COMBUSTIBLE AND REACTIVE METALS

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1.0 SCOPE

This data sheet contains property loss prevention guidance unique to combustible and water-reactive metals, including alkali and alkali-earth as well as refractory metals and metals with similar properties such as titanium and zirconium. Guidance offered in this data sheet applies to various portions of the combustible and reactive metal value chain, including molten processing such as extraction, refining and casting; transformation into intermediate materials via metalworking operations such as forging or rolling; and utilization to create finished products through metalworking operations such as machining.

In addition to molten processing of combustible and reactive metals, the guidance contained within this data sheet is also applicable to molten processing of noncombustible and non-reactive metals within a chamber (e.g., molten processing specialty steel alloys under vacuum). Examples of molten furnace technologies addressed within this standard include vacuum induction melting (VIM), induction skull melting (ISM), vacuum arc remelting (VAR), electroslag remelting (ESR), electron beam (EB) melting, and plasma arc melting (PAM).

This data sheet does not address all potential hazards associated with combustible and reactive metals. Refer to the respective data sheets for the following hazards:

- Combustible dust explosion. Refer to Data Sheet 7-76, *Combustible Dusts*, when combustible metal powder is produced, or dust may be liberated and form a flammable atmosphere when dispersed in air, thus posing a flash fire and dust explosion hazard.
- Radioactive contamination. Refer to Data Sheet 7-61, *Facilities Processing Radioactive Materials*, when handling and processing radioactive minerals or metals, and Data Sheet 7-33, *Molten Metals and Other Materials*, when handling and processing scrap metal, given the potential for inclusion of irradiated metal or radioactive sources.

This data sheet focuses on the unique hazards and exposures associated with combustible and reactive metals and any molten processing within a vacuum chamber or under special atmosphere. When encountering common hazards and exposures not specifically addressed in this data sheet, apply the relevant data sheet. Examples include the following:

- 1-series building construction and natural hazard data sheets for the design and installation of building assemblies enclosing metal occupancies
- Data Sheet 5-4, *Transformers*, for fire protection and maintenance of vacuum arc remelt transformers and vacuum induction melting transformers
- Data Sheet 7-33, *Molten Metals and Other Materials*, when not specifically addressed within this standard (i.e., radioactive contamination), apply the general molten hazard guidance.
- Data Sheet 7-37, *Cutting Fluids*, for systems supporting lathes and CNC machines
- Data Sheet *7-98*, Hydraulic Fluids, for hydraulic oil supplies cutoff from the metal occupancy
- Data Sheet 7-110, *Industrial Control Systems*, for control equipment rooms and operator control rooms

Application

This data sheet covers a number of different processes and metals.

- Alkali metals
- Most alkali-earth metals (except magnesium)
- Magnesium
- Refractory metals (niobium, molybdenum, tantalum, tungsten, rhenium)
- Metals that behave similarly to refractory metals (titanium, zirconium, hafnium, vanadium, ruthenium, osmium, rhodium, chromium, iridium)

Most of the guidance is directed towards metalworking occupancies handling and processing magnesium, refractory metals and metals similar to refractory metals. Guidance specific to alkali and alkali-earth metals (excluding magnesium) is highlighted, along with guidance for molten occupancies.

Note: This data sheet contains limited prescriptive guidance for alkali and alkali-earth metals (excluding magnesium). The property loss prevention guidance for these materials should be derived primarily from the process safety program and the associated process hazard analysis (PHA).

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

April 2025. Interim revision. Significant changes include the following:

A. Updated process safety guidance to align with Data Sheet 7-33, *Molten Metals and Other Materials*.

B. Clarified molten release guidance within vacuum chambers such as VIM furnaces.

C. Revised explosion mitigation and prevention guidance for molten equipment.

D. Added fire protection guidance for metal powders in combustible packaging.

E. Updated loss history.

2.0 LOSS PREVENTION RECOMMENDATIONS

2.1 General

2.1.1 Use FM Approved products whenever they are applicable and available, including FM Approved industrial fluids in accordance with Data Sheet 7-33. For a list of FM Approved products, see the *Approval Guide* and/or Roof*Nav*, as applicable.

