COMBUSTIBLE AND REACTIVE METALS

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1.0 SCOPE

This data sheet contains property loss prevention guidance unique to the fire, explosion, and equipment breakdown hazards posed by combustible and water-reactive metals. This data sheet does not offer guidance on the following hazards that also may be present in areas processing and storing combustible and water-reactive metals. Refer to the appropriate FM Data Sheet for guidance on these additional hazards.

- Combustible dust explosion hazard. Refer to Data Sheet 7-76, *Combustible Dusts* when combustible metal powder and dusts may be present or liberated posing a deflagration hazard when dispersed in air.

- Radioactive contamination hazard. Refer to Data Sheet 7-61, *Facilities Processing Radioactive Materials* when handling/processing radioactive metals, or Data Sheet 7-33, *Molten Metals and Other Materials* when handling/processing scrap metal.

1.1 Hazards

1.1.1 Combustible Metals (Fire Hazard)

In the absence of water, combustible metals burn generating metal oxides. Once ignited and beyond the incipient fire stage, a sizable quantity of burning metal will burn till the available metal or combustibles are consumed unless a compatible fire fighting agent can be applied. These fires burn intensely putting building integrity at risk early in the fire.

Metal fires can be controlled by applying a cover of compatible powder or by using certain gaseous firefighting agent to provide total flooding of the area. Even with the application of fire fighting agents, extinguishment may require hours to days as re-ignition is not uncommon. Application of water (and sometimes foam) to other than an incipient metal fire will intensify the fire through the evolution of hydrogen and rapid generation of steam. Water application should be limited to ncipient stage fires involving metal or ordinary combustibles in order to cool unburned fuel and the building. If automatic sprinklers are overwhelmed and the incident escalates beyond an incipient fire to an uncontrolled structural fire, the fire service may consider limiting water application to defensive actions to prevent fire spread to adjacent buildings or areas. Hose streams applied to a full-involved sizable metal fuel package akin to metal bins of scrap metal will intensify the fire and generate sparks/embers exposing adjacent combustibles and buildings potentially leading to multiple spot fires beyond fire origin. If the metal fire has generated a molten metal pool, continued application of a hose stream could result in an explosion.

1.1.2 Water-Reactive Metal Evolving Hydrogen (Fire/Explosion Hazard)

Upon moisture or water contact, water-reactive metals evolve hydrogen. Prior to ignition, the evolution of hydrogen increases the ignition sensitivity, and afterwards, the evolved hydrogen increases fire severity. Metals in some forms such as powders can become pyrophoric upon moisture or water contact. If the metal is not burning, the evolved hydrogen escapes the metal and if allowed to accumulate within containers or equipment, or within a building compartment the flammable hydrogen atmosphere poses an explosion hazard. Though hydrogen has a significant flammable range and is very ignition sensitive, hydrogen diffuses quickly through air given hydrogen’s low molecular weight. Sufficient ventilation within the metal occupancy allows the evolved hydrogen gas to pass to atmosphere where it dissipates reducing the likelihood of generating a flammable hydrogen atmosphere. In some building areas, properly designed mechanical ventilation may be necessary to remove trapped hydrogen.

1.1.3 Molten Metal-Water Rapid Phase Transition (Explosion Hazard)

Many combustible and reactive metals have high melting points along with high heat capacities and thermal conductivities. Upon water contact, molten metal has an affinity for oxygen atoms evolving hydrogen as well as generating steam. The molten metal-water interface continues to generate hydrogen and steam; however, if this interface is disturbed and molten metal is placed in direct contact or mixed with water a rapid phase transition (RPT) explosion can occur.

Unlike steam explosions that occur with lower melting point metals or less conductive metals, RPT explosion are more violent with greater impulse energies. The explosions release energy (overpressure) and projectiles into surrounding areas unless controlled by pressure-resistant and projectile-resistance barriers paired with pressure-relieving construction (vents). The energy release is a function of not only the quantity of molten-metal and water in contact, but also the triggering event (shock) that suddenly mixes the two liquids.

1.2 Changes

July 2022. This document has been completely revised. Significant changes include the following:

A. Changed the title from “Metals and Alloys” to “Combustible and Reactive Metals.”

B. Clarified where in a metal occupancy to recommend water-based fire protection as well as the protection design.

C. Revised recommendations for isolating molten titanium-water explosion hazards and expanded to apply this guidance to furnaces processing molten hafnium, niobium, tantalum, and zirconium (hydrogen and/or rapid phase transition explosion hazards).

2.0 LOSS PREVENTION RECOMMENDATIONS

This data sheet refers to any combustible or reactive metal storage or processing areas as a ″metal occupancy.″ Guidance in this section is provided for protection against those fire and/or explosion hazards.

