “puff” or minor blowout event, as these can be indicators of an ongoing root problem that could lead to a more severe upset event if unaddressed
- Changes in exhaust gas composition such as flammable components or oxygen (indication of increased air leakage).

2.7.4 Cupola Furnaces

2.7.4.1 Provide an emergency metal overflow drain just below the top of the refractory liner to prevent molten metal from rising above the top of the liner.

2.7.4.2 Where extensive flue gas handling and pollution control equipment is present for blast air heating, cleaning of furnace exhaust gases, etc., conduct a study on combustion explosion hazards and provide explosion prevention and mitigation features including:

A. Explosion protection (venting)

B. Explosion prevention (online monitoring of Carbon monoxide (CO) and hydrogen, plus suitable safety systems such as emergency bypass to atmosphere)

2.7.4.3 Provide redundancy for the hot blast air supply. For example, an N+1 (online spare) arrangement for blast air fans.

2.7.4.4 Create an EOP for loss of blast air, to prevent freezing or backup of molten material into the tuyeres and blast nozzles.

2.7.4.5 Restrict the use of water spray during bottom dropping to avoid water/steam entering the hot cupola and generating flammable gases.

2.7.4.6 Remove water accumulations under cupolas before dumping the bottom of the cupola.

2.7.5 Argon-Oxygen Degassing (AOD) Furnace

2.7.5.1 Provide an emergency tilting system capable of tilting the converter for emergency tapping in the event of a loss of the primary mover. Typical systems employ a nitrogen driven motor or a second electric drive backed up by an emergency power supply.

2.7.5.2 Provide redundant argon and oxygen sensors with alarms that sound in a constantly attended location to monitor gas flows to the furnace.

2.7.5.3 Provide an EOP for response to metal solidification in the AOD furnace.

2.8 Casting Specific

Apply the guidance in Sections 2.1 to 2.6 in addition to the following casting specific guidance.

2.8.1 Mold Casting (Automated or Batch)

2.8.1.1 Inspect molds prior to casting for clean and dry conditions.

2.8.2 Sand Casting

2.8.2.1 Store exothermic risers in a detached building separated from combustibles and critical utility, support or production equipment.

2.8.2.2 Minimize the quantity of exothermic risers staged in casting. Ideally, limit the quantity of risers required to support one shift of production.

2.8.2.3 Protect ignitable liquid binder agents in accordance with the appropriate data sheets (e.g., Data Sheets 7-32, *Ignitable Liquid Operations* and 7-29, *Ignitable Liquid Storage in Portable Containers*).

2.8.2.4 Evaluate and protect dust explosion hazards in accordance with FM Property Loss Prevention Data Sheet 7-76, *Combustible Dusts*. Of particular importance are mold breaking areas and potential combustible binders such as phenolic resins.

2.8.2.5 Protect bucket elevators and conveyors in accordance with FM Property Loss Prevention Data Sheet 7-11, *Conveyors*.

2.8.2.6 Protect ignitable liquid delivery systems associated with automatic casting machines in accordance with FM Data Sheet 7-32. Of particular importance is the use of properly arranged pipework, so that an exposing fire or radiant heat from a molten release does not result in ignitable liquid release.

2.8.2.7 Perform inspection, testing and maintenance for automatic molding/casting machines in accordance with FM Property Loss Prevention Data Sheet 13-8, *Power Presses*.

2.8.3 Investment (Lost Wax) Casting

2.8.3.1 Protect ignitable liquids used to form ceramic investment molds in accordance with the appropriate data sheets (e.g., FM Property Loss Prevention Data Sheets 7-9, *Dip Tanks, Flow Coaters and Roll Coaters*, 7-32 and 7-29).

2.8.4 Continuous Caster

2.8.4.1 Provide molten breakout containment for the tundish and ladle in accordance with Section 2.2.2.8.

2.8.4.2 Provide an emergency system to remove ladles from the caster or rotate the turret in the event of a power interruption, or to divert a molten release such as from failure of the ladle controls (e.g., the bottom gate fails to close). Divert the molten release into an emergency holding ladle beneath the casting floor or into a molten breakout containment pit.

2.8.4.3 Provide an emergency cooling water supply per Section 2.4.10 for starting block molds, cooled rolls and other cooled equipment.

2.8.4.4 Provide cooling system alarms that sound in a constantly attended location when large leaks, high and low surface temperature, or high/low water or air flow are detected.

2.8.4.5 Conduct an annual functional test of the emergency power system for removing ladles, moving the tundish or rotating the turret. Keep a written record of the testing for future review. Test the ladle empty, half full and full to ensure proper functionality.

2.8.4.6 Equipment breakdown spares for casters are spares intended to be used in the event of an unplanned outage of a caster to reduce downtime and restore operations. Provide the following equipment breakdown spares for a continuous caster.

A. Turret bearing

B. A mold and a set of rollers

2.8.5 Semi-Continuous (Vertical Direct Chill) Caster

2.8.5.1 Design vertical direct-chill casters to minimize the potential for a molten release and ensuing molten-water explosion. Incorporate the following design considerations.

A. Design casting pits to maintain a minimum water depth specified by the manufacturer, typically a minimum of 3 ft (1 m).

B. Provide a protective coating on steel and concrete in casting pits, including pit walls, pit floor and equipment not directly employed during casting operations (e.g., platens, but not molds or starting blocks) in accordance with the manufacturer guidelines and *The Aluminum Association, Guidelines for Handling Molten Aluminum*.

C. Install alarms, and permissive/trip interlocks to ensure key casting parameters remain within the respective safe operating limits. Parameters may include molten temperature, trough molten level, mold molten aluminum level, base plate descension speed, lubrication flow, cooling water flow rate and temperature, pit water level, or emergency cooling water supply level or pressure.

D. Design and install cooling-water systems for direct-chill casting operations in a manner that prevents a pressurized water leak from contacting molten material. Design features may include:

− Minimizing pressurized water pipe length around mold areas subject to a molten aluminum spill or spatter

− Protecting piping and flexible hose connections against molten aluminum spatter and spills

− Using pipe, joints and fittings with high thermal and mechanical integrity (e.g., high melting point materials such as steel with welded or compression fitting joints)

E. Provide an emergency cooling water supply capable of supporting a controlled caster shutdown or cast abort, whichever requires more time. Ensure the emergency and primary water supplies are not exposed to a common failure point. Refer to Section 2.4.10 for emergency supply options.

2.8.5.2 Visually inspect caster molds per manufacturer guidelines. At a minimum, inspect heat transfer components for water-side scaling or corrosion and hot-side for physical damage that may lead to bleed outs or hang-ups. Hot-surface damage may include cracks, deposits, or scratches along with damage to lubrication ports. Document inspection results, including any requests for corrective action.

2.8.5.3 Inspect casting pits for the following conditions and document inspections along with any findings, including any requests for corrective action:

A. Protective coatings on equipment, concrete pit walls and other surfaces

B. Metal accumulations at the bottom of pits that may reduce the effective water depth to less than the smallest amount required (i.e., 3 ft [1 m]).

2.8.5.4 At a minimum, include the following in SOPs and EOPs:

A. Pre-cast procedure and/or checklist consisting of at least the following activities:

1. Inspect trough drain pans for dry, clear conditions.
2. Inspect pit for water level and protective coating for evidence of burn-through.
3. Ensure the molten material and any preheated surfaces are within the desired temperature range.
4. Ensure molds have adequate cooling (e.g., uniform cooling water distribution) and lubrication (e.g., manually lubricated and/or lubrication ports are not plugged).
5. Inspect the hot-side surfaces of molds for scratches, cracks, deposits or corrosion.
6. Ensure equipment (e.g., mold, starting block, and platen) is properly aligned with appropriate clearances and level.
7. Ensure tools that may come in contact with molten material are warm and clean (e.g., plug rods).
8. Ensure the emergency cooling water supply is in-service.

