# GUIDELINES FOR HANDLING MOLTEN ALUMINUM

FOURTH EDITION
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The Aluminum Association

# Guidelines for Handling Molten Aluminum Fourth Edition - 2016

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The guidelines and recommendations in this book are based on information believed to be reliable and are offered in good faith but without guarantee. The precise causes of molten metal explosions, and the conditions under which problems arise, have been long studied but are still not fully understood. The operational conditions which exist in individual plants and facilities vary widely, and thus no definitive standards exist for handling molten aluminum. Accordingly, the Aluminum Association and its member companies assume no responsibility or liability for the completeness of the data or the general applicability of the guidelines and recommendations herein, which are based on state of the art knowledge but may not be appropriate in all situations. The photographs in this publication are illustrative only and are not intended to represent standard safety practices utilized in the industry. Users of these Guidelines should adapt the recommendations herein, as appropriate, to the precise conditions of the individual facility under consideration and should always exercise independent discretion in establishing plant or facility operating procedures. No warranty, express or implied, is made of this information by the Aluminum Association or by any of its member companies.

# Foreword

The original *Guidelines* were first issued by the Aluminum Association in 1980, quickly followed by a first revision in 1982. In 1990, a second edition was published which presented information and practices available up to that time. In 2002, a third edition was released which was reflective of the ongoing evolution of molten metal safety management programs.

It is clear from the revision history noted above that practices and equipment for melting and casting aluminum are continually being modified and improved for a variety of reasons. In addition, information from industry reporting programs and research efforts spearheaded by the Aluminum Association and its member companies is continually being generated Therefore, in order to capture and disseminate updated information in these areas, these guidelines undergo periodic review and revision toward the goal of making the aluminum industry workplace safer.

This fourth edition of the *Guidelines* was prepared with technical input and review by industry representatives with considerable expertise in all aspects of handling molten aluminum. Basic information has been retained, but considerable change has been made to the organization and presentation of the subject matter. New sections have been added and the existing sections have been significantly updated and expanded to incorporate the new information available since publication of the third edition. In particular, new information has been added on 1) the management of the hazards presented by combustible aluminum dust, 2) the unique hazards of managing aluminum-lithium alloys, and 3) mobile equipment safety in the casthouse.