2.1 Introduction

2.1.1 Use FM Approved products whenever they are applicable and available. For a list of FM Approved products, see the *Approval Guide* and/or Roof*Nav*, as applicable.

2.1.2 Protect metal occupancies containing metal powder dispersions in ignitable liquid in accordance with the process hazard analysis (PHA) per section 2.5.12 and the respective data sheets.

2.2 Construction and Location

2.2.1 Select sites for metal occupancies in areas not exposed to flooding in accordance with Data Sheet 1-40, *Flood*. Alternatively, mitigate flood exposures with physical protection features in accordance with Data Sheet 1-40. A key aspect in siting and building design is preventing flood waters from entering the metal occupancy.

2.2.2 Design buildings containing metal occupancies to minimize the potential for moisture entering, and/or a steam or water release. Route nonessential process and non-process (domestic) pressurized water piping, waste (sewer) drains, and stormwater drains (e.g., roof drains) outside metal containing areas. Furnace cooling water, and when appropriate sprinkler piping, are considered essential pressurized water piping.

2.2.3 Do not locate metal occupancies in below grade locations including basements and trenches.

2.2.4 Isolate metal occupancies from surrounding building areas using outdoor locations, detached buildings, or cutoff rooms in accordance with Figure 2.2.4 and Table 2.2.4. However, when the metal occupancy consists principally of noncombustible or non-reactive metal (e.g., titanium heavier castings) with minimal combustible or reactive metal (e.g., titanium fine or coarse scrap), Location 5 is acceptable.

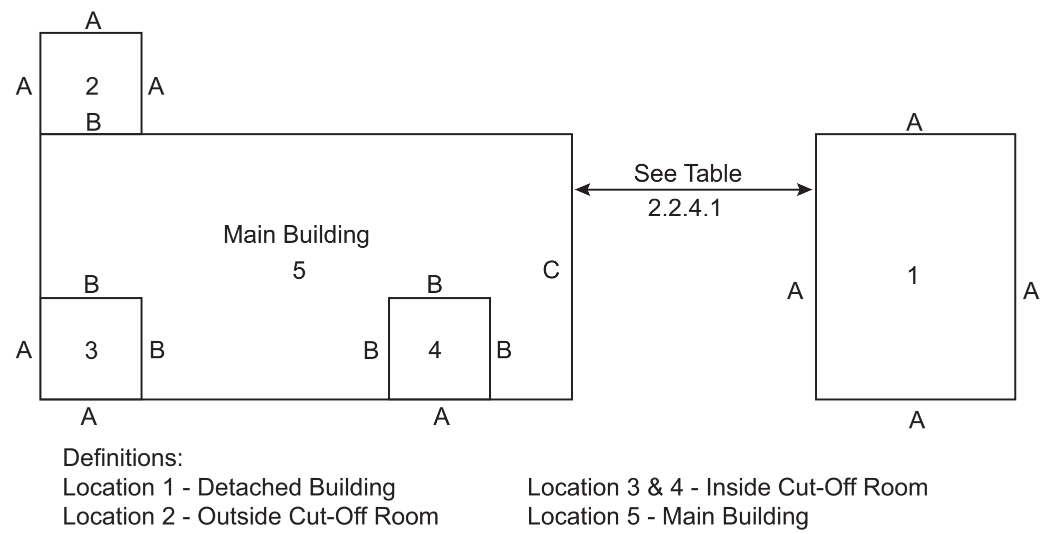

Fig. 2.2.4. Location and construction of buildings and cutoff rooms for metal occupancies

Table 2.2.4. Metal Occupancy Areas

Hazard	*Location (Note 1)*
Combustible or Reactive Metal Fire Hazard	1, 2, 3, 4
Molten Metal Hydrogen or Rapid Phase Transition (RPT) Explosion	1, 2, 3, 4

Note 1. Location 5 does not require a wall to separate the metal occupancy from the remainder.

2.2.4.1 Arrange outdoor locations, and construct detached buildings or cutoff rooms containing metal occupancies in accordance with Table 2.2.4.1 and sections 2.2.4.1.1. through 2.2.4.1.6.

Table 2.2.4.1. Location and Construction for Combustible/Reactive Metal Fire Hazards

Location	*Distance From Main Building ft (m)*	*Building/Cutoff Room Construction (Note 1)*			
		A	B	C	Roof
1	≥ Pile Height	Any	NA	Any	Any (for detached building and main building)
	< Pile Height	Any	NA	FR	NC (for detached building and main building)
2	Abutting	NC	FR	NA	NC
3 & 4	Inside	NC	FR	NA	FR

Note 1. The types of construction are defined as follows: FR = 1 hour fire rated (see Section 2.2.1.4.1); NC = noncombustible; and NA = not applicable.