2.1.2 Implement a process safety program for the combustible and reactive metal processes and molten processes listed below.

A. Alkali metal processing and storage

B. Processing or storage of metal powder dispersions in ignitable liquid

C. Production of metal powders from molten state

Process safety may not be warranted in downstream occupancies using powder, such as in metal additive manufacturing (metal AM). These operations have become more common. Thus, the hazards are known and prescriptive loss prevention guidance is available.

D. Passivation of unoxidized metal surfaces including scrap processing (i.e., milling or solvent-based cleaning)

E. Use of alkali metal heat transfer systems

F. Any molten occupancy addressed by this standard

2.1.2.1 For the non-molten occupancies listed in Section 2.1.2, align the process safety program with FM Data Sheet 7-43, *Process Safety*. The program should address at least fire and explosion associated with a flammable atmosphere, containing combustible dust and/or flammable off-gases generated by water contact such as hydrogen or acetylene.

2.1.2.2 For the molten occupancies listed in Section 2.1.2, align the process safety with Data Sheet 7-33. The program should, at a minimum, evaluate for the following hazards and assess their exposure:

- Molten release with damage to the subject molten equipment, as well as thermal damage in the surrounding area, and potential for an ensuing fire or molten-water/room explosion
- Water entering the furnace and a molten-water equipment explosion
- Combustion explosion associated with a flammable atmosphere containing vapor, gases, off-gases and/or combustible dust.

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.

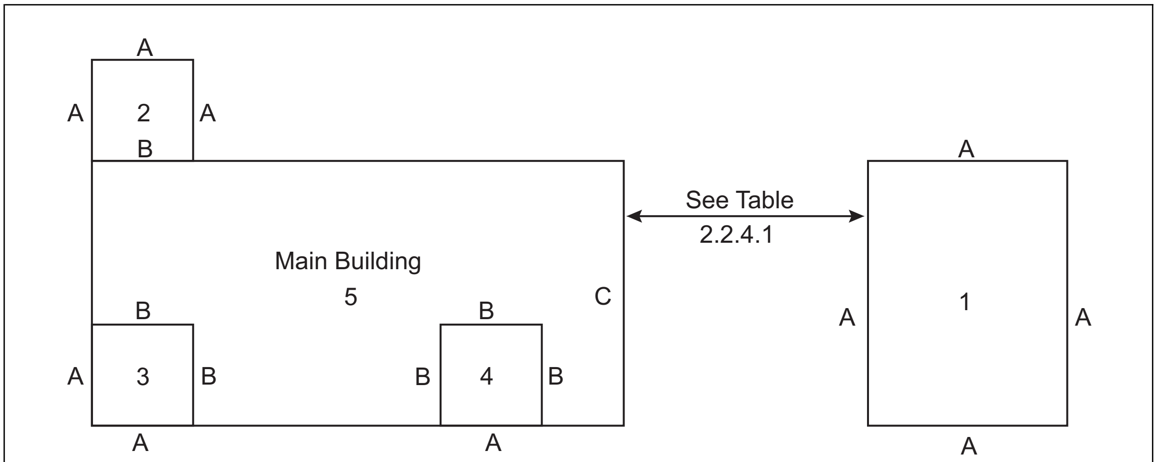

Fig. 2.2.4. Location and construction of buildings and cutoff rooms for metal occupancies

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 metalworking occupancies and metal storage 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.

2.2.4.2 For finely-divided and coarse scrap metal storage and processing, isolate storage and processing within a detached building (Location 1).

2.2.4.3 For indoor storage, isolate metal storage in a fire-resistant cutoff room. Of particular importance is isolating metal storage from combustible storage or other combustible occupancies.

