BLAST FURNACE IRONMAKING AND BASIC OXYGEN STEELMAKING

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1.0 SCOPE

This data sheet covers the iron and steelmaking using blast furnace and basic oxygen furnace technologies.

Additionally, it covers stoves and hot blast air systems, supporting a blast furnace; processing of raw materials used in ironmaking, including coke and sinter production; as well as basic oxygen furnace and off-gas collection, distribution and holders. Chemical cleaning or processing of coke oven gas is not addressed in this standard.

Refer to the following data sheets for downstream iron or steel processing.

- FM Property Loss Prevention Data Sheet 7-33, *Molten Metals and Other Materials*, for molten metal and slag transport (e.g., in ladles via cranes and mobile ladle vehicles or pot carriers)
- 7-33, *Molten Metals and Other Materials*, for molten furnace processing using other technologies (e.g., reverberatory furnace, electric arc furnace, cupola furnace, induction furnace, and other molten furnaces)
- 7-33, *Molten Metals and Other Materials*, for casting operations
- FM Property Loss Prevention Data Sheet 7-85, *Combustible and Reactive Metals*, for guidance on specialty steel alloys within a chamber (i.e., vacuum induction melting, vacuum arc melting, electroslag remelting, electron beam, and other specialty furnaces)
- FM Property Loss Prevention Data Sheet 7-21, *Rolling Mills*, and FM Property Loss Prevention Data Sheet 13-8, *Presses*, for downstream metal transformation processes
- FM Property Loss Prevention Data Sheet 7-104, *Metal Treatment Processes*, for metal surface treatment such as pickling

Application

This data sheet contains guidance specific to integrated steel mills with blast furnace and basic oxygen furnace technologies, and the unique hazards and exposures found in these occupancies. When more "common" hazards and exposures are encountered in these occupancies and not specifically addressed in this data sheet, refer to the applicable data sheet. Examples of "common" hazards and exposures (and their applicable data sheet(s)) include the following:

- FM Property Loss Prevention Data Sheet 5-4, *Transformers*, for fire protection and maintenance of a transformer
- FM Property Loss Prevention Data Sheet 5-12, *Electric AC Generators*, for maintenance of a heat recovery generator
- FM Property Loss Prevention Data Sheet 5-19, *Switchgear and Circuit Breakers*, for fire protection and maintenance of electrical switchgear
- FM Property Loss Prevention Data Sheet 6-23, *Watertube Boilers*, for maintenance of a heat recovery boiler
- FM Property Loss Prevention Data Sheet 7-11, *Conveyors*, for fire protection and maintenance of a belt conveyor
- FM Property Loss Prevention Data Sheet 7-76, *Combustible Dust*, for off-gas streams with combustible or noncombustible particulate filtering
- FM Property Loss Prevention Data Sheet 7-98, *Hydraulic Fluid*, for fire protection of a hydraulic oil supply in a dedicated cutoff room
- FM Property Loss Prevention Data Sheet 7-101, *Fire Protection for Steam Turbines and Electric Generators*, for fire protection of a turbine generator
- FM Property Loss Prevention Data Sheet 7-110, *Industrial Control Systems*, for cyber security and fire protection of a control equipment room or operator control room
- FM Property Loss Prevention Data Sheet 13-3, *Steam Turbines*, for maintenance of a steam turbine in the heat recovery plant or powerhouse

- FM Property Loss Prevention Data Sheet 13-17, *Gas Turbines*, for maintenance of a heat recovery turbine or top gas recovery turbine

1.1 Hazards

1.1.1 Coke Oven Battery

Coke oven batteries are exposed to fires, combustion explosions and mechanical breakdown hazards. By-product coking produces a flammable off-gas and vapor stream, processed downstream for chemical production, then returned to the integrated mill for use as fuel gas. Flammable releases from piping, or air (oxygen) ingress into piping can form a flammable atmosphere. Given the routinely present ignition sources, such as hot surface (oven and collection piping) and open flame (oven leaks), fires and combustion explosions can result. Mechanical breakdowns in individual ovens can reduce battery efficiency as ovens are repaired or retired, while an event that results in an uncontrolled cool-down of the battery can significantly reduce battery life or even force a several-year battery rebuild.

1.1.2 Sinter Machine

The sinter machine and associated operations present several hazards typically found in most manufacturing plants, including electrical and mechanical breakdown, fire, and structural collapse. Large motors driving sinter machine exhaust fans or the sinter cooler blower, and the gearbox for the sinter machine grate can be longer lead-time equipment if repairs or replacement parts are needed, given their size or uniqueness. Coal, coke, power cabling and control wiring, conveyor belts, and fuel gas represent the fuel packages posing fire hazards in this occupancy. Given the quantity of solid material being stored and handled, sinter plants can have a large conveyor network with various material flow paths, posing both fire and structural collapse hazards. Handling of fine particulate to aggregate-sized materials can result in accumulations on conveyor galleries and transfer houses, building roofs, and the underside of ceilings caused by spillover, process upsets or common dust liberation. Over time, when combined with moisture, these accumulations can lead to overloading or long-term structural member deterioration, culminating in structural collapse. Without sinter, blast furnace operating efficiency can be impacted. At some integrated mills, a blast furnace may not be able to operate without sinter or some other substitute feedstock such as iron ore pellets or briquettes.

1.1.3 Blast Furnace and Hot Blast Air

Like other molten containing equipment, the blast furnace is exposed to molten release with ensuing molten-water room explosion and fire hazards. The hazards unique to a blast furnace, or at least shared with other smelting furnaces, include chilled hearth and burden slip/drop. These hazards can result in lengthy forced outages. If not managed properly, these conditions can escalate to a severe chilled-hearth, molten-water furnace explosion. Internal pressurized cooling water circuits or combustion explosion can further increase furnace damage and recovery duration. A blast furnace outage on the order of months can have a significant impact on downstream operations.

1.1.4 Basic Oxygen Furnace (BOF)

Basic oxygen converting processes are exposed to hazards similar to other molten containing equipment, such as molten release with ensuing molten-water room explosion and fire hazards. The use of oxygen lances and flammable, off-gas generation introduces another set of hazards, including combustion explosion. A molten-water furnace explosion is possible, given internal, pressurized cooling-water circuits. Additionally, these converters can have complex structural support systems and tilting systems to allow for charging and tapping. The unique components in these tilt drive systems can be difficult to access for inspection and repair. Replacement requires extensive planning for access and long lead-times for the replacement parts.

1.1.5 Off-Gas Distribution Piping and Holder

Flammable off-gases and vapors produced by a coke oven battery, blast furnace or basic oxygen furnace pose fire and combustion explosion hazards similar to those discussed in the coke oven battery section (1.1.3). Loss of mechanical integrity can lead to air (oxygen) ingress under vacuum, forming a flammable atmosphere within the equipment. Flammable gas, escaping under pressure, can mix with air, forming a flammable atmosphere. It can also auto-ignite in air, depending on temperature. Inability to handle or process the generated off-gases can curtail production until a workaround is determined or temporary repairs are made.

1.2 Changes

April 2026. Interim revision. The following changes were made:

A. Expanded the scope to include coke oven battery, sinter machine, stoves and the hot blast air system, and off-gas distribution piping and gas holders.

B. Revised existing recommendations.

2.0 LOSS PREVENTION RECOMMENDATIONS

2.1 General

2.1.1 Introduction

2.1.1.1 Implement a process safety program for the following areas of the facility listed below.

- Coke over battery
- Sinter plant
- Blast furnace including hot blast air
- Basic oxygen furnace
- Off-gas collection and distribution piping, and gas holder
- Downstream molten processing and casting (refer to FM Data Sheet 7-33, *Molten Metal and Other Materials*)

2.1.1.1.1 Align the process safety program with FM Data Sheet 7-43, *Process Safety*, and when molten metal is present, 7-33, *Molten Metal and Other Materials*, as well. The process safety program should at a minimum evaluate for and assess the following hazards: fire; combustible dust explosion; flammable gas explosion; molten-water equipment explosion; molten-water equipment room; and molten release with thermal damage.

2.1.1.2 Within the process safety program, implement a management of change process for temporary or permanent changes in accordance with Data Sheet 7-43. The program should oversee capital improvement projects or unplanned repairs and alterations. It should also drive updates to all impacted process safety elements, including operators, asset integrity (maintenance), and process hazard analysis (PHA). Examples of changes at an integrated steel mill that should be overseen by management of change process include, but are not limited to:

- Reliability and redundancy of utility systems, including primary power sources (offsite power and onsite generation), and onsite power generation—whether primary, secondary or emergency
- Reliability and redundancy of critical support systems, such as cooling water, blast furnace hot blast air, or of material transfer to coal bunkers (coke oven battery) or to the top of the blast furnace
- Routing and protection of safety-critical power cabling, control wiring, cooling water piping, and hydraulic or pneumatic piping to minimize exposure to a molten release, fire, explosion, or insulation failure with arcing or arc flash
- Changes in raw materials or batching. This item is particularly important for coke-oven battery and blast furnace raw material supplies. It should include planned changes in suppliers, types, grade/quality or batching; or temporary changes due to unplanned forced outages at the coke oven battery or sinter plant. Coal or coke chemical properties that may impact the blast furnace include: the presence of alkali (corrosive attack refractory linings resulting in hot spots); low carbon, high ash or aluminum oxide content, which impact cast house conditions; and coke size, uniformity and mechanical strength.
- Refractory alterations or repairs
- Refractory redesign prior to relining, resulting in change to expected campaign life
- Blast furnace increased production capacity (increased heat) from adding auxiliary injections (i.e., pulverized coal injection, oxygen, natural gas).