B. Procedure for emergency abort with cast in-process

2.8.6 Centrifugal Casting

2.8.6.1 Implement a pre-cast SOP with checklist including a securement and alignment inspection.

2.8.6.2 Conduct non-destructive examinations (NDE) of mold securement components in accordance with the OEM. At a minimum, conduct visual examinations.

2.8.7 Die Casting

2.8.7.1 Use non-ignitable or FM Approved industrial fluid within hydraulic systems per Section 2.3.1.

2.8.7.2 Use a non-ignitable liquid or FM Approved industrial fluid within heat transfer fluid systems (a.k.a., thermal oil systems). Alternatively, refer to FM Property Loss Prevention Data Sheet 7-99, *Heat Transfer Fluid Systems*, for other fire protection options.

2.8.7.3 Maintain water-cooled die caster components per Sections 2.5.2.5 and 2.5.2.7. A cooling water leak can result in a molten-water explosion.

2.8.7.4 Implement an emergency response plan for fire or explosion incidents in accordance with Data Sheet 10-1, *Pre-Incident and Emergence Response Planning*. Highlight the need to isolate fuel-fired gas supplies.

2.8.8 Atomized Powder Production

2.8.8.1 Perform a reliability study on the atomizing media supply and delivery system to ensure that unintended interruptions in atomizing media delivery do not occur during production.

2.8.8.2 Ensure that a PHA is conducted and includes a study of the dust and equipment explosion potential for all operational modes of the atomizer (i.e., low-oxygen atmosphere). Include recommendations on safeguards needed to prevent incidents.

2.8.8.3 Provide an alternate (secondary) means of closing the ladle/tundish slide gates to interrupt the flow of molten material into the atomizer in case of an emergency.

2.8.8.4 Provide adequate methods to detect “jet-blockages” within the atomizer.

2.8.8.5 Perform atomizer shell integrity inspections (ultrasonic thickness measurements, weld inspections, etc.) on a regular basis.

2.8.8.6 Refer to Data Sheet 7-76, *Combustible Dusts*, when combustible metal powder and dusts are or may be present.

2.8.8.7 Refer to FM Property Loss Prevention Data Sheet 7-85, *Combustible and Reactive Metals*, when combustible and reactive metals are processed.

3.0 SUPPORT FOR RECOMMENDATIONS

3.1 Supplemental Information

Various pieces of molten equipment are involved in molten material release, molten-water explosion, fire, equipment breakdown and radiation contamination losses. These include electric induction furnaces, electric-arc melting furnaces, gas-fired and oil-fired melting furnaces or reverberatory furnaces, ladles and holding cars, spouts and chutes, cupolas, vacuum degassers, pressure casters, molds, tundish and casting machines. In addition, some losses have occurred because of water in the furnace charge or in slag dumps.

3.1.1 Molten Material Release

Breakthroughs can occur at any time in the life of the refractory. The highest frequency of refractory failures occurs immediately after installation. The most likely causes are faulty workmanship or defective materials. The frequency drops during the middle period of the refractory’s life span, then increases again toward the end of the anticipated life span. Higher than normal wear or weakness in the refractory may cause failure earlier than expected. All locations, even those where visual inspections of the furnace interior are regularly performed, experience molten material breakouts. In general, these losses have been accepted as an unavoidable occupancy hazard.

Monitoring of furnace refractory linings containing molten metal is needed to prevent molten metal breakouts. Regular visual inspections should be conducted; but other techniques are available for a more-detailed investigation of refractory health, including thermal imaging and continuous monitoring of temperature using thermocouples or other sensors embedded in the lining. Thermal imaging techniques have some limitations, such as in furnace areas that are obstructed by structural steel. When furnaces are provided with layer(s) of insulating blocks over the refractory, temperature readings may be different at the seams and joints and at the center of the blocks.

3.1.1.1 Refractory Management

Due to the high temperatures involved, molten containing equipment is provided with a thermally resistant lining, typically in the form of a hand-laid brick refractory, a rammed or loose-formed slurry, a one-piece (typically carbon) crucible or combinations thereof. In addition to thermal resistance, the lining must also be capable of withstanding the chemical and mechanical wear factors specific to the application and process involved. The lining is a key component of a furnace and vessel; and it must be properly designed, installed, operated and maintained over the lifespan of a campaign to minimize the potential for lining failure and molten material release.

Successful refractory management starts with a basic understanding of the forces at play within the furnace or equipment: melt thermodynamics; fluid dynamics, including areas likely to encounter high wear; impact of electrical forces and dynamics such as arc characteristics (EAF and SAF) and inductive stirring; and finally melt or smelt and slag chemistries. Establishing these parameters (process knowledge) informs the choice of refractory materials, layout, thickness, maintenance, campaign life, etc.

During the lifespan of a lining, ongoing inspection and maintenance is vital. Over the course of its operation, localized thinning of the lining due to mechanical abrasion or chemical attack may occur. Provided the overall health of the refractory is still satisfactory (thickness, mechanical integrity, etc.), localized repairs can be carried out by re-bricking or application of refractory slurry. This procedure is sometimes referred to as "guniting".

Equally important as proper installation and maintenance of the lining is determining a reliable service life ("campaign life") and adhering to it. Running a furnace beyond the useable life of its refractory has been the cause of many molten material release losses over the years.

3.1.1.2 Common Causes of Refractory Failure

A review of premature/mature refractory lining failures indicates the following most common causes, ranked roughly in order of occurrence during a campaign:

1. Flaws or defects during installation caused by unsatisfactory installation methods or workmanship error(s), or unauthorized/verified changes/substitutions in refractory materials

2. Improper break-in or sintering of the newly installed/formed lining

3. Undetected/uncorrected localized wear/thinning during operation, often caused by changes in melt chemistry or slag composition, leading to corrosion or oxidation of the brick; or a process upset such as bridging in a coreless induction furnace

4. Mechanical damage while charging

5. Hydration caused by leaking cooling water or other sources

6. Operating beyond established campaign life leading to thinning, loss of resilience or general lack of structural integrity

While the frequency of a breakout event can be reduced through good refractory management programs, all locations, even those where visual inspections of the furnace interior are regularly performed, can experience molten material breakouts. In general, these incidents have been accepted as an unavoidable occupancy hazard.

3.1.1.3 Refractory Assessment Methods

3.1.1.3.1 Manual (Non-continuous) Refractory Inspection

Two main categories of manual inspection exist: offline, in which the lining is inspected in a non-operational or resting state; and online, in which the lining is inspected while in operation. Typically, a combination of the two will be employed during a campaign, particularly when batch equipment or processes are present. Two main methods are used: direct and indirect. Examples of common direct methods include:

- Mechanical hearth profile/contour gauge (chain gauge)
- Laser profiling (laser interferometer)
- Videoscopic profiling
- Visual inspection
- Core sampling (destructive examination)

The most common manual indirect method of inspection is infrared thermography (thermographic scanning or imaging). Recent technological advances have produced reliable, relatively inexpensive infrared imaging systems with sufficient accuracy to detect hot spots in refractories. However, this technique has limitations such as image obstructions due to structural supports or water-cooling circuits/passages. FM Property Loss Prevention Data Sheet 5-20, *Electrical Testing*, explains in detail the theory and operation of these scanners. If a crack or worn spot in the refractory exists, the increase in temperature of the outside wall can be detected before a breakout occurs. Various steel companies use thermography to monitor hot metal ladle refractories.