2.2.4.4 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 For die-casting (molten) operations, isolate die-casting operations from surrounding building areas using outdoor locations, detached buildings, or cutoff rooms in accordance with Figure 2.2.4 and Table 2.2.4.

2.2.6 For molten alkali (heat transfer) systems, isolate 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).

2.2.7 For molten occupancies, install flooring, or floor coverings or coatings compatible with the given metal per the PHA. 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.

2.2.8 For store small quantities of metal powder, store powder in flammable liquid cabinets.

2.3 Protection

2.3.1 For a metalworking occupancy, provide automatic sprinkler protection over process and storage areas.

The objective is to control the incipient fire in order to prevent ignition or increase involvement of combustible metal. Additionally, sprinkler water helps to prevent ignition of adjacent combustibles and cool the building as well as equipment in the vicinity of incipient metal fire until the metal is consumed, removed, or extinguished.

2.3.2 For an alkali occupancy, provide automatic sprinkler protection over process and storage areas 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.

2.3.3 For a molten occupancy, do not install automatic sprinkler protection to mitigate the hazard posed by combustible loading. When combustible loading is present, apply one or more of the following alternative protection options.

A. 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.

B. 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.

C. Remove nonessential combustibles and install local automatic sprinkler protection over essential combustibles within the foundry occupancy.

2.3.4 For metalworking occupancies, design automatic sprinkler protection based on the presence of limited work-in-process metal or scrap accumulations 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*.

2.3.5 For indoor metal storage, provide automatic sprinkler protection 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 may be largely contingent upon type and quantity of packaging associated with the metal storage.

A. For alkali metal in sealed, noncombustible containers without ignitable liquid, protect per PHA but as a minimum Class 1 commodity.

B. For magnesium ingots and similar heavier forms, protect as a minimum of Class 4 commodity. Additionally, limit pile sizes to 150,000 lb (68,000 kg) with aisles widths at least equivalent to the pile height.

C. For scrap metal storage, protect as a minimum cartoned unexpanded plastic (CUP) 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 metal powder in sealed, noncombustible containers without ignitable liquid, protect as a minimum Class 1 commodity. Additionally, limit pile sizes to 1,000 ft^3 (28 m^3) with aisles widths at least equivalent to the pile height.

E. When storing metal powders in metallic containers is not feasible (e.g., titanium powder), protect metal powders within combustible containers as follows:

1. Limit storage to single-row and double-row racks up to four tiers or 24 ft. (7.3 m) under a maximum ceiling/roof height of 30 ft. (9 m).

2. Do not store powders above the top barrier level. Do not vertically mix the powder storage with other commodities.

3. Store the finest powder (smallest diameter particulate) on the lower tier.

4. Provide horizontal barriers within the racking, constructed of plywood (minimum 3/8 in. [10 mm]) or sheet metal (minimum 22 ga. [7 mm]) as follows:

   a. Limit barrier vertical spacing to 6 ft. (1.8 m)
   b. Design barriers without gaps in longitudinal flue spaces
   c. Design barriers with maximum transverse flue spaces of 3 in. (76 mm) between each barrier at rack uprights

5. Provide in-rack automatic sprinklers (IRAS) under each horizontal barrier, consisting of the following:

   a. For single row racks, sprinklers in each transverse flue space within 6 in. (152 mm) on alternating rack faces or on a centerline layout

   b. For double row racks, sprinklers in each transverse flue space within 6 in. (152 mm) of each rack face, along with a sprinkler in the longitudinal flue space at every transverse flue space

6. Install FM Approved, in-rack, automatic sprinklers (IRAS) with minimum K-factor of 8.0 (115) or K11.2 (K160), rated for quick response and having an intermediate rating (165°F or 70°C).