2.1.2 Location and Construction

2.1.2.1 Design and construct buildings, structures, and rooms housing these production processes and support systems using noncombustible construction (e.g., corrugated metal, concrete and mineral wool-insulated metal panels). If plastic materials are required, use FM Approved building materials. Install any 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.

2.1.2.2 Design and maintain the buildings and structures in accordance with Data Sheet 1-28, *Wind Design*. Of particular concern is preventing wind damage to the building envelope allowing snow or stormwater to enter a molten occupancy.

2.1.2.3 Design and maintain buildings and structures in accordance with Data Sheet 1-54, *Roof Loads and Drainage*. Preventing overload damage to the building envelope that could allow snow or stormwater to enter a molten occupancy is of particular concern. Additionally, consider the potential for raw material or liberated dust accumulations atop process structures, building roofs or along the underside of a building ceiling during routine operation between housekeeping cleanings.

2.1.2.4 Design buildings and structures in accordance with Data Sheet 1-40, *Flood*. Preventing flood water, stormwater or ground water from entering a molten occupancy—which can be a challenge with regards to the casting deck below the blast furnace—is of particular concern.

2.1.3 Protection

2.1.3.1 Provide fire detection in all electrical equipment rooms, control equipment and cable spreading rooms, and operator control rooms (i.e., pulpits).

2.1.3.2 When outside a molten occupancy, provide fire protection for power cabling and control wiring in accordance with Data Sheet 5-31, *Cables and Bus Bars*. Of particular concern are concentrations of cabling and wiring (e.g., entering or leaving a Motor Control Center [MCC], control equipment or cable spreading room); and cable trays or basements with poor fire service accessibility.

2.1.3.3. Provide fire and explosion protection for industrial exhaust systems as follows:

A. For exhaust systems handling combustible dusts in air, provide fire and combustible dust explosion protection in accordance with Data Sheet 7-78, *Industrial Exhaust Systems* and 7-76, *Combustible Dusts*.

B. For exhaust systems handling coking or furnace off-gas streams containing flammable gases, vapor, and/or combustible and noncombustible particulate, refer to the subject section for guidance. For example, refer to the following sections for equipment-specific guidance: Section 2.2 for coke oven gas, Section 2.4 for blast furnace gas, and Section 2.5 for BOF gas, and for off-gas distribution and gas holders.

2.1.3.4 Provide fire protection for cooling towers in accordance with Data Sheet 1-6, *Cooling Towers*.

2.1.3.5 Provide fire protection for hydraulic oil supplies cutoff from the surrounding occupancy in accordance with Data Sheet 7-98, *Hydraulic Fluids*.

2.1.3.6 Protect operator control rooms and associated control equipment rooms per Data Sheet 7-110, *Industrial Control Systems*.

2.1.4 Operation and Maintenance

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

2.1.4.2 Implement a hot work management program in accordance with Data Sheet 10-3, *Hot Work Management*. The program should identify specific, required precautions and procedures for working on flammable off-gas piping/ductwork. These procedures should include 1) acceptable methods for isolating/sealing flammable gas to prevent leakage or oxygen ingress to the off-gas stream, 2) verifying and monitoring the piping atmosphere prior to and during work, and 3) any unique requirements for permit authorization.

2.1.4.3 Establish and implement an inspection, testing and maintenance (ITM) program for critical equipment at the integrated steel mill. Refer to Data Sheet 9-0, *Asset Integrity*, for guidance on developing and structuring this program.

2.1.4.4 Implement an operator program for integrated steel mill 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.

2.1.4.5 Train 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 occupancy, which may include molten release, molten-water explosion, mechanical or 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

2.1.4.6 Maintain cooling water primary and emergency supply piping, mains and distribution to points of use.

2.1.4.7 Maintain off-gas collection and distribution piping in accordance with Data Sheet 12-2, *Vessels and Piping*, and 9-0, *Asset Integrity*. Refer to Sections 2.2.4 and 2.4.4 for additional guidance.

2.1.4.8 Maintain off-gas collection and distribution fans in accordance with OEM guidelines and Data Sheet 13-24.

2.1.4.9 Maintain oxygen distribution systems, including piping and valve rooms, per OEM guidelines. When conducting any repairs or alterations, ensure appropriate safeguards are followed to limit the potential for internal contamination that may result in fire or explosion when exposed to a high oxygen atmosphere.

2.1.4.10 Test alarms and interlocks mentioned in this standard in accordance with FM Data Sheet 7-33, *Molten Metal and Other Materials*, Section 2.5.

2.1.5 Contingency Planning

2.1.5.1 Equipment Contingency Planning

When equipment breakdowns in an integrated steel mill 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 XX 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.

2.1.5.2 Sparing

Sparing can be a mitigation strategy to reduce the downtime caused by a mechanical, electrical, or 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, *Asset Integrity*.

2.1.5.3 Routine Spares

Routine equipment spares in the integrated steel mill are spares that are considered to be consumables. These spares are expected to be put into service under normal operating conditions over the course of the life of the equipment, but not reduce equipment downtime in the event of a breakdown. This can include sparing recommended by the original equipment manufacturer.

2.2 Coke Oven Battery

2.2.1 Location and Construction

2.2.1.1 Locate the operator control room outside areas exposed to a coke oven battery fire or combustion explosion. When unavoidable, protect the control room and egress path from fire or explosion (e.g., using fire-rated or pressure-resistant construction).

2.2.1.2 Route concentrations of power cabling and control wiring that perform critical operations or safety functions outside areas exposed to process upsets, fire and combustion-explosion hazards.

2.2.1.3 Locate and design gas mixing system equipment in a naturally vented area to allow any gas leaks or ruptures to dissipate and relieve any partial volume, combustion-explosion overpressure.

2.2.1.4 Locate and design the under-fire gas system valving and connected piping to be naturally vented, allowing any gas leaks or ruptures to dissipate, as well as to relieve any partial volume combustion-explosion overpressure.

2.2.2 Protection

2.2.2.1 Use a nonignitable liquid or FM Approved industrial fluid within hydraulic systems in and around the coke oven battery and off-gas system (e.g., a larry car or pusher car).

2.2.2.2 Provide automatic fire protection for coal inload belt conveyors (i.e., those feeding coal bunkers) per Data Sheet 7-11, *Conveyors*.

2.2.3 Equipment and Processes

Table 2.2.3 contains a summary of the safety alarms and interlocks for a coke oven battery.

Table 2.2.3. Safety Alarms and Interlocks for Coke Oven Battery

Equipment Parameter Upset Condition	*Permissive*	*Alarm*	*Trip*	*Interlock Action/ Function*	*Reference*
Battery underfire, gas leak	-	X	-	SOP/EOP	2.2.3.1
Battery underfire, abnormal reversal valve position	-	X	-	SOP/EOP	2.2.3.2

2.2.3.1 If located in a non-naturally vented area per Section 2.5.1.3, provide flammable gas detection within equipment areas containing underfire gas equipment (e.g., reversal valves) and the gas mixing station, designed to alarm in a constantly attended location.

2.2.3.2 Provide position monitoring for reversal valves to detect a valve in an incorrect position, designed to alarm in a constantly attended location, to prevent a flammable gas atmosphere from forming in in the waste heat exhaust system.

2.2.3.3 Design the coke oven gas (COG) collection and distribution main to the gas cleaning plant with a secondary flow path (e.g., ring main) to allow for cleaning or repairs.

2.2.3.4 For coke oven gas collector mains, provide redundancy in flushing liquor primary pumping capacity to ensure liquor flow continues during the following failure scenarios:

- Loss of utility power
- Electrical breakdown involving a pump motor, power cable or switchgear, including damage to adjacent cabinets, busbars and cabling
- Mechanical breakdown of a pump

An example of a common redundancy arrangement includes pump motors supplied from an independent onsite substation with separate cabling, routed to a subset of motors.

2.2.3.5 For coke oven gas collector mains, provide an emergency flushing liquor supply independent of the primary flushing liquor supply, and sized to allow the coke oven battery to be banked. Configure the emergency flushing liquor supply to sense the loss of primary supply and automatically backfill or transfer from the primary supply. Ensure the primary and emergency flushing liquor supplies do not share a single point of failure.

2.2.3.6 Provide redundant primary power supplies (e.g., utility and onsite generation, double-ended or with switchgear). Limit single points of failure (such as common fire areas or electrical failure proximity) in the redundant primary power supplies.