Other methods of manual refractory monitoring and inspection have been developed over the years for more specialized applications such as use of weak radioactive sources embedded within the refractory of continuous furnaces, etc.

3.1.1.3.2 Online (Continuous) Refractory Monitoring Systems

Online monitoring of refractory linings serves to provide a continuous condition assessment of the lining, and in some cases can act as a safety device, providing an early warning of localized thinning and potential imminent failure of the lining.

Use of thermocouple arrays to monitor refractory wear and remaining life is well established in blast furnaces, which contain hundreds or more thermocouples embedded in the lining, providing a real-time profile of the lining wear. Simpler variations of these systems may be employed as a form of online monitoring in the furnaces covered by this data sheet.

Recent technological advancements have brought to market commercially available products which monitor changes in electrical resistance in the lining, which can indicate changes in lining condition (thinning or metal penetration). Along with the initial installation cost of these systems, replacement of the sensor arrays on some frequency is an ongoing cost.

3.1.2 Molten-Water Explosion

Molten-water explosions have resulted from water released within a furnace due to failure of an internal cooling circuit, water/moisture in scrap or moisture in materials/ore being melted. Additionally, molten material released from equipment have contacted water on the floor, in pits beneath the equipment, in molds, ladles or other containers, or in slag pits resulting in molten-water explosions. The mechanism of water-molten material explosions is not conclusively known. The most likely cause is quick vaporization of the water through very rapid heat transfer between the hot molten material and water.

Molten metal explosions have overpressure characteristics (maximum pressure and rate of pressure rise) that can be more severe than just a rapid steam overpressure event. Based on incidents and testing, the more severe events may be attributed to reactivity of high temperature metals and the potential for small molten metal droplets to be expelled into a confined volume. This situation significantly increases the surface area to volume of the droplets subject to reaction, which in turn produces extremely high steam production. This condition is also known as a rapid phase transition (RPT) explosion.

The proliferation of water-cooling systems associated with metallurgical furnaces since the early industrial revolution has coincided with a rise in the number of notable (and numerous unnoted) molten-water explosion incidents. The most severe events have typically involved large, continuous operations such as blast furnaces or ferroalloy/silicon smelters; but no molten operation is immune from the hazard due to the myriad potential sources of water, including that from leaking roofs, groundwater, cooling system leaks, etc.

3.1.3 Fire

Fires have started because hot molten material came into contact with combustible building construction, hydraulic oils or other ignitable liquids, and ordinary combustibles in the vicinity. Heat from fires or hot molten material has damaged exposed structural steel members, furnace and equipment supports, machinery and equipment, wiring, tubing and piping located under or near the molten material.

3.1.4 Equipment Breakdowns

Often, mechanical breakdowns (failures) are the initiating event leading to a molten release or molten-water explosion. Examples include pressure part failure within a furnace cooling system, leading to hydrated refractory or molten-water explosion. Mechanical failure of a motion-control system (hydraulic tilt cylinder or threaded jacking screw on a copper holding furnace) can lead to uncontrolled tilting and molten release with subsequent ensuing damage.

3.1.4.1 Routine Spares

Ensure the viability of routine spares by storing and maintaining them in accordance with the original equipment manufacturer's instructions. Refer to Data Sheet 9-0, *Asset Integrity*, for additional guidance. The following are common routine spares:

A. Refractory and mortar when appropriate

B. Water-cooled components

C. Operating controls such as slag analyzers

D. Induction coil for coreless furnace

E. Induction coil for channel-type furnace

3.1.5 Radioactive Contamination

Radioactive contamination can occur in any furnace processing scrap metal. The six metals for which there are scrap markets and the quantities of scrap metals processed in 1994 in the U.S. is shown in Table 3.1.5. These metals account for approximately 95% of the recycled metal. The majority of the metal recycled, about 88%, is iron and steel.

Table 3.1.5. Scrap Metal Recycled in the U.S. in 1994

Metal	*Scrap Consumption (Tons x 10^3)*	*Percent of Total Which is Scrap*
Aluminum	4,029	42
Copper	1,474	37
Iron & Steel	54,109	50
Lead	1,046	63
Nickel	703	41
Zinc	279	22

Three types of scrap exist: prompt or industrial scrap, obsolete scrap and scrap from household or municipal waste. Prompt scrap is scrap metal generated during manufacturing operations such as trimmings, stampings or castings that have been rejected. Obsolete scrap is from products that have been in use such as structural steel, automobiles, aircraft, appliances, etc. Municipal waste is that generated from household uses such as metal food and soft drink containers. Most products containing the desired metal can be recycled. Prompt and obsolete scrap are sold on the open market. Prompt scrap is unlikely to contain radioactive materials. Municipal waste may contain consumer products with radioactive materials such as smoke detectors or watches with luminous dials. The level of radiation would not be sufficient to cause contamination of the melt.

3.1.5.1 Cause

Radioactive contamination occurs when radioactive material is included in recycled scrap and melted in a furnace, or the radioactive material is dispersed during processing of recycled scrap. Contamination can occur in any metal recycling operation. Radioactive source may be included in scrap accidentally or to avoid disposal charges. Many radioactive devices in use will not result in significant contamination of scrap or dust from the furnace. Between 1 and 2 million radioactive devices exist in the U.S., approximately 150,000 of which are capable of causing significant contamination in scrap. These are medical devices used for cancer treatment or medical research and industrial devices such as those used for level and density monitoring. Gages are used in a wide variety of industries such as chemical, petroleum, food, electric utility (fossil), mining and construction industries. The device consists of a radioactive source in a shielded enclosure. The radioactive source is usually a gamma emitter. The shielding used is a high-density material, usually lead, designed to reduce external radiation to 5 mR/hr at a distance of 1 ft (30 cm) from the enclosure. When the source is in use, a shielded window is opened allowing radiation to pass through the object. In the case of industrial sources, radiation intensity is measured on the opposite side of the object. The reduction in radiation is used to determine liquid level in tanks or the density of liquid in pipes.

Many devices are not inspected by regulatory authorities. Regulatory authorities expect the owner to properly maintain and dispose of the device. The hazard presented by radioactive materials in recycled scrap is expected to continue for the foreseeable future. No effective means are available to ensure devices containing radioactive materials will be properly disposed. In the United States, two hundred radioactive sources are reported lost or stolen annually. Of these, about 20 are of concern to metal recyclers. However, other losses or thefts are not reported. The problem appears to be the same in other countries. The activity of regulatory authorities in countries such as France, UK and Canada appear to be similar to that in the United States. Naturally occurring radioactive material (NORM) is also encountered in metal recycling plants. NORM is typically steel piping containing surface deposits of radium or radium decay products. It is most often encountered in piping which has been used in oil, natural gas and mineral processing. The levels of radiation are high enough to alarm a radiation detector but are not as potentially dangerous as other materials.

3.1.5.2 Detection

The most effective way to prevent contamination is to detect devices containing radioactive material before they are loaded in the furnace (see Figures 3.1.5.2-1 and 3.1.5.2-2). Approximately 95% of the contaminated scrap was detected by fixed detectors, 2.1% were detected using hand-held radiation detectors and 1% were detected by operators who identified warning labels.