2.2.4.1.1 Where recommended in Table 2.2.4.1, provide minimum one-hour fire-rated walls (per ASTM E119, *Standard Test Methods for Fire Tests of Building Construction and Materials*, or local code equivalent). The one-hour fire-rated walls assumes sprinkler protection is provided. If sprinkler protection is omitted per the PHA (section 2.5.12), increase the fire rated wall construction to at least three-hours for walls and columns, and comparable fire-resistance for the ceiling and/or roof structural members and assembly.

2.2.4.1.2 Isolate molten furnaces with water cooled crucibles processing hafnium, niobium, tantalum, titanium, and zirconium in vaults with pressure resistant and pressure relieving construction. Design the vault withstand the anticipated energy release while relieving that energy from the vault in a safe direction. Pressure resistant walls and/or ceilings should separate the explosion hazard from adjacent building areas, furnaces, and areas containing support equipment.

2.2.4.1.3 Isolate alkali metal heat transfer system equipment within a vault constructed per section 2.2.4.1.1 when loss of mechanical integrity can result in a violent room explosion (i.e., hydrogen or RPT).

2.2.4.1.4 Isolate molten furnace power supplies from surrounding areas, the subject furnace, and other furnace power supplies in a fire-resistive cutoff room.

2.2.4.1.5 Isolate finely-divided and coarse scrap metal storage and processing by locating within a detached building (Location 1).

2.2.4.1.6 Isolate metal storage in a fire-resistant cutoff room. Of particular importance is isolating metal storage from combustible storage or other combustible occupancies.

2.2.4.1.7 For outdoor magnesium storage, limit storage piles to 150,000 lb (68,000 kg) with at least 10 ft (3 m) wide aisles between piles, and separation distances between piles and buildings equivalent to the pile height.

2.2.5 When flooring may be exposed to a molten magnesium or molten alkali metal release, install flooring, or floor coverings or coatings compatible with the given metal per the PHA discussed in section 2.5.12. Concrete is hydroscopic thus tends to contain moisture potentially leading to concrete spalling and spattering of molten metal when contacted by some reactive molten metals.

2.2.6 Provide molten metal breakout containment around furnaces, casting, or other refining or handling operations sized to control the largest anticipated breakout plus 10%. Construct containment of compatible materials (e.g., concrete may not be compatible).

2.2.7 Store small quantities of metal powder in flammable liquid cabinets.

2.3 Protection

2.3.1 For metal processing, provide automatic sprinkler protection over metal processing with the following exceptions:

A. Provide automatic sprinkler protection over alkali metal processing when the process hazard analysis identifies more severe fire or explosion hazards than the very reactive metal per Section 2.5.12.

Sprinkler protection may be omitted when the combustible loading within the occupancy is primarily limited to the very reactive alkali metal (i.e., the remaining occupancy is noncombustible, and building construction is noncombustible). When sprinkler protection is omitted, other fire protection safeguards become critical to mitigate the fire risk including restrictions to limit the quantity of metal, and isolation to separate the metal from adjoining building areas.

B. Do not provide water-based fire protection over molten metal process areas. When combustible loading is present within these molten metal areas, apply one or more of the following protection options.

1. Use FM Approved industrial fluid within electrical and hydraulic systems per section 2.4.1. Alternatively, install local automatic sprinkler protection over oil-filled equipment within in the foundry.
2. When combustible roofs or other combustible building assemblies are present, replace combustible construction with noncombustible or FM Approved building materials instead of installing automatic sprinklers.
3. Install local automatic sprinkler protection over other essential combustibles within the foundry.

2.3.2 For metal processing areas, design automatic sprinkler protection based on the presence of the work-in-process metal along with any combustible loading including ordinary combustible, plastics, and/or ignitable liquids. At a minimum, design protection for Hazard Category 2 (HC-2) in accordance with Data Sheet 3-26, *Fire Protection for Nonstorage Occupancies*.

2.3.3 Provide automatic sprinkler protection over indoor metal storage in accordance with Data Sheet 8-9, *Storage of Class 1, 2, 3, 4 and Plastic Commodities* along with the following commodity classification considerations. The applicable commodity classification is largely contingent upon type and quantity of packaging associated with the metal storage.

A. Protect storage of alkali metal in sealed, noncombustible containers without ignitable liquid, as a minimum Class 3 commodity.

B. Protect storage of magnesium ingots, and similar heavier forms, as a minimum of cartoned unexpanded plastic (CUP). Additionally, limit pile sizes to 150,000 lbs (68,000 kg) with aisles widths at least equivalent to the pile height.

C. For storage of non-alkali metal powder in noncombustible containers, protect as a minimum Class 3 commodity. Additionally, limit pile sizes to 1,000 ft^3 (28 m^3) with aisles widths at least equivalent to the pile height.