2.2.3.7 Provide a site blackout scenario emergency power supply for coke oven battery critical functions in accordance with the PHA. Critical functions may include control equipment, COG collection and distribution, or actions required for banking. Some critical functions may require an uninterruptable power supply (e.g., oven controls or back-pressure/gas control valve), while others can resume operation once emergency power is online (e.g., manipulate bleeder valves, whether normally open or normally closed, or flushing liquor pumps).

2.2.4 Operation and Maintenance

2.2.4.1 Implement an emergency response plan for coke oven battery hazards in accordance with Data Sheet 10-1, *Pre-Incident and Emergence Response Planning*. Integrate elements of the EOPs into these response plans as needed. The following are ERP scenarios to consider:

A. Fire in coal bunker fire along with options to unload or inert gas purge

B. COG release, exposing the larry car at the ensuing jet fire

C. COG or fuel gas release and sustained jet fire

D. COG or fuel gas release and combustion explosion

2.2.4.2 Implement standard operating procedures (SOPs) and emergency operating procedures (EOPs) for coke oven battery operations. Develop procedures based upon OEM operations and maintenance manuals, industry best practice guidelines, site experience and the process safety program, including the PHA. 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

- Managing permanently idle ovens (not in service)

EOP

- Gas detection alarm
- Inappropriate reversal valve position (valve failure)
- Increasing oxygen concentration in COG distribution main downstream of coke oven battery
- High carbon monoxide concentration in the waste heat system
- High or low pressure in the collector main
- Negative pressure (vacuum) in the collector main
- Loss of collector main flushing liquor (cooling system failure)
- Stuck coke oven pusher ram
- Banking the entire battery, including necessary materials (e.g., sealing materials for oven doors)

2.2.4.3 Implement a refractory lining management program in accordance with OEM guidelines and industry standards. 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 visual inspections of lining surfaces after each push, looking for any physical damage or other abnormal conditions (e.g., dark spots or build-up on the lining).

F. Perform regular thermographic inspections of online ovens, as well as prior to and after repairs or build-up. Increase the thermographic inspection frequency when suspected or known deterioration of the lining occurs until repairs are completed.

G. Inspect refractory support system components such as tie rods and springs per OEM or third-party consultant guidance.

H. Inspect oven structural systems supporting the tie rods and springs, such as steel members and concrete pedestals, for deterioration or damage.

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

2.2.4.4 Maintain a remaining useful life (RUL) study, updated based on any changes in operating conditions or maintenance findings. However, when approaching end of useful life, update the study at least annually.

2.2.4.5 Monitor for oven gas leaks; repair and document leaks within the established timeframe. Oven gas leakage may allow air ingress during pressure upsets, forming a flammable gas atmosphere within an oven.

2.2.4.6 Document oven stickers, along with corrective actions or repairs.

2.2.4.7 Maintain under-fire reversal valves and their actuation system in accordance with OEM guidelines.

2.2.4.8 Functionally test position monitoring alarms for under-fire reversal valves.

2.2.4.9 Maintain the coke oven battery under-fire waste heat, air and fuel-gas piping in accordance with OEM guidelines.

2.2.4.10 Maintain the coke oven battery under-fire waste heat stack in accordance with OEM guidelines.

2.2.4.11 Maintain coke oven battery bleeders in accordance with OEM guidelines.

2.2.4.12 Maintain back-pressure control valves in accordance with OEM guidelines.

2.2.4.13 Inspect coke oven battery gas collection mains for tar build-up, thickness and deterioration.

2.2.4.14 Maintain coke oven pusher ram in accordance with OEM guidelines.

2.2.4.15 Maintain a larry car in accordance with OEM guidelines.

2.2.4.16 Inspect coal bunker silos atop batteries for deterioration or damage.

2.2.4.17 Inspect the bunker inload coal conveyor for coal accumulations, deterioration or damage per Data Sheet 7-11, *Conveyors*.

2.2.4.18 Inspect the quenching tower structure for deterioration or damage.

2.2.5 Contingency Plan

2.2.5.1 Develop and maintain an equipment contingency plan (ECP) to prevent unplanned outages caused by equipment breakdowns impacting coke oven battery operations. Examples include the following:

A. Larry car breakdown or thermal damage due to fire exposure (including removal of subject car)

B. Pusher car breakdown including door machine

C. Quenching car breakdown

D. Inload coal conveyor drive system breakdown and structural collapse

2.3 Sinter Machine

2.3.1 Provide fire protection for power cabling and control wiring per Data Sheet 5-31, *Cables and Bus Bars*.

2.3.2 Seal power cabling and control wiring penetrations through fire-rated walls and floors into electrical and control equipment rooms per Data Sheet 5-32, *Data Centers and Related Facilities*.

2.3.3 Implement a housekeeping program to manage combustible dust (e.g., explosion hazard) and noncombustible dust (e.g., collapse hazard) as well as granule/particulate accumulations on or in buildings, elevated equipment (e.g., conveyors and cable trays), and exhaust ducting for the sinter machine. The housekeeping program should consist of:

A. Recorded visual inspections of material handling equipment with particular emphasis on common source points.

B. Inspection findings that drive accumulation removal.

C. Review of inspection and removal documentation to assess if fugitive dust/material controls are needed to reduce accumulation rates.

2.3.4 Develop an equipment contingency plan (ECP) for long lead-time machinery and support system equipment in the sinter operation, per Section 2.1.4. Common examples of such equipment include:

A. Sinter machine grate conveyor gear box

B. Sinter machine exhaust fan and drive system (e.g., gearbox, motor and power supply).

2.4 Blast Furnace and Hot Blast Air

2.4.1 Location and Construction

2.4.1.1 Locate the operator control room outside areas exposed to a tuyere burn-through and coke fire, molten release or molten-water room explosion. When unavoidable, protect the control room and egress path from fire, molten or explosion overpressure (e.g., fire-rated construction, molten breakout containment or diversion, or pressure-resistant construction).

2.4.1.2 Route concentrations of power cabling and control wiring performing critical operations or safety functions outside areas exposed to routine sparks and metal splatter, and heat; process upsets, and molten release hazards.

2.4.1.3 Locate support system equipment rooms outside areas exposed to:

- Routine corrosive off gases, sparks and metal splatter, and heat
- Upset conditions, including molten release or overpressure from a molten-water room explosion

Key support system equipment rooms may include, but are not limited to MCCs, cable spreading and control equipment, taphole equipment, cooling water pump, and blowers. When unavoidable, because the equipment is intrinsic to the blast furnace, protect the equipment rooms through engineering design, such as installing thermal or pressure-resistant barriers.

2.4.1.4 Locate slag pits a safe distance from structures to prevent upset molten-water room explosions from damaging the blast furnace, and other buildings and equipment (e.g., power lines).

2.4.1.5 Locate supplies of ignitable liquid (e.g., hydraulic oil) or flammable gas (e.g., natural gas or oxygen valve room) outside areas exposed to the hazards mentioned in Section 2.4.1.3. When unavoidable, protect equipment rooms as discussed in Section 2.4.1.3.

2.4.1.6 Provide thermal protection for blast furnace and building structural members (e.g., columns) within range of a molten release. Common molten release areas include but are not limited to casthouse floor and hot metal track areas, casting deck, and tuyere deck. 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 damage potential (i.e., moving equipment and materials). Install heat shielding or diverters to redirect flowing molten.

2.4.2 Protection

2.4.2.1 Provide fire protection for steam turbines and driven blast air compressors as well as any top gas turbines controlling blast furnace back-pressure in accordance with Data Sheet 7-101, *Fire Protection for Steam Turbines and Electric Generators*.

2.4.2.2 Use FM Approved industrial fluid within hydraulic oil systems the cast house (e.g., taphole drill, taphole mud gun and furnace charging bell operation).

2.4.2.3 Provide automatic fire protection for blast furnace charging belt conveyors per Data Sheet 7-11, *Conveyors*.

2.4.3 Equipment and Processes

Table 2.4.3 contains a summary of the safety alarms and interlocks for a blast furnace and hot blast air system.