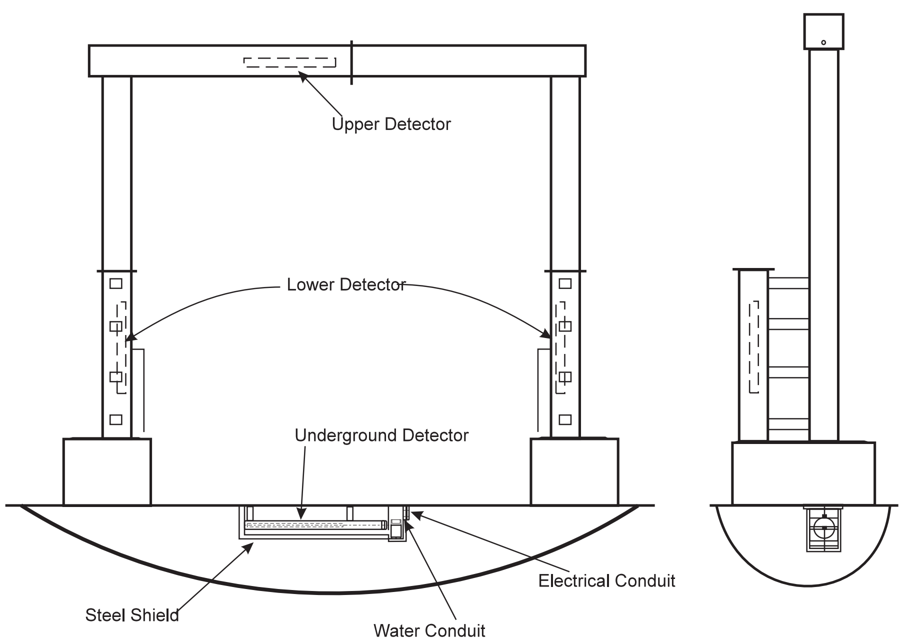

Fig. 3.1.5.2-1. Radiation detection system for truck and railcar scales

The effectiveness of radiation detection systems depends on:

1. The speed at which scrap passes the detectors
2. The number of detectors used
3. The sensitivity of the detectors
4. The density of the scrap
5. The location of the source within the scrap

The speed of the truck or railcar past the detectors must be controlled for optimum detection. A speed of 3 mph (4.8 km/h) is best. The speed of travel for truck traffic can be controlled by speed bumps or by instructing truck drivers to come to a complete stop before proceeding.

In some installations two detectors are used, one on each side of the vehicle. In other installations, three or four detectors are used. The three detector systems have detectors on both sides and the top. The four detector systems have detectors on both sides, top and bottom (Figure 3.1.5.2-2). The probability of detection is higher when more detectors are used. The most widely used scrap metal radiation detectors are termed “plastic” detectors. Each sensor is a large mass of polyvinyl toluene (PVT). The PVT is in a metal

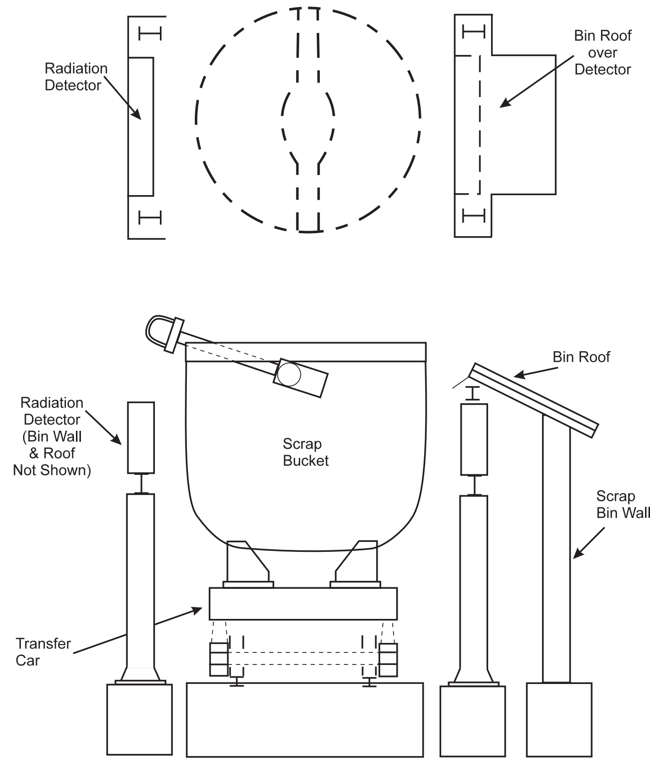

Fig. 3.1.5.2-2. Plan and elevation views of a radiation detection system for a bucket loading station

enclosure. The sides and back of the enclosure are thick steel to reduce the possibility of false alarm from background radiation. Radiation coming in contact with PVT generates light. The light is detected by a photocell, and the signal is amplified and sent to a microprocessor or a minicomputer. The computer continually adjusts the alarm settings to slightly above background radiation levels for maximum sensitivity. When a railcar full of scrap is in front of the detector, the background radiation decreases, and the computer lowers the alarm set point automatically. The alarm set point can be maintained a few percent above background. Other simpler types of radiation detection systems have alarm set points two to three times above background and are less likely to detect a radioactive device.

Computer controlled detection systems can store information which can only be accessed with the proper code. The monitoring system can also be connected by modem to the company providing the equipment. The code access allows periodic checks between the alarms received by the detection equipment and the operator's logbook to verify that the operator is taking the correct action. The modem allows the company providing the equipment to monitor its performance and assist in troubleshooting without the need to visit the plant. The density of the scrap is an important factor. The higher the density, the more radiation is absorbed; and the less likely the system is to detect the source. Hand-held radiation survey meters can be used as a supplement to radiation detection stations to pinpoint the location of a radioactive source in truck or railcar scrap shipments (see Figure 3.1.5.2-3). Hand-held survey meters can also be used to scan scrap in the yard.

Within the mill, the best chance of detection is by use of radiation detection equipment at a minimum of two locations where the configuration of the scrap has been changed. One location is the truck or railcar entry point. A second location is usually the bucket loading station. After a contamination incident, one mill installed a short length conveyor equipped with a radiation detection system. Scrap is run over the conveyor before charging the furnace. Detection equipment has also been mounted under the cab of the crane to monitor scrap steel. There have been 1,409 detections of radioactive scrap reported in the U.S. in the 11-year period 1985 to 1995 as follows:

- 195 were loads of scrap containing devices with radioactive materials

Fig. 3.1.5.2-3. Hand-held radiation survey meters

- 337 detections occurred in which the load was returned to the supplier without identification of the cause of alarm
- 877 where detections were caused by NORM

Most of the detections occurred at the end of this 11-year period as mills began to realize the importance of installing detection equipment. Some of the sources detected had the potential for significant radiological contamination of the mill, products and by-products. Approximately 50% of the scrap steel recycling mills have radiation detection equipment to monitor material coming into and leaving the mill.

3.1.6 Ferroalloy Production and Storage

3.1.6.1 Furnace Explosions: Overview of Bridge Formation and Collapse

The principal concept is preventing bridging inside a ferroalloy furnace. But what is bridging, and why is it hazardous?

Bridging is the cohesion of fine raw material in the upper portion of a ferroalloying furnace. Cohesion creates temporarily stable areas of raw material which can no longer flow like fluid down into the furnace depths. Intuitively we expect granular material to be more cohesive and very fine; in fact, the finer the particles, the more likely they will form a cohesive mass, and the harder it will be to break up that cohesive mass.