D. For storage other than alkali metal or metal powder, protect as a minimum of cartoned unexpanded plastic (CUP). Additionally, limit pile sizes to 1,000 ft^3 (28 m^3) with aisles widths at least equivalent to the pile height.

E. For scrap metal storage not containing alkali metal, protect as a minimum cartoned unexpanded plastic (CUP). Additionally, limit pile sizes to 1,000 ft^3 (28 m^3) with aisles widths at least equivalent to the pile height.

2.3.4 Install automatic sprinkler protection in accordance with Data Sheet 2-0, *Installation Guidelines for Automatic Sprinklers*.

2.3.4.1 At a minimum, design and install automatic sprinkler protection using schedule 40 or thicker sprinkler piping.

2.3.5 For alkali metal heat transfer systems, protect the areas based on the ignitable liquid, flammable gases, and other hazards present when applicable. Protect cooling towers containing a molten alkali metal heat transfer media in accordance with Data Sheet 1-6, *Cooling Towers*.

2.3.6 Provide compatible manual fire extinguishers as well as other means to apply solid fire extinguishing agents as identified in the emergency response plan for onsite personnel and fire fighting preplanning for the fire service.

2.4 Equipment and Processes

2.4.1 Use noncombustible or FM Approved industrial fluids within hydraulic systems, transformers, and heat transfer fluid (HTF) systems.

2.4.2 Use nonignitable, compatible cutting fluid/coolant. When not feasible, provide fire protection in accordance with Data Sheet 7-37, *Cutting Fluids*.

2.4.3 Use nonignitable, compatible rolling fluids. When not feasible, provide fire protection in accordance with Data Sheet 7-21, *Rolling Mills*.

2.4.4 For non-alkali metal operations processing or liberating (grinding) finely-divided particulate, use a noncombustible, wet dust collector protected in accordance with Data Sheet 7-76, *Combustible Dusts*, and the following safeguards.

2.4.4.1 Install safety interlocks to shut down the exhaust system and any upstream operations, and sound an alarm if the wet collector reaches an unsafe water level within or water spray is lost.

2.4.4.2 Provide each chamber of the collector with a vent to dissipate evolved hydrogen via a combination of a 1 in. (25 mm) open hole in the top of the chamber may be sufficient to vent hydrogen during shutdowns, and sufficient air flow through the unit during operation.

2.4.4.3 Provide ignition source controls within and around the collector as follows.

A. Ground conductive surfaces of the collector.

B. Install electrical equipment rated for use in accordance with Data Sheet 5-1, *Electrical Equipment in Hazardous Locations* or local requirements.

2.4.5 Perform the following operations under high vacuum or compatible inert atmosphere. Select an inert gas mixture compatible with the metal allow and operating conditions, and design and install the inerting system in accordance with Data Sheet 7-59, *Inerting and Purging Vessels and Equipment*.

A. Alkali metal processing

B. Non-Alkali metal processing involving sponge, molten metal, and handling or liberating finely-divided particulate (crushing/sizing, classifying, and blending). Refer to Data Sheet 7-76 for guidance on metal dust explosion hazards.

C. Magnesium process furnaces (e.g., heat treatment furnaces) operating above 750°F (400°C).

2.4.6 For magnesium process furnaces (e.g., heat treatment) that are not inerted, provide a high-temperature-limit interlock with setpoint below 750°F (400°C).

2.4.7 For magnesium process furnaces (e.g., heat treatment), ensure sufficient circulation within the furnace to avoid localized overheating.

2.4.8 Design and install machining tools based on industry best practices to prevent generating ignition sources (e.g., sparking or hot surface).

2.4.9 Design and install machining cells/stations to allow for the following.

A. Catch/collection pans beneath and around machining/grinding stations to confine scrap metal

B. Facilitate quick inspection and removal of catch pans

C. Access for applying compatible fire extinguishers for metal fires.

2.4.10 Provide ventilation above in metal occupancies (e.g., roof level) designed to allow for evolved hydrogen to dissipate to atmosphere.

2.4.11 For alkali metal heat transfer systems, provide a rapid drain system (scuttle) or drain tank designed to evacuate the heat transfer alkali metal system in case of an emergency to a safe location. Drain piping should be heated to prevent freeze.

2.4.12 Provide the safety permissives and/or interlocks in response to the following VAR furnace system emergency conditions.

A. Loss of cooling water. Initiate a DC furnace power supply shut down upon a lack of cooling water flow from the crucible water jacket.

B. When a manual isolation valve is needed in the VAR crucible water jacket return piping, provide a closed valve interlock. Initiate a DC furnace power supply shut down upon detecting a partially or completely closed valve position.

C. Loss of cooling water primary supply. Initiate a switch to the back-up water supply upon detecting lack of water pressure in the primary supply.