Table 2.4.3 Safety Alarms and Interlocks for Blast Furnace and Hot Blast Air

Equipment Parameter Upset Condition	*Permissive*	*Alarm*	*Trip*	*Interlock Action/ Function*	*Reference*
Furnace refractory, high temperature	-	X	-	SOP	2.4.3.6
Furnace cooling water, tuyere leak	-	X	-	SOP/EOP	2.4.3.1
Furnace cooling water, tuyere coolers leak	-	X	-	SOP/EOP	2.4.3.2
Furnace cooling water, other circuit leak	-	X	-	SOP/EOP	2.4.3.3
Cooling water, high or low temperature	-	X	-	SOP	2.4.3.5.G
Cooling water, high or low flow	-	X	-	SOP	2.4.3.5.H
Furnace blast, low flow	-	X	-	SOP	2.4.3.5.C
Furnace blast, high or low pressure	-	X	-	SOP	2.4.3.5.A
Furnace blast, low temperature	-	X	-	SOP	2.4.3.5.B
Furnace stockline, high or low temperature	-	X	-	SOP	2.4.3.5.D
Furnace top gas, high pressure	-	X	-	SOP	2.4.3.5.E
Furnace charging, abnormal condition	X	X	-	Prevent charging equipment cycling	2.4.3.5.F 2.4.3.7.A 2.4.3.7.B
Stove cooling water, hot blast valve leak	-	-	-	SOP	2.4.3.4
Stove dome, high temperature	-	X	-	SOP	2.4.3.5.I
Stove dome, high-high temperature	-	X	X	Shutoff burner	2.4.3.7.C
Stove dome, low-low temperature	X	X	-	Prevent burner trial for ignition	2.4.3.7.D
Stove burner, low pressure or low flow combustion air	X	X	X	Shutoff burner or prevent trial for ignition	2.4.3.7.E
Stove burner, high or low fuel gas pressure	X	X	X	Shutoff burner or prevent trial for ignition	2.4.3.7.E
Stove grate, high temperature	-	X	-	SOP	2.4.3.5.J

2.4.3.1 Install cooling water leak detection at a constantly attended location for each individual tuyere circuit with alarm. Leak detection should consist of flow meters with a high degree of accuracy (e.g., at least 1%) at individual tuyere cooling water circuit supply and return connections. Off-gas monitoring is not sufficient leak detection for tuyeres.

2.4.3.2 Install cooling water leak detection for tuyere coolers with alarm at a constantly attended location. Leak detection may consist of flow meters on supply and return headers.

2.4.3.3 Install cooling water leak detection for all other internal blast furnace circuits, such as hearth cooling plates, tapholes, bosh cooling plates, and stack staves and plates, with alarm at a constantly attended location. Methods may include monitoring cooling water tank level, with considerations for make-up water or flow meters on supply and return headers.

2.4.3.4 Install cooling water leak detection for stove hot blast valve circuits with alarm at a constantly attended location. Methods may include monitoring cooling water tank level, with considerations for make-up water or flow meters on supply and return headers.

2.4.3.5 Monitor for the following blast furnace and stove upset conditions, and alarm at a constantly attended location.

A. Furnace high or low blast pressure

B. Furnace low blast temperature

C. Furnace low blast flow

D. Furnace high or low stockline temperature

E. Furnace high top pressure

F. Furnace charging system abnormal condition

G. Furnace cooling water high temperature and low temperature (when freeze exposed)

H. Furnace cooling water high or low flow

I. Stove high dome temperature

J. Stove high grate temperature

2.4.3.6 Install temperature sensors within various positions of the furnace, such as the hearth for condition monitoring (e.g., refractory wear, metal penetration and furnace campaign end of life). Position sensors based on the OEM, consultant, or internal expertise and modeling requirements, as well as the following:

1. Embed thermal sensors within critical areas of the lining to aid in condition monitoring.
2. Determine the minimum distribution of in-service sensors required for the model to generate meaningful results. The sensor distribution should include additional sensors (redundant sensors) to account for sensor failures over the campaign, while still maintaining the minimum distribution needed until the end of campaign, when sensor data and condition monitoring is most critical.

2.4.3.7 Install the following blast furnace and stove interlocks and alarms at a constantly attended location.

A. Furnace with bell charging: loss of bell chamber gas seal permissive to prevent bells from cycling, allowing blast furnace gas (BFG) to escape and ignite

B. Furnace with bell-less charging: loss of bin gas seal permissive to prevent gates from cycling, allowing BFG to escape and ignite

C. Stove high-high dome temperature to shut off stove burner

D. Stove low-low dome temperature to prevent stove burner ignition attempt

E. Stove burner low pressure and low flow combustion air to shut off burner or prevent trial for ignition

F. Stove burner high- and low-fuel gas pressure to shut off burner or prevent trial for ignition

2.4.3.8 Provide redundant primary cooling water pumping with power supplies from different sources (e.g., utility and onsite generation, double-ended or with switchgear). Limit the single points of failure (such as common fire areas or electrical failure to pump motor drives) in the redundant primary cooling water supplies.

2.4.3.9 Provide an emergency cooling water supply for critical furnace circuits in accordance with the PHA (e.g., tuyere and tuyere coolers). Refer to Data Sheet 7-33, *Molten Metal and Other Materials*, for a discussion on emergency cooling water supply options.

2.4.3.10 Provide a site blackout scenario emergency power supply for blast furnace critical functions in accordance with the PHA. Critical functions may include control equipment, BFG collection, or actions to support a controlled shutdown and stable restart. Some critical functions may require an uninterruptable power supply (e.g., furnace controls or back-pressure/gas control valve), while others can resume operation once emergency power is online (e.g., charging system).

2.4.3.11 Provide redundant drills and mud guns at tap holes.

2.4.3.12 Provide redundant, online hot blast air blower capacity to allow for planned maintenance outages, as well as for an unplanned, forced blower outage (trip), without impacting furnace capacity or resulting in a burden drop. For example, if three blowers are needed to support furnace capacity, four blowers should be provided with all four operating at capacity should one blower trip or fail. In this scenario, a planned maintenance outage for one blower, with a trip or failure of a second blower, will only result in reduced furnace capacity and not in loss of hot blast air.

2.4.3.13 Design stove burner safety shutoff valves to be fail-safe. Alternatively, provide a reliable means to drive valves to safe condition upon loss of motive supply (e.g., uninterruptible power supply for electrically driven valves, or accumulators for hydraulic or pneumatically operated valves).

2.4.3.14 Design stove domes using materials resistant to stress-corrosion cracking (SCC) within the given integrity operating window.

2.4.4 Operation and Maintenance

2.4.4.1 Implement an emergency response plan for blast furnace hazards in accordance with Data Sheet 10-1, *Pre-Incident and Emergence Response Planning*. Integrate elements of the EOPs into these response plans as needed. The following are ERP scenarios to consider:

A. Tuyere burn through, with ensuing coke release and fire

B. Equipment fire on casting deck or furnace charging equipment (power cabling, control wiring, hydraulic oil, conveyor belt)

C. Off-gas release with ensuing jet fire

D. Molten burn through and release (tuyere, taphole, hearth)

E. Molten release through lining, with molten-water room explosion on or under the casting deck

F. Combustion explosion within the furnace or downstream off-gas system

2.4.4.2 Implement standard operating procedures (SOPs) and emergency operating procedures (EOPs) for blast furnace operations. Develop procedures based upon OEM operations and maintenance manuals, industry best practice guidelines, site experience and the process safety program, including the PHA. 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 (e.g., normal operating conditions)

- Blast furnace tapping (casting deck and torpedo car preparations, managing slag and metal flows, tap hole drilling, and mudding)
- Blast furnace cold start: Managing the atmosphere within the furnace and exhaust pipe/ductwork, from purging oxygen to off-gas concentration, passing through the flammable range to above the upper flammable limit.
- Blast furnace restart (blow-in)
- Blast furnace shut down
- Blast furnace planned shutdown, which may include manually opening bleeders to vent carbon monoxide and other flammable off-gases generated without blast air
- Glendon cold start (small furnace)
- Stove cold start (large furnace)
- Stove cold layup to prevent corrosion (i.e., inerting or passivating internal surfaces)
- Investigate suspected internal cooling leak (staves or plates)

EOP (e.g., upset operating conditions)

- Furnace emergency shutdown
- Drill or mud gun failure
- Unplanned molten release on tuyere deck or casting deck
- Burden bridging and slip
- Tuyere failure with coke or molten release
- Response to multiple suspected cooling water leaks or a known internal cooling water leak (staves or plates)
- Loss of metal connection (response to chilled hearth conditions)
- Recovery from chilled hearth
- Loss of primary cooling water supply
- Loss of cooling water flow
- Loss of hot blast air
- Unplanned stove outage
- Loss of a hot blast air blower
- Furnace hot spot management (response to high temperature or thermal model showing refractory deterioration/thinning)
- Loss of primary furnace controls (frozen controls or unoccupiable control room due to smoke or heat)
- Loss of all site electrical power (blackout)

2.4.4.3 Implement a refractory lining management program in accordance with OEM guidelines and industry standards. 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. Use a thermal model to monitor critical areas of the furnace refractory for unexpected wear (thinning) or damage (metal penetration), using the following:

1. Over the course of the campaign, refresh the thermal model results at least annually until approaching end of campaign when more frequent refreshes are necessary.

2. Perform core drilling as needed to validate thermal model results (e.g., towards lining end of life). If thermal sensors have been lost, embed additional sensors in the core drilling holes before patching and backfilling.

F. Use volumetric non-destructive examination techniques to assess refractory thickness and evaluate for metal penetration or lining cracks.

G. Use thermography (thermal imaging) to scan accessible areas of the furnace (e.g., tuyeres and tap holes) at least quarterly for abnormally high temperatures or temperature gradients.

H. Establish a minimum refractory thickness based on furnace OEM, refractory supplier and consultant guidance.

I. Inspect furnace foundation connections, supports, and shell for deterioration or damage.

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

2.4.4.4 When the furnace campaign calls for areas of the furnace to have spray refractory coatings (e.g., stack) re-applied or re-bricked (e.g., bosh) at some frequency, continually evaluate the adequacy of the established frequency (e.g., based on the number of failed or burned coolers staves, cooler failure rate, and/or thicknesses and thin areas observed during the minor reline outages).