7. Design in-rack automatic sprinklers for a minimum flow of 60 gpm (227 L/min) from the most hydraulically remote six (6) sprinklers for a single tier (e.g., three face and three flue sprinklers for double-row rack) of metal powder storage or eight (8) sprinklers for multiple tiers of metal powder storage (e.g., two flue and two face sprinklers on two tiers for double-row racks). The ceiling automatic sprinkler protection should be designed based on the surrounding occupancy. The ceiling protection does not need to be balanced at the point of connection.

8. Provide a 500 gpm (1900 L/min) hose stream allowance.

9. Design the water supply for a fire protection water demand of two hours.

10. For any adjacent rack arrays not dedicated to metal powder storage, provide one of the following.

   a. A minimum aisle width of 10 ft. (3.1 m), or

   b. A minimum aisle width of 8 ft. (2.4 m), and protect racks across the aisle by providing a line of face sprinklers at 4 to 5 ft. (1.2 to 1.5 m) on-line spacing at the 10 ft. (3 m) elevation. Design the face sprinklers for six (6) sprinklers operating, each discharging 60 gpm (227 L/min); and balance the hydraulic demand for this line of sprinklers with the protection over the hydraulic demand for the metal powder storage.

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

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

2.3.7 For molten alkali (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*.

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

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

2.4.3 For metalworking operations processing or generating finely-divided particulate, use a noncombustible, wet dust collector protected in accordance with Data Sheet 7-76, *Combustible Dusts*, and the following safeguards.

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

2.4.3.2 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.

2.4.3.3 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.

2.4.4 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 metalworking

B. Metalworking liberating finely-divided particulate (crushing/sizing, classifying, or blending). Refer to Data Sheet 7-76 for guidance on metal dust explosion hazards.

C. Molten processing involving sponge, molten metal, and handling or liberating finely-divided particulate (crushing/sizing, classifying, and blending).

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

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

2.4.6 For magnesium process furnaces that are not inerted, ensure sufficient circulation within the furnace to avoid localized overheating.

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

2.4.8 Design and install metalworking cells/stations to allow for the following:

A. Catch pans beneath and around stations to collect scrap metal

B. Easy inspection and removal of catch pans

C. Access for applying compatible fire extinguishers during a metal fire

2.4.9 Provide natural ventilation above metalworking occupancies (e.g., roof level) designed to allow for evolved hydrogen to dissipate to atmosphere.

2.4.10 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.

2.4.11 For molten occupancies where loss of cooling can result in refractory damage or molten release, provide redundancy in the primary cooling supplies serving the molten equipment in accordance with Data Sheet 7-33.

2.4.12 For molten occupancies, provide an emergency cooling water supply, independent of the primary cooling water supply, in accordance with Data Sheet 7-33.

2.4.13 For molten occupancies, arrange the emergency cooling water supply piping to connect as close as practical to the water-cooled molten equipment in accordance with Data Sheet 7-33.

2.4.14 For molten occupancies, provide onsite emergency power generation capable of supporting molten equipment hot-hold or controlled shutdown during a service interruption (i.e., loss of utility power).

2.4.15 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

Operation

2.5.1 Minimize fuel loading in the metalworking occupancy as follows:

2.5.1.1 Remove nonessential combustibles materials including discarded combustible packaging materials, or idle wood or plastic pallets.

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 combustible and reactive 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 For molten and metalworking occupancies, establish a cleaning frequency to limit swarf (waste metal) 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 swarf (waste metal) from catch pans and bins to limit combustible and reactive 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 combustible and reactive metal occupancy at an established frequency, and prior to scheduled outages. Preferably inspect the combustible and reactive metal occupancy daily. Ensure inspection findings are reviewed, and conclusions and any take corrective actions documented. The following are of particular concern.

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

1. Excessive swarf accumulations in catch trays
2. Increased number of swarf bins in metalworking areas or scrap/reclaim in storage areas
3. Swarf and scrap/reclaim bins are noncombustible with low point drain (e.g., oil and water)
4. Excessive swarf accumulations within areas surrounding automated scrap conveying systems and exhaust ventilation ducts

B. Excessive nonessential combustibles such as combustible packaging or pallets

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

E. Excessive combustible dust deposits within vacuum chambers and vacuum piping.

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 local authority having jurisdiction (e.g., Department of Transportation when within the US).