D. High furnace pressure. Initiate a DC furnace power supply shut down upon high pressure in the furnace upper chamber.

2.4.13 Provide operator alarms for the following VAR furnace system emergency conditions.

A. Primary water supply abnormal or out-of-service condition (e.g., low flow, low pressure, low tank level, or pump or driver trouble alarms)

B. Back-up water supply abnormal or out-of-service condition (e.g., low flow, low pressure, low tank level, or pump or driver trouble alarms)

C. High cooling water outlet temperature from crucible water jacket.

D. Low flow in cooling water discharge from crucible water jacket.

E. Loss of cooling water flow through power cables and electrode ram/shaft.

F. Limit reached for electrode travel.

G. Loss of furnace power (DC power for melting).

H. Loss of power to magnetic arc-focusing coil.

I. Loss of vacuum pumping.

J. High hydrogen concentration in furnace exhaust.

2.4.14 Provide a VAR furnace system water cooling system per OEM guidelines and the following.

2.4.14.1 Install two redundant water supplies with independent supply piping connections to distribution manifolds: primary water supply; and back-up water supply.

2.4.14.2 Design the primary water supply as follows.

A. Use a closed-loop cooling water system.

B. Install at least one additional water pump to accommodate a pump failure before switching to back-up water in a N-1 arrangement (i.e., hot or standby pump).

2.4.14.3 Design the back-up water supply to be independent of the primary water supply in terms of water source and pressurization, and sufficiently sized to cool the furnace to a safe temperature. Ensure the primary and back-up water supplies do not share a single point of failure from supply to the distribution manifold (e.g., loss of electricity, public water supply, or plugging of supply piping to the distribution manifold).

Preferably if the primary system consists of a closed loop system with electric pump motor and tank, install an elevated tank to serve as a gravity back-up supply. Alternative back-up water supplies include the following.

A. Install an onsite closed loop primary water system with back-up water supply from domestic water or reliable, enhanced onsite fire protection water supply designed, installed, and maintained per FM standards.

B. Install pump drivers of utilizing different motive force (e.g., electric motor vs. diesel engine) or at least one electric pump motor supplied by an automatic transfer switch and back-up emergency generator.

2.4.15 Provide a pressure relief system in VAR furnace upper chamber in accordance with OEM guidelines and the following.

2.4.15.1 Design the pressure relief to reseal after venting to prevent an in-rush of air.

2.4.15.2 Arrange pressure relief piping to discharge in a safe location using as short run of pipe as possible.

2.4.16 Design and install a vacuum system capable of overcoming higher furnace pressures created by minor water leaks.

2.4.17 Design and install mechanical clamping furnace assembly connections in accordance with OEM design/guidelines.

2.4.18 Provide emergency shutdown controls for each furnace in at least one safe location that will remain occupiable during anticipated fire and explosion conditions.

2.5 Operation and Maintenance

2.5.1 Minimize combustible loading in metal occupancies as follows.

2.5.1.1 Remove nonessential combustibles including cellulose and plastic. Nonessential materials may include removed combustible packaging materials to be discarded as well as for outdoor storage combustible vegetation, and trash.

2.5.1.2 Limit combustible packaging to that required for approximately one shift of production. Combustible packaging may include: cardboard boxes; wood pallets or bins; and plastic foam, plastic wrap, bins, pallets, and containers. Store combustible packaging materials outside of metal occupancies.

2.5.1.3 Limit the amount of metal in the process area to that required for one shift. Metal may be raw material, work-in-process, and finished product.

2.5.1.4 Establish a cleaning frequency of foundries and machine workstations/cells to limit scrap or waste layers or piles, and combustible deposits (finely-divided, coarse scrap, and/or combustible oil/coolant residues in/around equipment that can help a fire spread. Surfaces at equipment level should be cleaned along with surfaces elevated above, positioned beneath the source point, and within exhaust systems.

2.5.1.5 Establish a frequency to remove readily accessible scrap metal from catch pans/trays and bins to limit scrap metal available for a fire. Preferably remove scrap metal every shift but at a minimum remove scrap daily.

2.5.2 Perform housekeeping inspections within the metal occupancy at an established frequency, and prior to outages/shutdowns. Preferably inspect the metal occupancy daily. The following are of particular concern while inspecting the metal occupancy. Ensure inspection findings are reviewed, and conclusions and any take corrective actions documented.