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# I

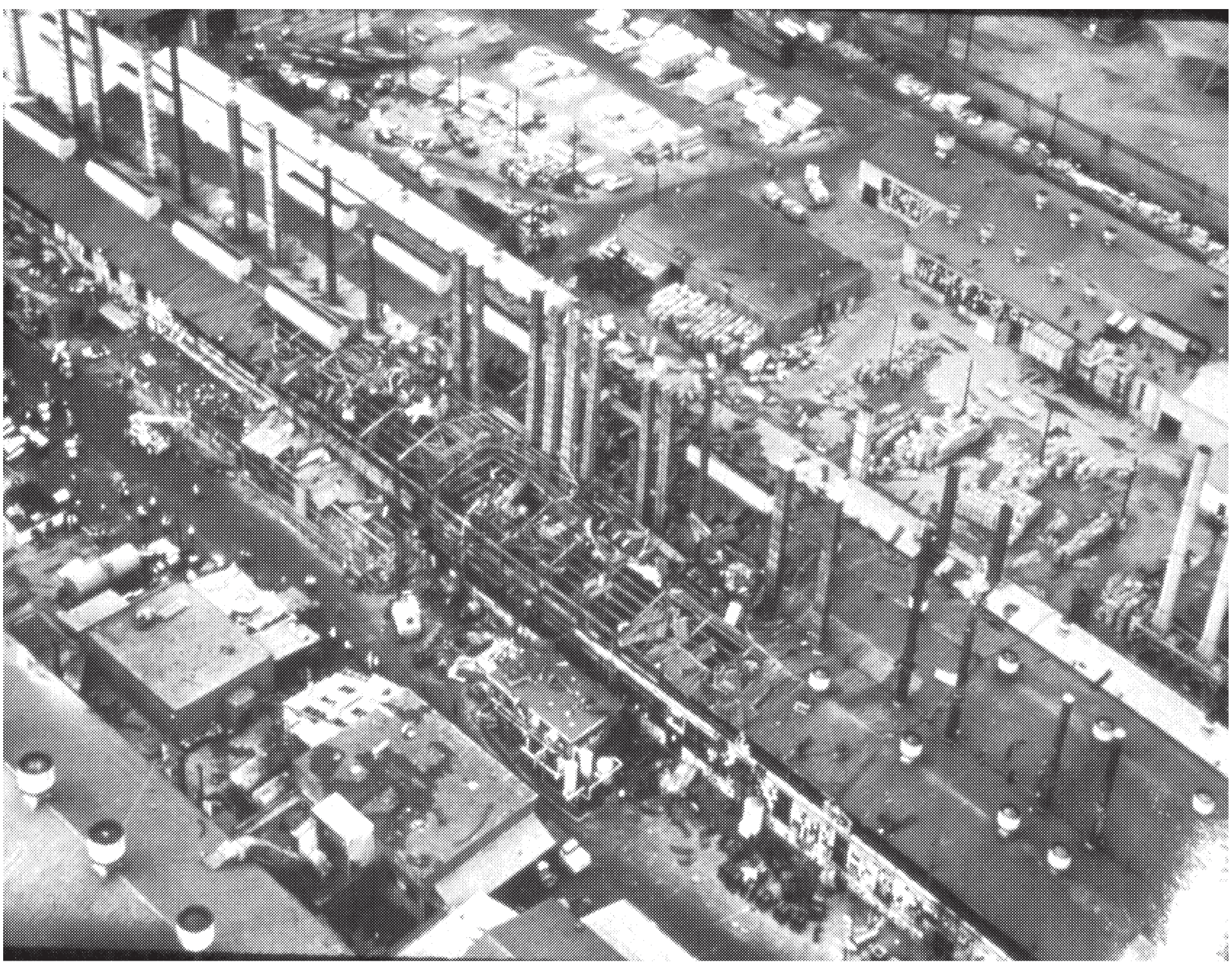
# INTRODUCTION

# Section 1
# Introduction

As evidenced by globally available injury and illness statistics gathered by the Aluminum Association and other sources, aluminum plants are relatively safe, healthy workplaces. However, every industry has its potential hazards depending on the processes and/or products involved. The aluminum industry is no exception.

Billions of pounds of aluminum are melted and cast safely every year in cast shops, foundries, recycling and reclamation plants all over the globe. However, there are inherent hazards in handling molten aluminum, just as there are in virtually any activity. These hazards can be minimized and eliminated by careful attention to safe handling practices.

Failure to use proper procedures in melting and casting aluminum can be dangerous. Contact with molten aluminum can burn personnel or set materials on fire. Mixing water and many chemical substances or contaminants with molten aluminum can cause explosions. These explosions can range widely in violence and can result in injury or death as well as significant destruction of equipment and plant facilities. Examples of the damage resulting from catastrophic molten metal explosions in the aluminum industry are shown in 1 Figure 1 and 1 Figure 2.



**1 Figure 1 – Aerial view of a casthouse following a molten metal explosion**

**1 Figure 2 – Ground level view of a casthouse following a molten metal explosion**

# Section 2
# Scope, Format, and Organization of the Guidelines

## 2.1: Scope

These *Guidelines* were prepared for use by all personnel concerned or associated with activities involving molten aluminum, and particularly for those involved in everyday plant operations. All major steps in remelting, treating, transferring, and casting molten aluminum and its alloys are discussed, excluding potline operations in reduction plants. Details are not given on specific operating practices for proprietary melting, melt treatment, and casting systems. For information on specific safety procedures for these systems, please consult the vendors of those systems.

Emphasis is placed on large-scale melting and casting practices for the production of process ingot. Slabs or billets produced are subsequently mechanically worked into forms such as sheet, plate, foil, forgings, or extrusions. Alternately, cast shapes such as T-bar, sow, and Remelt Scrap Ingot (RSI) may be produced and then shipped offsite for remelting at another site. Information is also provided on scrap remelting activities.

Terminology used in these guidelines reflects that employed in the industry.

## 2.2: Format

The wire bound format of the *Guidelines* is intended to allow the publication to lie flat for ease of reference to the information and to allow for easy copying of relevant sections for use as handouts at safety and training meetings.