But if the material is not fine enough to be cohesive, an external material could cause particles to adhere. Adherence could occur when slag is improperly channeled into the upper, cooler zones of a furnace. Zinc oxide condensing in the space between the particles of the raw material charge could also cause adherence.

As stated, a bridge will not fall smoothly into the furnace with the surrounding granular material. Instead, the raw material flow tends to create voids underneath the bridges. As molten material below the bridge continues to be drawn off, the cavity created grows ever bigger. At some point, the roof or walls of the cavity can no longer support the weight of the material above, and the bridge collapses. Very small, weak bridges will only allow small cavities to form. The collapse of these cavities might only produce small pressure pulses in the furnace. Bridging is unacceptable and hazardous when the magnitude of the pressure pulse damages the furnace or gas removal system.

When the raw material supported by the bridge suddenly drops deep into the furnace, a large quantity of gas can very rapidly form by one of two mechanisms:

A. Gases can explosively release when chemically or physically bound water is suddenly exposed to the very high temperatures deep in the furnace. This is explained further in Section 3.1.3.

B. The instantaneous dissociation of oxides and carbonates in the ore can suddenly release gases. Chemical compounds in the ore usually reduce gradually (i.e., their oxygen atoms are removed) by their chemical reaction with the gases rising up through the material. However, when a bridge collapse suddenly plunges the ore near the top of the furnace much deeper into the furnace, the high temperatures rapidly decompose the ore. This ore has not yet been prereduced. Because this reaction occurs very quickly and usually quite deeply within the furnace, it typically results in an explosive rise in pressure. Rising pressure blows the cover off and ejects hot material out of the furnace.

The furnace cover failing suddenly will create and propagate shock waves into the surrounding area damaging other nearby equipment and building elements. Impulse to the reactor cover can project the cover for a considerable distance or through a wall or roof. Ejected hot material can also damage nearby building elements and equipment.

3.1.6.2 Importance of Using Raw Material with Appropriate Grain Size

When the raw material charged to the electric furnace is too fine, the pressure drop of the gas evolving below the surface and flowing up through the furnace charge becomes higher. This increased resistance to flow deteriorates the uniformity of gas flow through the furnace charge. Generated gasses blow out along the circumference of the electrodes where the pressure drop is lower. (This action is known as gas blowing.) Under impaired gas flow, the evolved gases fail to properly contact the furnace charge. As a result, the material predries inadequately; the prereduction, i.e., chemically removing excess oxygen from the ore is inadequate; and the heat exchange is inadequate. Aside from increasing the required power consumption and decreasing the furnace yield, these problems can also create the hazardous conditions described in Section 3.1.

As a guide, one ferromanganese (FeMn) producer has set the following size specifications for raw material grain size:

Ore: 5 to 70 mm
Limestone: 5 to 30 mm
Coke: 3 to 25 mm

If the crude ore (as-received) has a smaller grain size than what is considered safe, a common practice is sintering the ore to increase particle size significantly. One FeMn producer claims sintered ore accounts for half the total ore charged to the reactor. This significantly improves gas flow conditions. Yet another option for the ferroalloy producer is to accept from the mines only well-screened material in the desired size range.

If coke charged with the raw materials has a substantial amount of fines, a possible bridging problem results, but if furnace material erupts, the coke dust can be suspended into the surrounding room, creating a combustible dust explosion. Such events have caused severe property damage.

3.1.6.3 Effect of Raw Material Moisture Content

Raw materials first charged to a reactor are exposed to approximately 300 to 570˚F (150 to 300˚C) at the top of the charge. Materials moving downward into the reactor are exposed to increasing temperatures, until finally they reach the melting zone of 2190 to 2730˚F (1200 to 1500˚C). Any moisture that is part of the raw material charge, either as surface moisture or chemically bound, is completely driven off by the time the material reaches the melting zone. This gradual moisture release does not lead to any hazardous condition.

Occasionally, a bridge collapse might drop material that has not been completely dehydrated into the melt zone. This can occur in a minor way under routine operating conditions after slag tapping. Under abnormal conditions, a significant bridge can form and collapse. See Section 3.1.14.1.

When the water containing material falls into the melt zone, surface moisture and water very rapidly transform into vapor, or, at very high temperatures, dissociate into H_2 and O_2. This rapid phase change from liquid to gas, and the associated volume increase, rapidly pressurizes the reactor. Depending on how much water was converted to vapor, the result might be a small, but measurable pressure pulse within the reactor, or a very large pressure increase that blows off the furnace top and body seal. Often such large pressure increases also eject slag and raw materials from the furnace through the blown-off top.

One FeMn producer specifies measuring moisture content every shift, using the following percentages as a guide:

Ores (including limestone): 2% ± 1%
Coke: 5% ± 1%

A loss report for one furnace explosion shows that this FeMn producer usually used coke at a moisture content of 10%. This increased to about 17% in the days preceding the explosion. Using raw materials with a lower moisture content is obviously less likely to lead to bridging. However, an upper safe limit cannot be established here with any certainty.

Aside from creating a furnace explosion hazard, high-moisture, raw material charge can also shorten the life of the furnace lining. Extensively exposing magnesia brick in the sidewall lining to high moisture feed stock hydrates the magnesia creating a highly undesirable situation. The hydrated magnesia, known as brucite, occupies over 50% more volume per mass than does the magnesia, and its expansion disturbs the layout and bonding of the brick. Because the bonding is destroyed, hydrated refractory cannot protect against molten metal breakout.

3.1.6.4 Effect of Improper Coke Dosage

Control of the amount and quality of coke charged to the reactor can be a root cause of furnace explosions. If excess coke is charged, the electrical resistance of the raw material layer in the furnace changes. As a result, there is less raw material melting, slag boiling and gas blowing. If insufficient coke is charged, the overall raw material density increases, reducing the rate of mix travel and increasing the melting rate. Either event increases the likelihood that a bridge will form and an explosion will occur.

3.1.6.5 Effect of Zinc Concentration in Ore

Zinc, which may be in the ore used for ferroalloying processes, usually comprises much less than 1% by weight. However, even in small amounts, zinc can be very troublesome to furnace operation.

Zinc's primary hazard is its ability to accumulate in the furnace slowly, causing raw material to bridge in the upper parts of the furnace. Zinc is part of the charged ore as zinc oxide (ZnO). In the hotter (lower) parts of the furnace, the zinc oxide is reduced to form elemental or metallic zinc.

Because the boiling point of zinc is well below the reduction temperature of the oxide, the zinc is released as a gas, and moves up through the charge with other released gases. Most zinc vapor exhausts from the furnace along with other gases, but if it encounters any oxygen during its ascent, it re-oxidizes to ZnO. This re-oxidized material has a significant cementitious effect on the raw material in the upper (cooler) part of the furnace, causing the material to bridge. When the bridge containing the zinc oxide collapses into the reaction zone below, the ZnO reduces to metallic zinc; the vapor rises, partly oxidizes, and the cycle continues.

Very low levels of zinc in the ore do not seem to cause a significant problem when zinc accumulates. Bridges formed are small enough that they do not cause large pressure pulses when they collapse. However, increased zinc tends to accumulate to form larger and stronger bridges. When a large enough bridge collapses, a large pressure excursion can damage the reactor.