A. Excessive quantities of scrap in raw material, work-in-process, and finished product areas including the following:

1. Excessive scrap accumulations in catch trays/pans in machining and conveying areas
2. Increased number of scrap bins in machining or scrap storage areas
3. Scrap bins are noncombustible with low point drain (e.g., oil and water)
4. Excessive scrap accumulations along any automated scrap conveying systems

B. Nonessential combustibles, and combustible packaging.

C. Ignitable liquid system leaks, and excessive combustible oil accumulations or residues (e.g., cutting oil).

D. Sufficient water levels and sprays within wet dust collectors.

2.5.3 Package and store raw materials, work-in-progress, and products based on safety data sheet (SDS). Of particular importance is packaging finely-divided metals, alkali metals, and alkali-earth metals in compatible noncombustible (metal) containers Approved by the US Department of Transportation or applicable local authority.

2.5.4 Inspect metal for ignition sensitive metal particulate or forms prior to loading a process furnace (e.g., dust and ribbon).

2.5.5 Inspect roofs above metal occupancies for deterioration or damage that may result in stormwater entering the building. Inspect roofs quarterly to annually depending on age and previous inspection results.

2.5.6 Implement standard operating procedures and training for operators and maintenance staff on the hazards of metal occupancies and practices in place to manage metals in receiving/shipping, warehouse, and processing.

2.5.7 Implement hot work management program in accordance with Data Sheet 10-3, *Hot Work Management*, along with the following additional required precautions.

A. When working within or around dry or wet dust collectors, inspect and remove combustibles within ductwork and filters/collectors, and continuously monitor hydrogen concentrations.

B. When working within or around machining cell/stations, inspect and remove scrap accumulations, combustible oil/coolant deposits, and leaking ignitable liquid systems. Also shut down any local exhaust ventilation systems that may capture sparks.

C. Presence of moisture or water that may render reactive metals more ignition sensitive.

2.5.8 Treat the mechanical removal of hot ″condensate″ or other deposits from crucibles as hot work and manage combustibles and ignitable liquids within the surrounding areas per Section 2.5.7.

2.5.9 Limit thermite ignition sources by ensuring metal equipment surfaces remain free and clean of any metal oxides or scale (e.g., rust on iron or steel surfaces). When present, include potential thermite sources as part of the housekeeping inspections.

2.5.10 Inspect molten metal spill containment areas, containers, and equipment for moisture or water prior to use.

2.5.11 Inspect metal for clean and dry conditions prior to charging a molten furnace.

2.5.12 Implement core process safety elements for select parts of the metal occupancy tailored based on occupancy hazards present, complexity of the hazards. Refer to Data Sheet 7-43, *Process Safety* for guidance. The following metal and occupancy operations may warrant process safety elements.

A. Alkali metal storage and processing

B. Molten metal processing

C. Finely-divided metal processing

D. Metal heat treatment

E. Controlled passivation of unoxidized metal surfaces prior to exposure to air

F. Surface treatment (e.g., salt bath compatibility such as nitrates or nitrites with magnesium)

G. Use of alkali metal heat transfer systems

2.5.12.1 Employ the following process safety elements.

A. Process knowledge

B. Process hazard analysis

C. Management of Change (MOC)

D. Asset integrity

E. Incident investigation

F. Contractor management

G. Operators

2.5.13 Implement emergency response plans for combating metal occupancy fire and explosion in accordance with Data Sheet 10-1, *Pre-Incident and Emergency Response Planning* along with the following considerations.

2.5.13.1 Train operators, maintenance, and/or the emergency response team on the proper response to incipient stage metal fires using appropriate fire extinguishers. Alternatively, if the emergency response plan places reliance on the fire service for all fire responses, install local fixed fire extinguish systems over machining workstations/cells.

2.5.13.2 Train operators, maintenance, and/or emergency response team on the proper response to an explosion with fire following in die casting operations.

2.5.13.3 Within the plan, identify where sprinkler protection is provided and omitted. Additionally, determine how to isolate all water supplies to a metal occupancy in the event of an uncontrolled metal fire. Isolation may include pressurized water, drains, and sprinkler systems.

2.5.13.4 Conduct a fire preplanning with the local fire service. Identify metal occupancy areas, types and quantities of metal, and onsite fire fighting agents besides water. Update plans based on facility changes.

2.5.14 Implement an asset integrity program for the VAR furnace system in accordance with Data Sheet 9-0, *Asset Integrity* and the following.

2.5.14.1 Inspect the mechanical and structural integrity of furnace assemblies, support system equipment, and load-bearing supports at least annually. Furnace assemblies may include furnace water jacket and upper chamber/bell, crucible, and electrode/ram/shaft support and manipulation. Inspections should look for visual signs of damage, tightness of connections, appropriate assembly, and indications of leaks.

2.5.14.2 Verify electrode assembly alignment with the crucible at least annually.

2.5.14.3 Implement a crucible examination, testing, and management program consisting of the following.

2.5.14.3.1 Visually inspect crucible interior surfaces (electrode facing) for damage and deposits between heat/melts. Remove deposits by buffing, polishing, or other methods in accordance with OEM guidelines.