2.5.4 Inspect metal for ignition-sensitive particulate or forms prior to loading a heat treat furnace for ignitable metal debris, such as dust or ribbon.

2.5.5 For all occupancies, inspect roofs 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 metalworking cell/station, 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 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.

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

2.5.10 For molten occupancies, inspect molten breakout containment areas, containers, and equipment for moisture or water prior to use.

2.5.11 For molten occupancies, inspect metal for clean and dry conditions prior to charging a molten furnace.

2.5.12 For all occupancies, 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.

2.5.12.1 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.

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

2.5.12.3 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 fire water from sprinklers and hose streams, as well as process water and cooling water.

2.5.12.4 Conduct a fire preplanning with the local fire service. Identify metalworking occupancies and molten occupancies, types and quantities of metal, and onsite fire-fighting agents besides water. Ensure the manual response to a metal powder fire uses the appropriate nozzle spray pattern (i.e., fog nozzle for rack storage of combustible metal powders in combustible packaging). Update plans based on facility changes.

2.5.13 For molten occupancies, implement an operator management program in accordance with Data Sheet 10-8, *Operators*, as well as the following general guidance and any furnace-specific guidance in Section 2.7.

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

B. Implement an operator training and qualification program for molten operations in accordance with Data Sheet 10-8, *Operators*.

C. Implement a jumper and force management program for molten operations in accordance with Data Sheet 10-8, *Operators.*

Maintenance

2.5.14 For molten occupancies, implement an asset integrity program in accordance with Data Sheet 9-0, *Asset Integrity*, as well as the following general guidance and any furnace specific guidance in Section 2.7.

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

B. Leak test cooling water system components following repairs or alterations and prior to each melt or cycle.

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

2.5.14.1 Functional test interlocks at least annually.

2.5.14.2 Test furnace system alarms at least annually.

2.6 Contingency Planning

2.6.1 When the breakdown of critical metalworking equipment such as heat treatment furnaces or molten equipment and molten furnace systems such as remelt furnaces 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.

Sparing

2.6.1.1 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*.

2.6.1.2 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.

2.7 Furnace Specific Guidance

2.7.1 Vacuum Arc Remelt (VAR) - Combustible/Reactive

Location and Construction

2.7.1.1 Locate the melt zone for each primary and secondary electrode VAR furnace within a dedicated, pressure-resistant vault. The vault should have pressure-relieving construction designed to manage overpressure and limit projectile damage to the furnace system of origin.

2.7.1.2 For a casting VAR furnace, provide explosion isolation based on the pressure relieving design of the furnace chamber.

2.7.1.3 Construct any molten breakout containment below the furnace of compatible materials (e.g., concrete may not be compatible with some reactive metals).

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

Equipment and Processes

In the absence of a PHA, the following prescriptive guidance is a starting point for assessing alarms and interlocks for a combustible/reactive VAR furnace. Ultimately, the PHA should be the authoritative source for this guidance.

Table 2.7.1-1. Alarms and Interlocks for Combustible/Reactive VAR Furnace

Equipment Parameter or Upset Condition	*Permissive*	*Alarm*	*Trip*	*Action*	*Reference*
Furnace cooling water, flow	X	-	-	Allow melting	2.7.1.6.A
Furnace cooling water, return valve open	X	-	-	Allow melting	2.7.1.6.B
Furnace trapped air monitoring, cooling water present(design dependent)	X	-	-	Allow melting	2.7.1.6.C
Furnace cooling water, low flow	-	X	X	Terminate melting	2.7.1.6.D
Furnace cooling water, primary water supply upset	-	X	X	Terminate melting & switch to emergency cooling supply	2.7.1.6.E
Furnace cooling water, return high temperature	-	X	-	-	2.7.1.6.J
Furnace, low vacuum (increasing pressure)	-	X	X	Terminate melting & initiate inert gas purge	2.7.1.6.F
Furnace, loss of arc with limit met	-	X	X	Terminate melting	2.7.1.6.G
Power supply cooling water/air, flow	X	-	-	Terminate melting	2.7.1.6.H
Power supply cooling water/ air,low flow	-	X	X	Terminate melting	2.7.1.6.I
Power supply cooling water/ air,return/equipment high temp	-	X	-	-	2.7.1.6.K