2.4.4.5 For furnaces, maintain a remaining useful life (RUL) study, updated based on previous study findings. However, when approaching end of remaining useful life, update at least annually.

2.4.4.6 Develop an asset integrity program for blast furnace structural components, including foundation, pedestals, support columns and mantel ring, and shell in accordance with OEM and Data Sheet 9-0.

2.4.4.7 Maintain furnace off-gas collection piping, including uptakes, downcomers, and expansion joints and their support structures in accordance with OEM guidelines, and Data Sheets 12-2, *Vessels and Piping*, and 9-0, *Asset Integrity*.

2.4.4.8 Maintain the dust catcher in accordance with OEM guidelines.

2.4.4.9 Maintain BFG collection piping to downstream air-material separators (AMS) such as the dust catcher, quenching tower or electrostatic precipitator, per OEM guidelines.

2.4.4.10 Maintain furnace bleeders in accordance with OEM guidelines.

2.4.4.11 Maintain furnace off-gas backpressure control devices in accordance with OEM guidelines.

2.4.4.12 Maintain furnace hot blast air piping at the furnace in accordance with OEM guidelines (e.g., bustle pipe, bellows joint and blowpipe).

2.4.4.13 Evaluate the tuyere replacement schedule against historical performance (i.e., low frequency of failure or burn-through) and validate by inspection and satisfactory condition of removed tuyeres.

2.4.4.14 Functionally test the furnace top quench system at least annually.

2.4.4.15 Maintain the top charging system in accordance with OEM guidelines. For bell charging systems, conduct nondestructive examination on bell rods and visual inspection for bell wear.

2.4.4.16Maintain BFG blowers in accordance with OEM guidelines and Data Sheet 13-24, *Fans and Blowers*. Maintain BFG blower drive systems based on the applicable standards, which may include Data Sheet 5-17, *Motors and Adjustable Speed Drives*, or Data Sheet 13-3, *Steam Turbines*.

2.4.4.17 Examine cowper stove domes for stress corrosion cracking (SCC) when the subject dome is prone, based on operating conditions and metallurgy.

2.4.4.18 Maintain cowper stove refractory linings and checkering in accordance with OEM guidelines. At a minimum, conduct the following:

A. An internal visual inspection through access ports (e.g., borescope via a top access point to see top of checkering and burner box).

B. Regular external thermography on accessible stove surfaces.

2.4.4.19 Maintain hot blast air valves (HBV) in accordance with OEM guidelines.

2.4.4.20 Maintain cold and hot blast air piping in accordance with OEM guidelines.

2.4.4.21 Maintain hot blast air blowers in accordance with OEM guidelines and Data Sheet 13-24. Maintain hot blast air blower drive systems based on the applicable standards, which may include Data Sheet 5-17, *Motors and Adjustable Speed Drives*, or Data Sheet 13-3, *Steam Turbines*. Include any blow-off valves for compressor anti-surge protection and snort valves (bleeder valves).

2.4.5 Contingency Plan

2.4.5.1 Develop and maintain an equipment contingency plan (ECP) to prevent unplanned outages caused by equipment breakdowns from impacting furnace operations. Examples include:

A. Batch handling systems include hoist systems (skip cars, rails, hoist drums, gearbox, motor, and drive system) or belt conveyor (belt, pulleys, gearbox, motor, and drive system)

B. Bell charging system (large bell, small bell, bell rods) or bell-less charging system (distributor, gearbox)

C. Off-gas exhaust system (blower, gearbox, motor, drive controls)

D. Tap hole block

E. Tap hole drill and mud gun

F. Shell plate for breakout repairs

G. Bustle pipe and blow pipes

H. Molten iron handling (torpedo car and cast floor railways)

2.4.5.2 Equipment breakdown spares are spares intended to be used in the event of an unplanned outage to reduce downtime and restore operations. Provide the following equipment breakdown spares for the BOF.

A. Steel plate for shell repairs

B. Refractory for repairing thin or damaged area, or following molten release (breakout)

C. Materials for bustle pipe repairs (e.g., steel plate and refractory)

2.5 Basic Oxygen Furnace (BOF)

2.5.1 Location and Construction

2.5.1.1 Locate the operator control room outside areas exposed to a fire, molten release, molten-water room explosion and combustion explosion. When unavoidable, protect the control room and egress path from fire, molten, or explosion overpressure (e.g., using fire-rated construction, molten breakout containment or diversion, or pressure-resistant construction).

2.5.1.2 Route concentrations of power cabling and control wiring that perform critical operations or safety functions outside areas exposed to routine sparks and metal splatter, and heat; process upsets and molten release hazards.

2.5.1.3 Locate support system equipment rooms outside areas exposed to:

- Routine corrosive off gases, sparks and metal splatter, and heat
- Upset conditions, including molten release or overpressure from a molten-water room explosion

Key support equipment rooms may include but are not limited to MCCs, cable spreading and control equipment, lance equipment, cooling water pump, and gas and flux supplies. When the equipment is intrinsic to the BOF and cannot be relocated, protect the equipment rooms by limiting the exposure through engineering design, such as installing thermal or pressure-resistant barriers.

2.5.1.4 Locate supplies of ignitable liquid (e.g., hydraulic oil) or flammable gas (natural gas or oxygen valve room) outside areas exposed to the hazards mentioned in Section 2.5.1.3. When unavoidable, protect equipment rooms as discussed in Section 2.5.1.3.

2.5.1.5 Provide thermal protection for BOF and building structural members within range of a molten breakout. 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 (i.e., moving equipment and materials). Install heat shielding or diverters to redirect flowing molten.

2.5.2 Protection

2.5.2.1 Use FM Approved industrial fluid within hydraulic oil systems within the BOF room or enclosure (e.g., lance manipulation or hood movement).

2.5.3 Equipment and Processes

Table 2.5.3 contains a summary of the safety alarms and interlocks for a basic oxygen furnace.

Table 2.5.3. Safety Alarms and Interlocks for Basic Oxygen Furnace

Equipment Parameter Upset Condition	*Permissive*	*Alarm*	*Trip*	*Interlock Action/Function*	*Reference*
Furnace cooling water, oxygen lance leak	-	X	X	Stop blow and isolate cooling water upon retraction	2.5.3.3
Furnace cooling water, other lance leak	-	X	X	Stop blow and isolate cooling water upon retraction	2.5.3.3
Cooling water, high or low temperature	-	X	-	SOP	2.5.3.6.A
Cooling water, high or low flow	-	X	-	SOP	2.5.3.6.B
Cooling air, high or low flow	-	X	-	SOP	2.5.3.6.C
Furnace oxygen lance, abnormal flow or pressure	-	X	X	Stop blow	2.5.3.7.B
Furnace other lance, abnormal condition	-	X	-	SOP	2.5.3.6.D
Furnace lance, abnormal position	X	X	X	Stop blow or prevent blow	2.5.3.7.A
Furnace charging system, abnormal condition	-	X	-	SOP	2.5.3.6.G
Furnace tilt, limit reached	-	X	X	Stop furnace tilt	2.5.3.7.D
Furnace tilt, lance position	X	-	-	Prevent furnace tilt	2.5.3.7.E
Hood cooling water, circuit leak	-	X	-	Stop blow and retract lances	2.5.3.4
Hood cooling water, low flow	-	X	X	Stop blow	2.5.3.7.C
Hood cooling water, high temperature	-	X	X	Stop blow	2.5.3.7.C
Furnace exhaust, abnormal temperature	-	X	-	SOP	2.5.3.6.E
Furnace exhaust, high oxygen concentration	-	X	-	SOP	2.5.3.6.F

2.5.3.1 Provide radiation detection for facilities processing scrap metal. Refer to Data Sheet 7-33 for guidance.

2.5.3.2 When scrap metal or other charge materials are stored outdoors and a wet charge hazard exists, install a canopy and preheating system in accordance with Data Sheet 7-33 to remove trapped moisture prior to charging.

2.5.3.3 Install cooling water leak detection, dedicated to the oxygen lance and any other lance, with interlocks and responding actions; and alarm at a constantly attended location. The interlock should stop the blow, isolating cooling water flow upon reaching a minimum height or retraction, and lock out furnace tilt. Leak detection should consist of flow meters with a high degree of accuracy (e.g., at least 1%)at individual lance cooling water circuit supply and return connections. Off-gas monitoring is not sufficient leak detection for a BOF lance.

2.5.3.4 Install cooling water leak detection with interlocks and responding actions for BOF exhaust system circuits, such as skirt and hood. Alarm at a constantly attended location. The interlock should stop the blow and retract lances. Methods may include monitoring cooling water tank level, with considerations for make-up water or flow meters at headers. Off-gas monitoring is not sufficient leak detection for a BOF.