2.5.14.3.2 Visually inspect assembled crucible and water jackets and leak test prior to every melt/heat (e.g., vacuum leak test).

2.5.14.3.3 Examine crucibles for damage and wastage (thinning) on routine intervals in accordance with OEM guidelines.

2.5.14.3.4 Audit the crucible management programs at least annually.

2.5.14.3.5 Prior to disposal, inspect and examine spent crucibles to validate that the maintenance and management program maintained appropriate safety margins throughout the end of campaign.

2.5.14.4 Implement a water jacket examination, testing, and management program consisting of the following.

2.5.14.4.1 Visually inspect the water jacket for damage at crucible change-out.

2.5.14.4.2 Examine crucibles for damage and conditions that may impact water cooling effectiveness on routine intervals in accordance with OEM guidelines.

2.5.14.4.3 Conduct crucible and water jacket repairs in accordance with OEM guidelines.

2.5.14.5 Maintain cooling water quality in accordance with OEM guidelines to prevent waterside damage (corrosion) or deposits (flow restriction or reduced thermal conductivity).

2.5.14.6 Leak test cooling water system components following repairs or alterations and prior to the next melt/heat.

2.5.14.7 Inspect, test, and maintain control systems including instrumentation in accordance with OEM guidelines and the following.

2.5.14.7.1 Functional test loss of primary water supply and high furnace pressure interlocks at least annually.

2.5.14.7.2 Functional test the loss of water-cooling interlock for the crucible prior to every melt/heat (e.g., with one rectifier powered, shut down the primary water supply).

2.5.14.7.3 Test furnace system alarms at least annually.

2.5.14.7.4 Test electrode position control system and alarms at least annually.

2.5.15 Implement the following measures to control the arc and prevent crucible strikes in VAR furnace systems.

2.5.15.1 Use high frequency starters.

2.5.15.2 Install arc control systems to operate effectively and efficiently but minimize arc length. Factors that may impact arc length include metal, furnace geometry, consumable electrode geometry, melting rate, current, and pressure/vacuum.

2.5.15.3 Install an arc-focusing coil system that creates a magnetic field that spans the entire length of the melting zone. Field strength should be adjusted based melt recipe (operating conditions).

2.5.16 Implement the following measures to maintain sufficient clearance between consumable electrode and crucible wall.

2.5.16.1 Establish a minimum wall clearance in accordance with OEM guidelines.

2.5.16.2 Verify primary melt consumable electrode concentricity and integrity (securely welded).

2.5.16.3 Verify consumable electrode positioning and alignment with the crucible prior to every melt/heat.

2.5.17 Install cameras for remote operating of unoccupiable furnace areas (e.g., around the melt zone).

2.5.18 Develop and maintain standard operating procedures (SOPs) for furnace system operations in accordance with OEM guidelines and Data Sheet 10-8, *Operators*.

2.5.19 Develop and maintain emergency operating procedures (EOPs) for furnace system operations in accordance with OEM guidelines, Data Sheet 10-8, *Operators* for at least the following upset conditions. Reinforce operator authority to shut down the furnace system and production upon suspecting or detecting an emergency condition.

A. Primary water supply abnormal or out-of-service condition (e.g., low flow, low pressure, low tank level, or pump or driver trouble alarms)

B. Back-up water supply abnormal or out-of-service condition (e.g., low flow, low pressure, low tank level, or pump or driver trouble alarms)

C. High cooling water outlet temperature from crucible water jacket.

D. Low flow in cooling water discharge from crucible water jacket.

E. Loss of cooling water flow through power cables and electrode ram/shaft.

F. Limit reached for electrode travel.

G. Loss of furnace power (DC power for melting).

H. Loss of power to magnetic arc-focusing coil.

I. Loss of vacuum pumping.

J. High hydrogen concentration in furnace vacuum exhaust.

2.5.20 Implement an operator training and qualification program in accordance with Data Sheet 10-8, *Operators*.

2.5.21 Implement a jumper and force management program in accordance with Data Sheet 10-8, *Operators*.

2.5.22 Record and maintain the following data for each melt/heat. Review and trend as needed.

A. Arc voltage and current

B. Furnace pressure/vacuum

C. Electrode position of the electrode

D. Melt duration

E. Current on any magnetic arc-focusing coil

F. Cooling water inlet and outlet temperatures

G. Furnace vacuum exhaust if provided (e.g., hydrogen)

2.6 Contingency Planning

2.6.1 When the breakdown of critical metal treatment furnace systems (e.g., heat treatment) and molten metal furnace systems (e.g., melting, refining, and casting) 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 (ECP) 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 ECP.