The cementitious effect of the oxidized zinc metal in the upper, cooler part of the furnace also prevents gases from flowing uniformly and evenly up through the charge. The resulting inadequately pre-dried and pre-reduced material can suddenly release hazardous gases when the material finally drops into the hotter layers below.

Zinc has negative effects on the furnace refractory. Where alumina-based firebrick is used, the zinc oxide tends to combine with the alumina to expand the brick. Results are damaging. Carbon blocks used to line a furnace will wear away due to the carbon's chemical involvement in the reduction of zinc oxide to zinc.

As an example of high and low zinc levels, one FeMn operation operated safely with 0.075% zinc content in the ore, but using ore with 0.22% zinc content resulted in an explosion.

3.1.6.6 Other Hazardous Operating Conditions Related to Furnace Explosions

Several operating conditions exist that can create hazards leading to explosion, but there are no published guidelines for safe operation. The following hazardous condition scenarios should heighten your awareness of the risks. Consider them when analyzing a post-explosion incident. Keep in mind, we are not able to offer specific recommendations at this time.

An increase of slag viscosity inside the furnace can form bridges (via molten slag attachment to raw materials) followed by collapse and subsequent explosions. Unacceptable fluidity results from an improper ratio of calcium oxide (CaO), silica (silicone dioxide-SiO2) and alumina (aluminum oxide-Al2O3) in the slag. However, because detailed slag chemistry is beyond the scope of this TAB, we offer no specific guidance on slag compositions.

Soderberg (self-baking) anodes used in a ferroalloy furnace may result in an explosion within the electrode case if the height of carbon paste charged into the electrode case is much too high or low. Apparently no published guidelines exist on electrode case charging; therefore guidance on safe practice is not provided here.

Ores used as raw material for ferroalloys can have varied oxidation states (i.e., different number of oxygen atoms per desired metal atom). Highly oxidized ores seem to be more readily available and save energy, because they release more heat energy as they are reduced in the furnace. However, using larger proportions of highly oxidized ores also creates a greater explosion risk. With more oxygen atoms available, decomposition resulting from a bridge collapse will release more gas than the less-oxidized ore and create a higher pressure and a faster rate of pressure rise. This difference in gas release can mean the difference between a safe pressure puff and a destructive pressure excursion. Assuming all other variables are constant, an unexpected furnace explosion could result from increased high-oxidized ore in the raw materials. A high proportion of carbonates in the ore will have a similar effect. In spite of this, a furnace can be safely operated with a high amount of high-oxidized and carbonatic ores. However, using such ores makes the it much more important to prevent all bridging.

Consider using pressure monitoring under the electrode tips. When increasing pressure is detected, which indicates poor upwards gas flow (e.g., as caused by bridging), move the electrodes slightly to break up material bridges at the electrodes. Because we lack sufficient information on the practical aspects of this arrangement, we are not presenting this as a recommendation.

3.1.6.7 Flammable Gas Explosion Potential

The normal operation of a ferroalloying process will produce large volumes of gas containing carbon monoxide (CO). For process energy efficiency, this flammable gas is often collected and used for its heating value. Alternatively, gas can be collected in a ductwork system attached to the furnace cover and routed into a scrubbing system. Because the headspace and the gas collection system contain a flammable gas, an explosion hazard may exist if air is allowed into the system. To minimize the risk of a gas/air explosion within the furnace or gas collection system, use engineering measures to exclude air. As an added level of security, take reasonable precautions to prevent ignition sources from occurring inside the system.

3.1.6.8 Ferrosilicon Storage Hazard

Ferrosilicon in solid form will react with water or steam to produce hydrogen, acetylene, phosphine, and arsine. The first three are flammable gases. If stored ferrosilicon might contact water, provide ventilation and possibly flammable gas detection to prevent creating a flammable or explosive atmosphere in the storage area. Even without direct contact with water, ferrosilicon can react with high levels of atmospheric moisture to produce flammable gases, although at a much lower rate. Quantities of flammable gases evolved by water/moisture contact are relatively small. Adequate ventilation will readily disperse them. For this reason, damage-limiting construction and hazardous location electrical equipment have not been recommended for this hazard.

3.1.6.9 Prevention of Molten Metal Breakout

Literature suggests that carbon refractory used in lining the furnace shell is dissolved quickly by the reactive ingredients in a ferroalloying furnace. For this reason, breaching the refractory lining and subsequently releasing the molten metal is particularly hazardous. Adequate shell design will maximize its useful life, but temperature monitoring is essential for detecting the thinning of the carbon refractory before molten material breaks out.

Using imbedded thermocouples appears to be an accepted practice in this industry; however, molten metal escapes occur too often. Temperature monitoring has not helped reduce the loss record effectively because of improper follow-up upon detection of increasing localized temperatures. Plant operators have often reacted by cooling the high temperature area (e.g., by blowing air onto the area). This can bring the localized temperature back down to an acceptable range, but it fails to solve the cause of problem which is usually a thinning refractory.

A good way to monitor carbon lining thickness is to use radioactive isotopes. Weak radioactive sources are implanted into the carbon lining of the furnace. Every week, a geiger counter verifies whether the source is still there or not. When the source is no longer detected, the lining has eroded down to where the source was implanted. When this minimum level is reached, furnace relining is needed.

3.2 Loss History

3.2.1 Loss Data

The following tables were derived from a review of losses that occurred within molten occupancies during 1993 through 2024 (i.e., molten occupancies downstream of smelting and other metallurgical refining operations addressed in other data sheets). Table 3.2.1-1 contains losses sorted by loss peril, while Table 3.2.1-2 contains losses by molten substance. All values are indexed to 2024 USD.

Table 3.2.1-1. Molten Occupancy Losses by Peril

Initiating Peril	*Ensuing Damage (Peril)*	*No. of Losses*	*Gross Loss (US$M)*
Molten material release (MMR)	n/a	128	519.56
	Explosion	14	222.92
	Fire	41	123.21
Fire	n/a	47	447.78
Electrical Breakdown	n/a	67	416.87
	Fire	14	199.35
Explosion	n/a	21	130.72
	Fire	5	51.70
Mechanical Breakdown	n/a	52	140.18
	Explosion	25	81.25
Collapse	n/a	4	105.23
Radioactive Contamination	n/a	4	58.59
Service Interruption	n/a	12	25.37
	Temperature Change	11	24.89
Temperature Change	n/a	4	5.88
Contamination	n/a	1	1.27
Mechanical Impact	n/a	1	1.25
Total(s)	n/a	341	1,852.69

Two groups of explosion incidents are shown in Table 3.2.1-1. In the first group of 21 incidents, the equipment explosion was the initiating event, attributed to wet charge, cooling water leakage into molten containing hearth, or combustion explosion involving fuel gas or combustible dust. In the second group of 14 incidents, a molten release encountered water in the molten occupancy. The source was stray water, or water from when the molten release burned through pressurized cooling water components or entered a vertical-direct chill casting pit.