2.5.3.5 Monitor for the following BOF upset conditions and alarm at a constantly attended location.

A. Cooling water high temperature or low temperature (when freeze exposed)

B. High or low cooling water flow

C. High or low cooling air flow

D. Abnormal other lance operating condition

E. Abnormal furnace exhaust system temperature

F. High furnace exhaust oxygen concentration

G. Abnormal charging system condition

2.5.3.6 Install the following BOF interlocks and responding actions, and alarm at a constantly attended location.

A. Furnace abnormal position for oxygen lance and other lances stopping blow and retracting lances, or preventing start of a blow

B. Oxygen lance high pressure or high flow stopping blow and retracting lances

C. Furnace exhaust hood low water flow or high temperature stopping blow and retracting lances

D. Furnace tilt limit stopping movement

E. Furnace tilt permissive requiring retracted lances

2.5.3.7 Provide redundant primary cooling water pumping capacity with power supplies from different sources (e.g., utility and onsite generation, double-ended or with switchgear). Limit the single points of failure (such as common fire areas or electrical failure to pump motor drives) in the redundant primary cooling water supplies.

2.5.3.8 Provide an emergency cooling water supply for critical furnace loads in accordance with the PHA (e.g., all water-cooled lances). Refer to Data Sheet 7-33, *Molten Metal and Other Materials*, for a discussion on emergency cooling water supply options.

2.5.3.9 Provide a site blackout scenario emergency power supply for BOF critical functions in accordance with the PHA. Critical functions may include control equipment, basic oxygen furnace gas (BOFG) handling, or actions to support a controlled shutdown and stable restart. Some critical functions may require an uninterruptable power supply (e.g., furnace controls or back-pressure/gas control valve), while others can resume operation once emergency power is online (e.g., charging system).

2.5.4 Operation and Maintenance

2.5.4.1 Implement an emergency response plan for BOF hazards in accordance with Data Sheet 10-1, *Pre-Incident and Emergence Response Planning*. Integrate elements of the EOPs into these response plans as needed. The following are ERP scenarios to consider.

A. Molten release through lining

B. Equipment fire (power cabling, control wiring, hydraulic oil)

C. Off-gas release with ensuing jet fire

D. Molten-water furnace explosion

E. Combustion explosion within the furnace or downstream off-gas system

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

SOP

- Coat BOF refractory with slag when possible.
- Blow start to manage flammable off-gas until oxygen is purged in accordance with the PHA.
- Scrap charge bucket loading and charging into the furnace
- Restart following a heat stoppage with a partially solidified charge

EOP

- Furnace emergency shutdown
- Unplanned molten release below furnace
- Suspected or known internal cooling water leak

- Loss of primary cooling water supply
- Loss of all cooling water flow
- Stuck water-cooled lance with continued cooling water flow (retraction system failure)
- Furnace hot spot management (response to high temperature or thermal model showing refractory deterioration/thinning)
- Loss of primary furnace controls (frozen controls or unoccupiable control room due to smoke or heat)
- Loss of all site electrical power (blackout)

2.5.4.3 Implement a refractory lining management program in accordance with OEM guidelines and industry standards. 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. Prior to each heat/run, visually check the internal refractory for lining damage or deterioration.

F. Evaluate for refractory lining wear or damage every shift. Methods may include chain gauging or laser scanning.

G. Use thermography (thermal imaging) to scan accessible areas of the furnace to monitor for abnormal high temperatures at least quarterly (e.g., trunnions, ring, tap hole and shell).

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

2.5.4.4 Maintain a remaining useful life (RUL) study, updated based on previous study findings. When approaching end of remaining useful life, update at each reline.

2.5.4.5 Develop an asset integrity program for BOF structural components, including foundation, pedestals, trunnions, trunnion ring and shell, in accordance with Data Sheet 9-0.

2.5.4.6 Maintain trunnion bearings in accordance with OEM guidelines and Data Sheet 9-0.

2.5.4.7 Maintain primary and secondary gearboxes and bearings in accordance with OEM guidelines, Data Sheet 13-7, *Gears*, and Data Sheet 9-0.

2.5.4.8 Maintain lances and lance tips in accordance with OEM guidelines and Data Sheet 9-0.

2.5.4.9 Maintain the movable hood (skirt) and fixed hood in accordance with OEM guidelines and Data Sheet 9-0.

2.5.5 Contingency Planning

2.5.5.1 Develop and maintain an equipment contingency plan (ECP) to prevent unplanned outages caused by equipment breakdowns impacting furnace operations. Examples include the following

A. Vessel shell

B. Trunnion ring

C. Trunnions

D. Tilt drive system, including primary drives, secondary gearbox and associated motors

E. Off-gas fans and drive system (blower, motor, and drive system)

2.5.5.2 Equipment breakdown spares are spares intended to be used in the event of an unplanned outage to reduce downtime and restore operations. Provide the following equipment breakdown spares for the BOF.

A. Plate for shell repairs

B. Refractory for repairing thin or damaged area, or following molten release (breakout)

C. Bull gear

D. Drive side trunnion

2.6 Off-Gas Distribution Piping and Holder

2.6.1 Location and Construction

2.6.1.1 Separate a gas holder from other nearby gas holders, gas distribution piping, and any flares or other gas handling equipment to minimize damage during a holder rupture with collapse, projectile debris damage and thermal damage from an ensuing jet fire.

2.6.2 Equipment and Processes

able 2.6.2 contains a summary of the safety alarms and interlocks for a basic oxygen furnace.

Table 2.6.2. Safety Alarms and Interlocks for Off-Gas Distribution Piping and Holder

Equipment Parameter Upset Condition	*Permissive*	*Alarm*	*Trip*	*Interlock Action/ Function*	*Reference*
Holder headspace, gas leak	-	X	-	SOP/EOP	2.7.2.1
Holder piston roof, high-high	-	X	-	SOP/EOP	2.7.2.2
Holder piston roof, misalignment	-	X	-	SOP/EOP	2.7.2.3
Off-gas piping or holder, high oxygen concentration	-	X	-	SOP/EOP	2.7.2.4

2.6.2.1 For a gas holder, provide gas leak detection in the headspace between the fixed roof and piston roof, arranged to alarm at a constantly attended location.

2.6.2.2 For a gas holder, provide a high-high piston roof level alarm (high-high volume), arranged to alarm at a constantly attended location.

2.6.2.3 For a gas holder, provide a piston roof misalignment (level) alarm, arranged to sound an alarm at a constantly attended location.

2.6.2.4 Provide high oxygen concentration alarm arranged to sound an alarm at constantly attended station in accordance with the PHA. Often above the flammable range, the off-gas system can form a flammable atmosphere if air (oxygen) is drawn into equipment through leaks during normal process conditions or upsets. Monitoring may be warranted at the following locations.

- Downstream of off-gas generators (e.g., coke-oven batteries, blast furnace, or basic oxygen furnace), which is particularly important because gas conditioning equipment often contains ignition sources such as an electrostatic precipitator (ESP)
- At positions in the off-gas distribution piping system
- At gas holders
- Prior to incineration

2.6.2.5 For a gas holder, provide a volume relief system to directly vent gas to atmosphere upon reaching a high-high piston roof level (high-high volume condition).

2.6.2.6 For Wiggins type gas holders, select a membrane compatible with all gases expected to be handled within the holder at the design gas temperature and ambient temperature range.

2.6.2.7 For Klonne type gas holders, select grease and ring materials compatible with all gases expected to be handled within the holder at the design gas temperature and ambient temperature range.

2.6.3 Operations and Maintenance

2.6.3.1 Develop and maintain an off-gas emergency response plan to manage upset conditions at collection, distribution, holding or cleaning/incineration. Planned responses should be based on a PHA.

2.6.3.2 Implement an emergency response plan for jet fire or combustion explosion hazards in accordance with Data Sheet 10-1, *Pre-Incident and Emergence Response Planning*. Integrate elements of the EOPs into these response plans as needed.

2.6.3.3 Implement standard operating procedures (SOPs) and emergency operating procedures (EOPs) for gas handling operations. Develop procedures based on OEM operations and maintenance manuals, industry best practice guidelines, site experience and the process safety program, including the PHA. 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.

SOPs

- Practices to prepare piping for repairs or alterations (isolation and purge) and to confirm safe conditions

EOPs

- Piping high gas temperature and/or pressure
- Piping high oxygen concentration
- Gas holder high piston roof level (high volume)
- Gas holder high-high piston roof level (high-high volume)
- Gas holder low piston roof level (low volume)
- Gas holder leak detection (headspace)

2.6.3.4 For Klonne type gas holders, maintain the gas holder foundation, shell, piston roof, fixed roof and support systems in accordance with OEM guidelines and Data Sheet 9-0.

2.6.3.5 For Wiggins type gas holders, maintain the gas holder foundation, shell, piston roof, fixed roof and support systems in accordance with OEM guidelines and Data Sheet 9-0.

3.0 SUPPORT FOR RECOMMENDATIONS

3.1 Supplemental information

3.1.1 Coke Oven Battery

Coke is a necessary raw material for blast furnace operation, as it functions as both fuel and reducing agent within the blast furnace. Coke is produced in a series of ovens often referred to as a battery. Coal is charged to ovens from the top via a “larry car”. Adjoining ovens are separated by chambers used for combustion to generate heat and transfer that heat into the oven.