2.7 Sparing

2.7.1 Sparing can be a mitigation strategy to reduce the downtime caused by a furnace system 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*.

2.7.2 Routine spares 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 furnace systems, but not reduce equipment downtime in the event of a breakdown. This can include sparing recommended by the original equipment manufacturer. See Section 3.3 for guidance on routine spares.

3.0 SUPPORT FOR RECOMMENDATIONS

3.1 Loss History

3.1.1 FM Loss History

Table 3.1.1 contains the results of a review of combustible and reactive metal losses between 1996 and September 2021.

Table 3.1.1. Combustible and Reactive Metal Losses By Peril

Peril	*No. of Losses*	*Gross Loss (US$M)*
Explosion	7	135.99
Fire	6	127.62

4.0 REFERENCES

4.1 FM

Data Sheet 1-5, *Cooling Towers*
Data Sheet 1-40, *Flood*
Data Sheet 2-0, *Installation Guidelines for Automatic Sprinklers*
Data Sheet 3-26, *Fire Protection for Nonstorage Occupancies*
Data Sheet 7-21, *Rolling Mills*
Data Sheet 7-33, *Molten Metals and Other Materials*
Data Sheet 7-37, *Cutting Oils*
Data Sheet 7-43, *Process Safety*
Data Sheet 7-59, *Inerting and Purging of Vessels and Equipment*
Data Sheet 7-76, *Combustible Dusts*
Data Sheet 8-9, *Storage of Class 1, 2, 3, 4 and Plastic Commodities*
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*

4.2 NFPA Standards

NFPA 484, *Standard for Combustible Metals*

APPENDIX A GLOSSARY OF TERMS

Approved: References to “Approved” in this data sheet means the product and services have satisfied the criteria for FM Approval. Refer to the *Approval Guide*, a publication of FM Approval, for a complete listing of products and services that are FM Approved.

Combustible Metal: A pure or alloyed metal in a solid form or molten state that burns in air (20.9% oxygen). Once ignited, a combustible metal continues burning upon removal of the ignition source or exposure fire.

(Water-) Reactive Metal: A pure or alloyed metal in a solid form or molten state that reacts with moisture or water resulting in:

- Evolution of hydrogen posing an increased fire hazard (i.e., in terms of ignition sensitivity or intensity) or explosion deflagration hazard; or
- A rapid phase transition (RPT) explosion (i.e., a molten state concern).

APPENDIX B DOCUMENT REVISION HISTORY

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

July 2022. This document has been completely revised. Significant changes include the following:

A. Changed the title from “Metals and Alloys” to “Combustible and Reactive Metals.”

B. Clarified where in a metal occupancy to recommend water-based fire protection as well as the protection design.

C. Revised recommendations for isolating molten titanium-water explosion hazards and expanded to apply this guidance to furnaces processing molten hafnium, niobium, tantalum, and zirconium (hydrogen and/or rapid phase transition explosion hazards).

July 2015. Interim revision. Incorporated information from Data Sheet 7-47, *Physical Operations in Chemical Plants*, regarding alkali metals used for heat transfer.

April 2013. Changed the terminology ″dry powder″ to ″dry compound″ when referring to extinguishing agents for metals to be consistent with *Approval Guide* listings. Provided editorial updates in several areas.

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

This document does not have any revision history.

APPENDIX C COMBUSTIBLE AND REACTIVE METALS

The fire and explosion hazards posed by combustible and reactive metals vary based on metal alloying and impurities, surface conditions, metal temperature, and surrounding atmosphere.

• The presence of inert impurities and alloys can retard ignition and reactivity.

• The following surface conditions influence combustible and reactivity characteristics.

  ❍ Presence of moisture/water - Water-contact can evolve hydrogen gas increasing ignition sensitivity and fire severity. Some metal forms become pyrophoric in the presence of moisture/water.

  ❍ Lack of a stable passivation film (e.g., oxide layer) - Uncontrolled metal oxidization can generate heat potentially leading to spontaneous ignition.

  ❍ Unstable coatings - Loss of a coating can result in uncontrolled metal oxidization as discussed previously (e.g., loss of an oil film).

  ❍ Surface-area to mass or volume ratio - With increasing ratios, metal forms require less heat input to raise the metal temperature becoming more ignition sensitive and burning more intensely.

• Higher metal temperatures can increase water-reactivity as well as requiring less energy for ignition; however, ignition sensitivity depends on the metal. For example, lithium spontaneously ignites around the melting point, while magnesium spontaneously ignite around their boiling points. In contrast, zirconium can spontaneously ignite below the melting point.

• Metals in certain forms can spontaneously ignite at elevated temperatures in pure carbon dioxide or nitrogen atmospheres. These temperatures are much lower than the spontaneous ignition temperature in air. Titanium and tantalum are two such examples.