Table 3.2.1-2. Molten Occupancy Losses By Metal or Material

Molten Material	*No. of Losses*	*Gross Loss (US$M)*
Steel	122	716.07
Iron	85	486.78
Aluminum	47	210.17
Copper	31	268.3
Zinc	15	20.46
Slag	12	26.61
Ferroalloy	10	50.64
Lead	8	17.26
Silicon	7	37.72
Mineral	4	17.51
Precious	2	2.24

Table 3.2.1-3. Molten Occupancy Losses By Molten Equipment Technology

Operation	*Technology (Type)*	*No. of Losses*	*Gross Loss (US$M)*
Furnace	Furnace (ALL)	260	1,484.82
	Induction (ALL)	103	304.66
	Channel	42	91.63
	Coreless	61	213.03
	Electric Arc (EAF)	82	651.82
	Fuel-Fired	28	102.78
	Submerged Arc (SAF)	22	281.47
	Zinc Kettle (ALL)	10	18.73
	Kettle (Fuel-Fired)	4	2.58
	Kettle (Induction)	3	6.09
	Kettle (Unknown)	3	10.06
	Cupola	6	5.35
	Lead Pot (Fuel-Fired)	4	2.40
	Argon-Oxygen Decarb. (AOD)	3	12.17
	Ladle Refining	1	12.45
	Vacuum Degasser	1	93.00
Casting	Casting(ALL)	47	324.41
	Sand (ALL)	14	52.39
	Sand (Automated)	10	44.76
	Sand (Manual)	2	5.70
	Sand (Not Reported)	2	1.944
	Die	13	33.51
	Continuous	6	87.14
	Pan/Ingot	2	5.29
	Centrifugal	3	2.06
	Investment	3	37.62
	Atomized Powder	2	1.44
	Vertical Direct Chill (VDC)	2	82.70

Table 3.2.1-3. Molten Occupancy Losses By Molten Equipment Technology

Operation	*Technology (Type)*	*No. of Losses*	*Gross Loss (US$M)*
Molten Transfer	Molten Transfer (ALL)	23	18.70
	Heavy Duty Mobile Equipment (HDME)	12	11.61
	Crane	6	6.14
	Launder	2	0.37
	Fork Truck	2	0.15
Utility Power	Utility Power (ALL)	12	25.37
	Power Lines	9	24.20
	Substation	3	1.17

Table 3.2.1-4. Furnace and Casting Losses By Peril

Peril	*Description*[1]	*No. of Losses*	*Gross Loss (US$M)*
Fire	Exhaust & Emissions Control Equipment	14	12.94
	Hydraulic	6	10.48
	Cabling	5	19.73
	Die	5	18.88
	Valve Room	4	24.36
	Wax	3	37.62
	Commodity Storage	3	281.49
	Combustible Mold Storage	2	22.25
	Belt Conveyor	1	5.91
	Sand Resin	1	5.57
	Mold Release Agent	1	5.17
	Control Room	1	2.46
Electrical Breakdown	Arc Furnace Transformer (AFT)	35	143.02
	Power Transformer	9	65.57
	Induction Furnace Transformer (IFT)	8	4.43
	Capacitor	7	165.66
	Reactor (PF Correction)	2	2.69
	Inductor	1	1.26
Explosion	Molten-Water Equipment	25	158.49
	Molten-Water Room	16	164.58
	Combustion	10	95.29
	Wet Charge	7	27.34
	Charge	1	4.08

Note 1. Combustibles for fire loss, equipment of origin for electrical breakdown loss, and source of energy release for explosion loss

4.0 REFERENCES

4.1 FM

Data Sheet 1-28, *Wind Design*
Data Sheet 1-40, *Flood*
Data Sheet 1-54, *Roof Loads and Drainage*
Data Sheet 1-62, *Cranes*
Data Sheet 3-29, *Reliability of Fire Protection Water Supplies*
Data Sheet 5-4, *Transformers*
Data Sheet 5-8, *Static Electricity*
Data Sheet 5-19, *Switchgear and Circuit Breakers*
Data Sheet 5-30, *Power Factor Correction and Static Reactive Compensator Systems*

Data Sheet 5-31, *Cables and Bus Bars*
Data Sheet 7-9, *Dip Tanks, Flow Coaters and Roll Coaters*
Data Sheet 7-11, *Conveyors*
Data Sheet 7-25, *Blast Furnace Ironmaking and Basic Oxygen Steelmaking*
Data Sheet 7-26, *Glass Manufacturing*
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 7-59, *Inerting and Purging Vessels and Equipment*
Data Sheet 7-64, *Aluminum Smelting*
Data Sheet 7-76, *Combustible Dusts*
Data Sheet 7-83, *Drainage and Containment Systems for Ignitable Liquids*
Data Sheet 7-85, *Combustible and Reactive Metals*
Data Sheet 7-98, *Hydraulic Fluids*
Data Sheet 7-99, *Heat Transfer Fluid Systems*
Data Sheet 7-110, *Industrial Control Systems*
Data Sheet 9-0, *Asset Integrity*
Data Sheet 10-1, *Pre-Incident and Emergency Response Planning*
Data Sheet 10-4, *Contractor Management*
Data Sheet 10-8, *Operators*

APPENDIX A GLOSSARY OF TERMS

Bridging: Formation of a solid (immovable) bridge of raw material within a furnace that prevents the raw material above from moving down into the furnace. Bridging is of particular concern in continuous process furnaces, e.g., ferroalloy, where fine feedstocks can “sinter” and form a bridge, which later collapses violently. Bridging can also occur in coreless induction melting furnaces, leading to superheating of the melt below the bridge and subsequent refractory failure.

Control Room, Hardened: An operator control room (sometimes referred to as a “pulpit”) that has been engineered to resist the inherent hazards to which it is exposed (i.e., fire-rated construction, blast resistance, shatterproof glass, etc.).

Cooling System, Emergency: An independent source of cooling media, not subject to common points of failure with the primary system. Typical examples include a dedicated gravity tank or a connection to a domestic or fire water system. The emergency cooling supply must be of sufficient duration to allow for the safe and orderly shutdown of equipment and removal of residual heat energy below a pre-established resting state.

Cooling System, Primary: The primary means of cooling molten equipment or processes when the equipment is in service. Water is typically used; although, in some cases (i.e., low-volume or low-temperature equipment), air or other gases can be the cooling media.

Cooling Water, High Pressure: Water-filled, pressurized components in contact with hot furnace surfaces such as refractory, coatings or shell.

Cooling Water, Low Pressure, Enclosed: A type of low-pressure cooling system in which a “jacket” is provided around the furnace/equipment shell, forming an interstitial space in which the water spray is contained and collected. This type of system is a modern variation of low-pressure spray cooling that significantly reduces the problems of overflow, stray water accumulation and corrosion of surrounding structures/equipment.

Cooling Water, Low Pressure, Open (Not Enclosed): Water spray applied externally to the molten-containing equipment (e.g., furnace shell) to cool hot surfaces and transfer heat away from the equipment. In such systems, no water-filled, pressurized components are in contact with hot surfaces. Instead, the applied water forms a film which runs down the outer shell and is collected in a trough for disposal or recycling. A variation of this type of system is spray cooling on EAF electrodes, where water runs down the electrode body and is evaporated prior to or just as it enters the furnace.

Failsafe: Upon loss of energy (e.g., electrical power or compressed air), the system or equipment automatically returns to a safe condition.

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

Hearth: The lower part of a furnace containing the molten material.

Ignitable Liquid: Any liquid or liquid mixture that is capable of fueling a fire, including flammable liquids, combustible liquids, inflammable liquids or any other liquids that burn. An ignitable liquid must have a fire point.

Integrity Operating Window (IOW): Sets of limits used to determine the variables that could affect the integrity and reliability of a piece of machinery or process. Machinery operated outside of IOWs may cause otherwise preventable damage or failure. See Data Sheet 9-0, *Asset Integrity*, for additional IOW information.

Molten Equipment, Stationary: Equipment processing or containing molten materials that is permanently anchored or otherwise restrained and not transported through the facility (e.g., furnaces, whether tiltable or non-tiltable).