The flammable off-gas generated by the coking process is known as coke oven gas (COG). The off-gas produced in each oven is often transferred to a collection main via a standpipe and gooseneck pipe arrangement. The gases are initially sprayed and cooled with flushing liquor (as shown below in Figure 3.1.1-1). The collector main has additional flushing liquor sprays to regulate gas temperature. Oven pressure is maintained slightly positive by a back pressure control valve, before the gasses enter the suction main and are transferred downstream to a by-products gas cleaning plant where chemicals are stripped from the COG stream. Alternatively, COG is transferred downstream to a heat recovery plant, where the gas is incinerated in a boiler to generate steam for steam turbine generators and other plant uses.

The coke is removed from ovens using a pusher car, and moved into a quench car via a transfer car. The quench car travels down to the quench tower to cool the coke for processing and use in a blast furnace or for stockpiling. After the oven is pushed, the larry car again fills the empty oven to start coking another batch of coal.

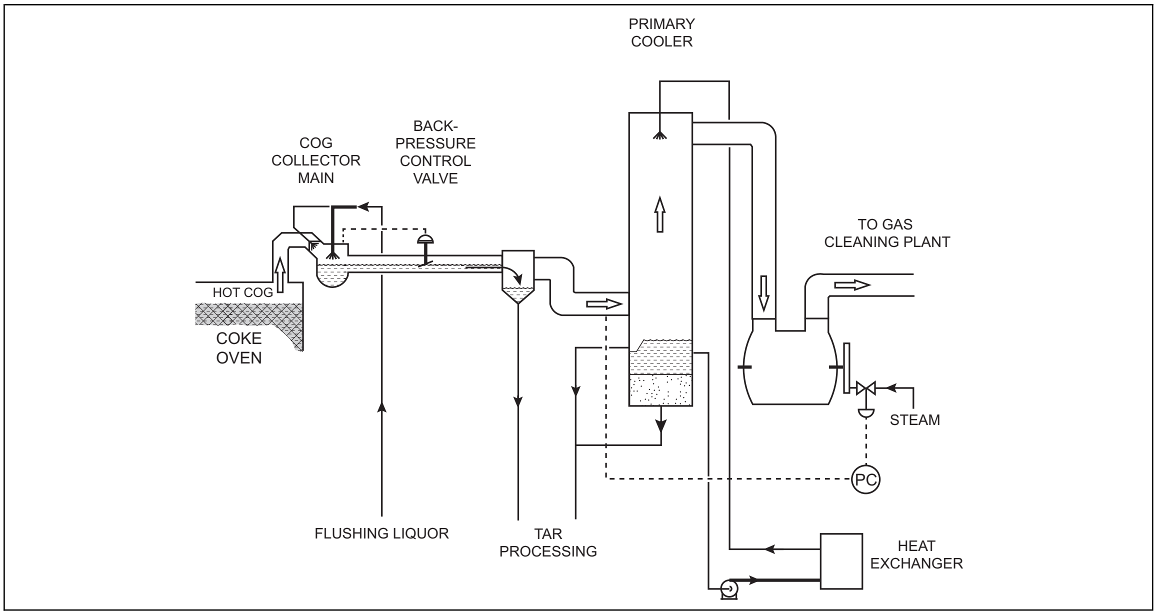

Fig. 3.1.1-1. Example of coke oven gas (COG) collection and primary conditioning

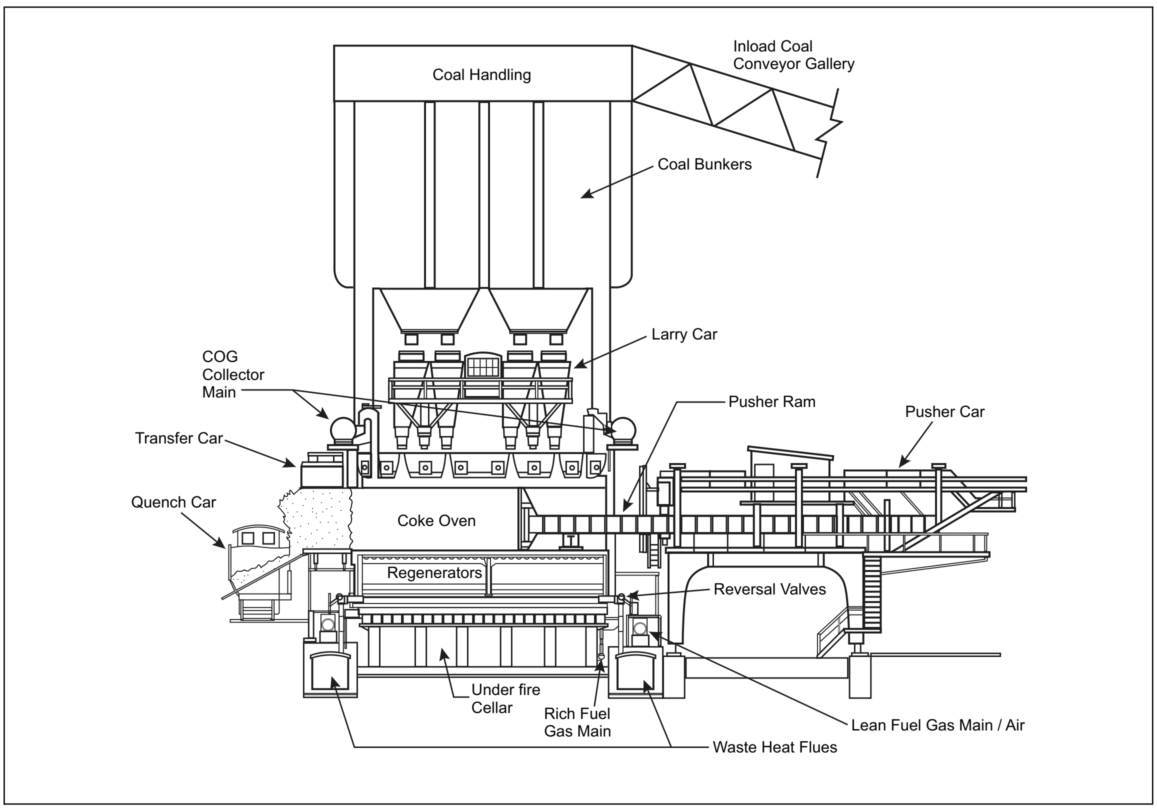

Fig. 3.1.1-2. Coke Oven Battery Cross Section with Support Cars

3.1.2 Sinter Machine

The sinter plant processes iron ore fines, fluxes, coke and other waste streams into an agglomerated, porous material that is then crushed and cooled into an aggregate-type material that can be charged into a blast furnace. The process occurs on a sinter machine which has a metal belt onto which blended material flows, forming a thick layer, before being ignited by an overtop burner system. Large suction boxes under the belt pull oxygen, fumes and particulate through the belt as the combustion front passes through the layer material. At the belt end, the off coming sinter is cooled and crushed.

The sinter machine and related operations utilize some of the largest electrical loads and extensive electrical systems at an integrated steel mill. Exhaust fan motors produce larger electrical loads, while the material handling, sinter machine, and exhaust system can contain a complex electrical power and control system.

Sinter increases blast furnace efficiency but is also a critical means of delivering fluxes to the furnace. Without sinter, blast furnace operating efficiency can be impacted. At some integrated mills, a blast furnace may not be able to operate without sinter or some other substitute feedstock, such as iron ore pellets or briquettes.

3.1.3 Blast Furnace (BF)

The basic steps of ore-based production in blast furnaces are:

A. The ore is crushed, homogenized, and mixed with limestone, then sintered.

B. The sintered ore is fed with coke, iron ore pellets, mill scale, flux (limestone, dolomite, etc.), and basic oxygen furnace scale into a blast furnace.

C. Heated air (blast), coal, and gas injection burns part of the coke to produce heat for the chemical reactions involved and to melt the iron.

Within the blast furnace, the carbon reduction and thermal energy are supplied by combustion of coke in pre-heated air. Coke has to contain a high grade of carbon in order to generate less powder, which could possibly condense or obstruct the blast furnace. Coke is poured through the top of the furnace. The amount of sulfur contained in coke is an important factor because sulfur can pollute cast iron. Wood charcoal is often used in mini blast furnaces as a substitute for coke when coke is unavailable. The use of wood charcoal is less efficient than using coke.

To promote combustion, a large volume of heated air (approximately 5230 cubic yards per ton [4000 m^3 per ton] of iron) is injected from turbo blowers through tuyeres into the bottom of the furnace. Gases generated on top of the furnace are used to pre-heat the blast air and to generate power for the blowers.

Blast furnaces are costly investments to increase productivity as the volume is increased, typically to the extent that daily production has increased from 100 tons to 1000 tons (102 metric tons to 1016 metric tons). This increased productivity causes even more problems with the refractory lining. The thermal level within a blast furnace is very unstable due to irregular fluxes of gas in the furnace associated with noncontinuous combustion of coke. Since coke is very expensive, the industry has tried to use other combustibles such as atomization of pre-heated oil, gas, or coal powder mixed with oil. However, coke is still the most common combustible.