2.7.1.5 Design the water jacket in a manner that eliminates the possibility of trapped air (i.e., air pocket) forming with the crucible and water jacket assembled. If not feasible, refer to section 2.7.1.6.C.

2.7.1.6 Provide permissives and/or interlocks with alarms in response to the following VAR furnace system emergency conditions (also listed in Table 2.7.1-1)

A. Proof of furnace cooling water flow start-up permissive to energize power supply.

B. When a manual isolation valve is needed in the cooling water return, proof of open valve start-up permissive to energize the power supply (e.g., valve position indicator).

C.If the water jacket design does not eliminate the potential for an air pocket forming when assembled, provide a start-up permissive within the water jacket to monitor for trapped air (e.g., low-water or water detection sensor).

D. Loss of furnace cooling water circulation trip (e.g., low return pressure or low flow). Initiate a furnace power supply shut down.

E. Loss of cooling water primary supply trip. Initiate a furnace power supply shut down, and switch to the emergency cooling water supply.

F. Furnace low vacuum (increasing pressure). Initiate a furnace power supply shut down and initiate inert gas purge.

G. Loss of arc with electrode travel limit or time-out limit met. Initiate a furnace power supply shut down.

H. Proof of power supply cooling water flow start-up permissive to energize the power supply.

I. Loss of power supply cooling water circulation trip (e.g., low return pressure or low flow). Initiate a furnace power supply shut down.

J. Alarm when reaching furnace cooling water high return temperature.

K. Alarm when reaching power supply cooling water high return temperature.

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

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

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

C. Cooling water return high temperature, or high differential temperature between the supply and return for the crucible or electrode stub circuits.

D. Cooling water return, low flow from crucible water jacket or electrode stub circuits

E. Loss of cooling water circulation through all circuits

F. Electrode position limit reached

G. Loss of arc with either approaching electrode travel limit or time-out limit.

H. Loss of furnace power (power supply)

I. Furnace power high voltage (at electrode)

J. Loss of power to arc-focusing coil

K. Loss of vacuum pumping

L. High hydrogen concentration in furnace or vacuum system

2.7.1.8 Provide a pressure relief system for the furnace melt chamber and vacuum system. Design and install the pressure relief system for the VAR furnace in accordance with OEM guidelines and the following.

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

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

2.7.1.8.3 If leveraging vacuum sealed components as a means pressure-relief, mitigate those components becoming projectiles during an overpressure event by either installing physical barriers (isolation) or providing restraint such as using mechanical piping connections to the vacuum sealed component.

2.7.1.9 Design the vacuum system to overcome higher furnace pressures created by a minor cooling water leak. Alternatively, provide an inert gas purging system (e.g., argon) to limit the potential to form a flammable hydrogen atmosphere within the furnace.

2.7.1.10 Design furnace assembly connections in accordance with OEM design/guidelines. Mechanical clamping or vacuum sealing are two potential options.

Maintenance

2.7.1.11 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.

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

2.7.1.13 Implement a crucible examination, testing, and management program consisting of the following:

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

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

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

2.7.1.13.4 Audit the crucible management programs at least annually.

2.7.1.13.5 Prior to disposal, evaluate spent crucible condition to validate that the maintenance and management program maintained appropriate safety margins throughout the end of campaign.