Molten Material Release: An unplanned and unintentional release of high temperature liquid metal or material. The release is capable of causing thermal damage to structural members or equipment, igniting combustibles or causing a molten-water explosion while immersed or exposed to radiant energy. Molten releases can be referred to as a molten breakout, run-out, splash, or froth-over.

Molten/Metal Line/Level: The level or elevation in a piece of equipment that marks the transition from molten or semi-molten state. Below this level molten or semi-molten material is found, and furnace burden, gases, etc. can be found above. The level will vary over time as material is processed, tapped, etc. but must stay within defined safe operating limits to avoid molten metal releases, cooling system leaks, equipment damage, etc.

Molten Occupancy: Areas within a facility where materials are melted into molten state, transferred and/or cast. These areas are exposed to molten release, molten-water explosion and other molten-related hazards.

Production Critical Equipment: Molten metals production, utility and/or support system equipment considered key to the continuity of operations. Key equipment may extend to the following system components if required for production equipment operation: power cabling or control wiring, piping, fans, compressors, pumps, motors, hydraulic cylinders, control panels, and gas/fume collection and treatment.

Refractory: Thermal, mechanical and chemical-resistant material installed or applied within molten equipment that is responsible for maintaining the molten material within the equipment. Molten equipment may have a working lining backed with a safety lining.

Refractory Lining Inspection, Offline: Manual inspection of a molten-containing equipment refractory lining with the equipment out of service (hot or cold), typically using visual observation and direct measurement techniques.

Refractory Lining Inspection, Online: Manual inspection of a molten-containing equipment refractory lining with the equipment in service (hot), typically by indirect techniques such as thermographic imaging.

Refractory Lining Monitoring System, Online (Continuous): A system which continuously monitors the thickness and other health indicators of the lining of a molten-containing piece of equipment, typically a furnace. Examples include thermocouples embedded in the refractory to establish a temperature profile or a state-of-the-art online refractory monitoring system.

Scrap, Home: Waste metal that is generated “in-house” at facilities handling, processing and machining metal. This waste metal typically remains within the company and is collected and transported back to the melt shop to be remelted.

Scrap, Prompt: Waste metal from manufacturing products at downstream facilities. This waste metal is either sold to third-party scrap buyers or returned to the metal source as part of a buy-back agreement between upstream supplier and downstream customer.

Scrap, Reclaim or Revert: Waste metal from manufacturing. This waste stream can be further classified as “home” scrap, reclaimed from onsite or offsite manufacturing under the client’s control, or “prompt” scrap, reclaimed from the customer’s immediate downstream manufacturing processes (also known as “buy-back”). In both cases, the metal is under the client’s control or immediate downstream customer’s control with no potential for recycled scrap being added.

Scrap, Recycled: Post-consumer or post-industrial waste metal streams possibly comingled with other materials such as glass, fiber, plastic or metals. These waste streams originate from municipal, industrial or government sources. It is likely sold, consolidated and sorted, changing hands several times with less control of material being added to the stream. This waste metal stream may contain reclaimed metal from manufacturing, but without the control of reclaim/revert (home or prompt scrap).

Semi-Integrated Mill: Specific to steel, a production facility which uses an electric arc furnace process rather than traditional iron ore smelting or iron refining using a blast furnace and basic-oxygen steelmaking technologies. Sometimes referred to as a “remelter” or “mini-mill”. A full, semi-integrated mill will also contain downstream transformation processes such as continuous casters and rolling mills.

Sinter: To form a coherent bonded mass by heating metal powders without melting them. Sintering frequently causes bridges to form. Electrodes should move with sufficient magnitude and frequency to keep bridge collapses small enough to produce only very small pressure excursions.

Slag: By-product of smelting base materials or the remelting process, typically a mixture of metal oxides and silicon dioxide. While usually considered a byproduct, slag is an essential part of the process, aiding in material transformation (smelting) or protecting the molten bath (remelting). Understanding slag chemistry is a key component in refractory lining material selection and management.

Smelting: An often pyrometallurgical process whereby an ore or ore-containing substrate is reduced to its base or elemental form. The process involves chemical reaction(s) and phase transformation with at least one constituent− usually the final product−and various slag byproducts, entering a molten phase during the process.

Tap: The process of transferring molten material from a furnace or other molten-containing equipment such as ladles.

Tap, Wild: Accidental or otherwise unintentional opening of the material discharge port (tap) of a furnace or ladle during transport or without the appropriate transfer equipment in place.

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).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. This document has been revised. Significant changes include the following:

A. Revised radiation detection and testing.

B. Clarified molten equipment cooling system guidance and aligned with other molten standards

C. Updated loss history.

January 2024. This document has been completely revised. Significant changes include:

A. Changed title.

B. Re-organized the document to align with current operating standard development guidelines.

C. Merged and revised breakout containment and thermal protection.

D. Expanded guidance on refractory systems, including online refractory monitoring.

E. Expanded guidance on water cooling systems, including leak detection and maintenance guidance.

F. Added a preference for low-pressure cooling systems on new installations.

G. Expanded guidance on alarms and interlocks.

H. Expanded guidance on process safety in molten occupancies.

I. Revised guidance on radiation detection for non-ferrous scrap processing facilities.

J. Addressed molten release hazards and exposures during molten transport.

K. Consolidated general guidance for the molten occupancy, and added furnace- and casting-specific guidance.

L. Added explosion isolation construction features for coreless induction furnaces.

M. Separated ferroalloy specific guidance from guidance for submerged arc furnaces (SAF).

N. Added fire hazard guidance for casting operations.

O. Added guidance on molten atomization process for metal powder production.

P. Relocated content on EAFs (including AFTs) and continuous casters from FM Global Property Loss Prevention Data Sheet 7-25.

Q. Relocated content on induction furnaces from FM Global Property Loss Prevention Data Sheet 6-3, *Induction and Dielectric Heating Equipment*.

R. Updated loss history.

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

January 2019. Interim revision. The following major changes were made:

A. Added loss prevention guidance from OS 7-64, *Aluminum Smelting*, on aluminum melt, refining, and casting operations. In some instances two subsections were created to temporarily integrate the OS 7-64 content into 7-33. A full revision to 7-33 will be completed in 2019 to consolidate guidance for all molten metal melting, refining, and casting operations.

B. Added a reference to OS 7-26, *Glass Plants*, for guidance on the hazards of molten glass processing.

C. Added a recommendation for providing ITM on vertical DC caster molders molds.

D. Added a recommendation for implementing a management of change (MOC) program.

E. Added a recommendation for equipment contingency planning.

F. Added a supplemental information section on molten metal-water explosions and vertical direct-chill casting operations.

January 2013. Interim revision. The following changes were made:

1. The recommendation for when radioactive monitoring is needed was updated to include metal from any external source.

2. The loss history was updated to cover the period from 2000 to 2010.

3. Recommendations and supporting information for blast furnaces, basic oxygen furnaces, and electric arc furnaces was removed as it is now covered in more detail in Data Sheet 7-25, *Molten Steel Processes*.

4. Recommendations and supporting information on glass plants was removed as it is covered in more detail in Data Sheet 7-26, *Glass Plants*.

5. Editorial changes were made to provide a consistent format.

January 2012. Terminology related to ignitable liquids was revised to provide increased clarity and consistency with FM Global's loss prevention recommendations for ignitable liquid hazards.

September 2003. Clarifications were made in the section 3.1.3 *Blast Furnaces*.

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