Blast furnaces operate continuously until they need to be relined.

The product produced from a blast furnace is liquid pig iron or solid sponge iron. Both of these products contain large amounts of impurities. The next stage in the production of steel is the refining process, in which these impurities are removed. This is done using a basic oxygen furnace.

Pig iron is tapped from the iron notch at the bottom of the furnace and put into torpedo cars where it is transferred to the basic oxygen furnace.

The blast furnace gas is cleaned by first a dustcatcher followed by large scrubbers in the duct work and circulate to the powerhouse for use as fuel. A bag house dust collection system pulls the dirty, sooty air from the cast houses (where the molten steel and slag leaves the furnace and is directed into pits or vessels). This air is heavily laden with soot and must be cleaned before being released. The bag houses are very large, multi-sectioned, and have redundant N+1 fans and motors.

The boiler house (often located in an adjacent integral powerhouse) generates steam for blast furnace turbo-blowers (wind) and steam turbine generators to generate power.

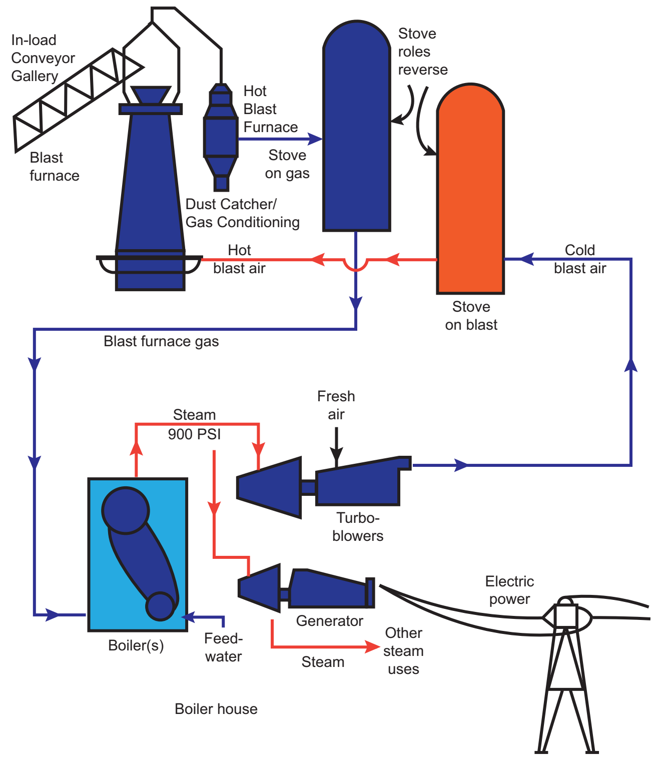

Fig. 3.1.3. Simplified blast furnace; power house arrangement

A key component of blast furnace operation is the blower. Turbo blowers may be located in an adjacent integral powerhouse and provide wind to the furnace. A single steam turbine usually drives a multi-stage turbo blower. There are usually several boilers and at least two steam turbine-driven blowers for each blast furnace to provide some redundancy. Some blowers might be motor driven and/or have a gear box between the driver and blower.

3.1.4 Basic Oxygen Furnace (BOF)

Basic oxygen furnaces take molten iron produced in a blast furnace along with scrap steel and various raw materials and refine them into molten steel. In the refining stage iron is processed in either a basic oxygen furnace (BOF), or an electric arc furnace. The BOF is a pear-shaped vessel in which the molten iron is refined by blowing oxygen into the liquid metal by water-cooled lances, and combined with various fluxes and alloys.

The molten pig iron is tapped from a blast furnace at regular intervals (usually every few minutes) and the iron is carried to the blast oxygen shop (also known as the BOF shop or blast oxygen process [BOP] shop) via heavy iron refractory-lined tank cars. Basic oxygen furnaces need to be kept in production to maintain the flow of pig iron from the blast furnace; otherwise, the blast furnace would have to shut down.

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 5-4, *Transformers*
Data Sheet 5-12, *Electric AC Generators*
Data Sheet 5-19, *Switchgear and Circuit Breakers*
Data Sheet 6-23, *Watertube Boilers*

Data Sheet 7-11, *Conveyors*
Data Sheet 7-21, *Rolling Mills*
Data Sheet 7-33, *Molten Metals and Other Materials*
Data Sheet 7-43, *Process Safety*
Data Sheet 7-76, *Combustible Dusts*
Data Sheet 7-85, *Combustible and Reactive Metals*
Data Sheet 7-98, *Hydraulic Fluids*
Data Sheet 7-101, *Fire Protection for Steam Turbines and Electric Generators*
Data Sheet 7-104, *Metal Treatment Processes*
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 10-3, *Hot Work Management*
Data Sheet 10-8, *Operators*
Data Sheet 12-2, *Vessels and Piping*
Data Sheet 13-3, *Steam Turbines*
Data Sheet 13-7, *Gears*
Data Sheet 13-17, *Gas Turbines*

APPENDIX A GLOSSARY OF TERMS

Basic Oxygen Furnace (BOF): A converter used to reduce pig iron carbon content and otherwise refine the iron. As referred to as a basic oxygen process vessel (BOPV). The Quick bottom-blown oxygen process (Q-BOP) is another converting process that uses a different process configuration.

Belly: Section of the blast furnace between the bosh below and upper stack above. Contains the largest diameter of the furnace.

Blast Furnace: A vessel used to reduce, or smelt, iron ore to produce pig iron using coke, hot blast air, and other additives (fluxes).

Bosh: Section of the blast furnace that tappers down from the stack at the mantle ring to the hearth.

Coke Oven Battery: A row of baking ovens bordered by shared heating flues (combustion and waste heat chambers) for converting coal to coke. Also referred to as a coke battery. An associated By-Products plant extracts chemicals from the coke off gas (COG) or heats the recovery plant where coke oven gas is consumed to generate steam that drives the steam turbine generators.

FM Approved: The term “FM Approved” is used to describe a product or service that has satisfied the criteria for Approval by FM Approvals. Refer to the *Approval Guide* for a complete list of products and services that are FM Approved.

Flushing Liquor: An aqueous solution, often weak-ammonia, sprayed directly into the hot COG stream leaving the oven chambers. It lowers the gas temperature in the collection main and downstream piping and knocks out heavy, vaporized components such as tar.

Hearth: Section of the blast furnace below the bosh where molten slag and metal are collected and tapped (cast). Tuyeres are located in the upper hearth near the bosh transition.

Integrated Steel Mill: A facility with both blast furnace ironmaking and BOF steelmaking as well as downstream casting and possibly rolling and finishing.

Larry Car: A rail-mounted vehicle with hoppers atop the coke oven battery. Used to transport coal from the coal bunker tower to each oven.

Pusher Car: A rail-mounted vehicle with a ram on one side of the coke oven battery. Used to push or remove coke to the opposite side of the oven and into a transfer car to the quench car for processing.

Reversal Valve: A component in the underfire heating system responsible for alternating fuel gas and combustion air. Waste heat flows between the oven heating flues.

Stack: Section of the blast furnace extending from above the belly to the throat.

Sticker: A coke oven batch unable to be removed using the pusher ram requiring other means to remove, often leading to oven refractory damage.

Trunnion: The two structural members supporting the basic oxygen furnace and trunnion ring. The trunnion contains the cooling water supply for the furnace and provides the means to tilt the vessel for tapping and charging.

Tuyere: A nozzle used to deliver oxygen and combustion air into the interior of the blast furnace.

Underfire: A regenerative heating system commonly used in coke oven batteries. Flammable gases are distributed under the battery and introduced to a heating flue on the side of each oven, along with air to combust and generate heat. The hot waste gases (products of combustion) flow over the oven and down through the opposing heating flue into a heat recovery regenerator containing refractory blocks. At a given frequency, the waste gas and fuel- air flows are reversed, using a set of reversal valves This action allows preheating of the combustion air using the heat recovery regenerator.

APPENDIX B DOCUMENT REVISION HISTORY

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

April 2026. Interim revision. The following changes were made:

A. Expanded the scope to include coke oven battery, sinter machine, stoves and the hot blast air system, and off-gas distribution piping and gas holders.

B. Revised existing recommendations.

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

January 2024. Interim revision. The following changes were made as part of the FM Global Data Sheet 7-33, *Molten Metals and Other Materials*, revision.

A. Changed the title of the data sheet from *Molten Steel Production* to *Blast Furnace Ironmaking and Basic Oxygen Steelmaking*.

B. Relocated electric-arc furnace and continuous caster guidance to DS 7-33.

C. Consolidated radioactive contamination guidance to DS 7-33.

July 2023. Interim revision. Added additional guidance on standard and emergency operating procedures.

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

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

July 2021. Interim revision. Minor editorial changes were made.

July 2020. Interim revision. Updated contingency planning and sparing guidance. Added process safety guidance.

October 2013. Removed recommendation 2.4.1.2 on top gas monitoring on blast furnaces as it was technically invalid.

January 2013. This is the first publication of this document.

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