2.7.1.14 Implement a water jacket examination, testing, and management program consisting of the following:

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

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

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

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

2.7.1.15.1 Use high frequency starters.

2.7.1.15.2 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.

2.7.1.15.3 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).

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

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

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

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

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

2.7.1.18 Record and maintain the following data for each melt, when applicable. Periodically review data for negative trends.

A. Arc voltage and current

B. Furnace pressure/vacuum

C. Electrode position and/or weight

D. Melt duration

E. Current on any magnetic arc-focusing coil

F. Critical cooling water supply and return temperatures

2.7.1.19 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. Refer to the emergency conditions listed under permissives/interlocks and operator alarms in Section 2.4.12 and 2.4.13 for EOP considerations.

2.7.2 Vacuum Arc Remelt (VAR) – Noncombustible/Non-Reactive

2.7.2.1 For a VAR or ESR furnace processing specialty steel alloy or similar noncombustible or non-reactive metal, provide pressure-resistant construction between each furnace melt zone when closely spaced.

2.7.2.2 Construct any molten breakout containment below the furnace of compatible materials (e.g., concrete may not be compatible with some metals).

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

2.7.3 Electron Beam (EB) - Combustible/Reactive

2.7.3.1 For an EB furnace processing hafnium, niobium, tantalum, titanium, or zirconium, locate each furnace in a dedicated room cutoff from other melt shop areas as described in Section 2.2.4.1.1.

2.7.3.2 When a dual-chamber furnace design is used, provide independent vacuum systems for each chamber to avoid the potential for flammable off-gas generated in one chamber to accumulate in the other chamber.

2.7.3.3 Isolate the furnace power supply from surrounding areas, the subject furnace, and any adjacent furnaces or occupancies by locating the supply within a fire-resistive cutoff room.

2.7.4 Vacuum Induction Melter (VIM) – Noncombustible/Non-Reactive

2.7.4.1 For a VIM furnace processing specialty steel alloy or similar noncombustible or non-reactive metals, isolate each furnace in a dedicated room cutoff from other melt shop areas.

2.7.4.2 Provide molten breakout containment around the furnace and casting chamber in accordance with Data Sheet 7-33. Additionally, provide a combination of molten breakout containment and thermal protection strategy to minimize thermal damage within the melt chamber, as well as to any attached casting chamber. Leverage the process hazard analysis (PHA) and any original equipment manufacturer (OEM) guidelines to devise the strategy. Construct containment of compatible materials (e.g., concrete may not be compatible with some reactive metals).

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

2.7.4.4 Provide permissives to prove necessary conditions within the melt or casting chamber to allow pouring based on the PHA.

3.0 SUPPORT FOR RECOMMENDATIONS

3.1 Loss History

3.1.1 Loss Data

The following tables were derived from a review of losses that occurred involving combustible and reactive metals, or other molten metal in special atmosphere furnace during 1996 and 2024. Table 3.1.1-1 contains losses sorted by loss peril, while Table 3.1.1-2 contains losses by metal. Figure 3.1.1-1 is loss severity over time. All values are indexed to 2024 USD.

Table 3.1.1-1. Combustible and Reactive Metal Losses by Peril

Initiating Peril	*Ensuing Damage (Peril)*	*No. of Losses*	*Gross Loss (US$M)*
Explosion	n/a	13	295.92
	Fire	7	15.79
Fire	n/a	27	221.20
MMR	n/a	6	29.64
	Explosion	2	0.25
	Fire	2	4.32
Electrical Breakdown	n/a	1	6.26
Service Interruption	n/a	1	2.95
Mechanical Breakdown	n/a	1	0.26
Total(s)	n/a	49	549.97

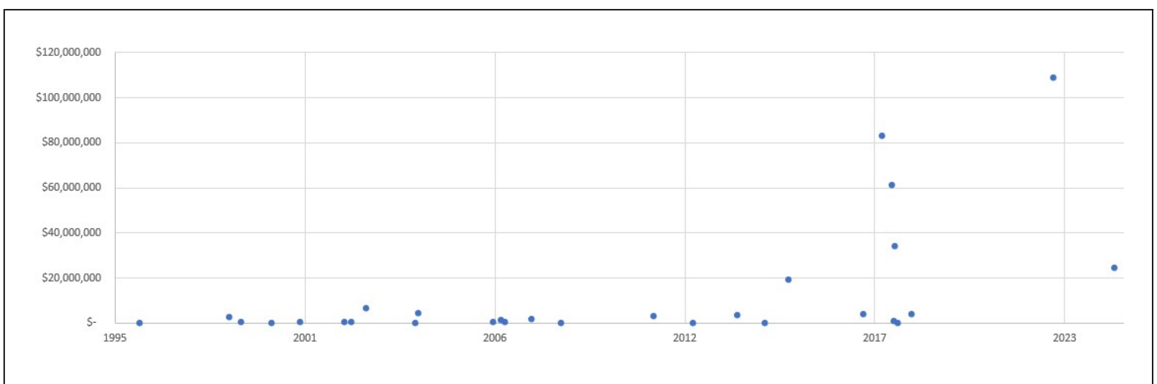

Fig. 3.1.1-1. History of loss severity

Table 3.1.1-2. Combustible and Reactive Metal Losses by Metal

Metals	*No. of Losses*	*Gross Loss (US$M)*
Titanium	21	382.24
Magnesium	18	130.92
Specialty Steel	9	36.81
Precious	1	6.26

Table 3.1.1-3. Molten Occupancy Losses By Molten Equipment Technology

Operation	*Technology*	*No. of Losses*	*Gross Loss (US$M)*
Metalworking (Solid)	Metalworking (ALL)	18	248.25
	Scrap Processing	2	122.85
	Machining	14	57.25
	CNC	6	53.37
	Grinding	6	3.54
	Lathe	2	0.33
	Metal Spray	1	9.92
	Heat Treatment	1	0.97
Molten Processing	Molten Processing (ALL)	30	365.23
	VAR	8	293.90
	VIM	9	40.64
	EB	1	19.35
	Die Caster	12	10.80

4.0 REFERENCES

4.1 FM

Data Sheet 1-6, *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 Fluids*
Data Sheet 7-43, *Process Safety*
Data Sheet 7-59, *Inerting and Purging of Vessels and Equipment*
Data Sheet 7-73, *Dust Collectors and Collection Systems*
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

Alkali: Metal elements within the periodic table Group 1 (1a), consisting of six elements, including lithium (Li), sodium (Na), potassium (K), rubidium (Rb), cesium (Cs), and francium (Fr).

Alkali-Earth: Metal elements within periodic table Group 2, consisting of six elements, including beryllium (Be), magnesium (Mg), calcium (Ca), strontium (Sr), barium (Ba), and radium (Ra).

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.

Swarf: Machining waste in the form of scrap metal created when metal is cut or shaped. Machine waste comes in the form of chips, shavings, filings, turnings, and dust.

(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).

Water Strike: Inadvertent (unintentional) contact between the motive melting power (arc or electron beam) and a water-cooled component of a VAR or EB furnace. If the mechanical integrity of the water-cooled component is sufficiently compromised by the strike, cooling water may contact molten. This contact will lead to hydrogen gas or other flammable gas evolution and formation of a flammable atmosphere, creating the potential for a combustion explosion.

APPENDIX B DOCUMENT REVISION HISTORY

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

April 2025. Interim revision. Significant changes include the following:

A. Updated process safety guidance to align with Data Sheet 7-33, *Molten Metals and Other Materials*.

B. Clarified molten release guidance within vacuum chambers such as VIM furnaces.

C. Revised explosion mitigation and prevention guidance for molten equipment.

D. Added fire protection guidance for metal powders in combustible packaging.

E. Updated loss history.

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.