## 2.3: Organization

The revised *Guidelines* consist of eleven parts. The presentation of material under headings of both general information and specific procedures results in some repetition. This was done deliberately to be reflective of the reference nature of this material so as to allow it to be read in individual sections for reference to specific information needed at a point in time rather than in a front-to-back cover to cover style as would be done in a traditional book format.

# II

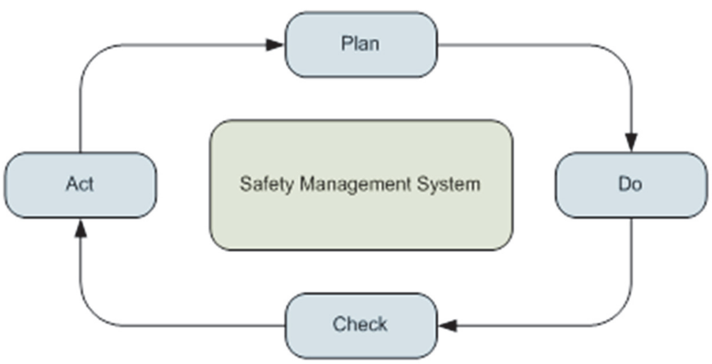
# SAFETY MANAGEMENT

# Section 3
# Safety Programs and Training

## 3.1: Safety-General

Experience shows that the best safety records in industries of all kinds exist where safety is given the same level of importance and attention as quality, production, and cost. This means safety can and must be actively led and managed to achieve a safe workplace.

As in the case of newer approaches used to achieve outstanding improvements in product quality, successful management of accident prevention goes beyond simple directives from supervision to the work force. Success in safety comes from the implementation of a safety management system that includes the fundamentals of plan, do, check and act. The diagram below represents a typical management system model.




This model represents a continuous cycle of improvement.

- One goes through a planning process to decide what safety exposures they want to reduce and determine what resources are needed to make that happen.
- One takes actions in the plan to reduce exposure.
- One evaluates the impact of the actions taken.
- One decides if the desired reduction in risk occurred or not. If yes, the cycle starts anew by revising the plan to target new exposures. If the desired risk reduction was not achieved, the plan is modified to include new actions to reduce the exposure.

This model has direct application to managing molten aluminum risk. Assume a site is concerned about a molten metal explosion triggered by putting sows that may have water/moisture on or in them into a melting furnace.

- The site should identify the risks associated with this activity in the planning phase of the management system. The site also can set objectives to reduce the risk, as well as the action items necessary to make that happen. The site will need to provide the resources needed to implement the actions.
- This is followed by taking action; one example of which could be installing sow dryers.
- Once the actions are taken, the site should then decide if the actions taken provided the risk reduction that was anticipated. In this case, did installation of dryers reduce the potential for molten metal explosions?
- Once the site knows the impact of the actions, it can decide whether it needs to take additional actions to reduce molten metal explosions.

The process does not stop at this point. Once the site is satisfied that they have reduced this specific exposure, they can move onto the next risk they want to tackle; e.g. reduce molten metal explosion risk from another source.

## 3.2: Training and Job Safety Practices

Each company necessarily has its own safety program, rules, and regulations. The following are sound, tested recommendations for consideration in these programs:

a. Operators should not work in any jobs involving molten aluminum until they have been trained in both safety and operating procedures, including emergency procedures and escape routes.

b. Standard Operating Practices and Job Safety Practices should be established in writing for all operations involving molten aluminum. It is recommended that these practices be available in the workplace for easy review by the operators. It should be the responsibility of supervision and top management to ensure that these are reviewed by operators on a periodic basis, e.g., every six months.

c. If non-English speaking persons are employed, Job Safety Practices should be available in languages other than English.

d. Operators should be required to read and sign off on pertinent Job Safety Practices before starting to work in a given job.

e. Operators and all personnel involved in melting/casting operations should report to their supervisors any and all suspect or unsafe conditions or equipment.

f. Training programs should emphasize inspection techniques for finding contaminants on materials to be charged into furnaces. All personnel involved in receiving and storing these materials as well as in melting, melt treatment, and casting operations should be familiar with the various contaminants that can create a fire, explosion or other hazard.

The details of establishing a "Safety Culture" (shared common values) within groups of employees who work with molten aluminum are beyond the scope of these *Guidelines*. However, the record again shows that the most effective safety programs are those which enlist the know how and input of workers in the development of and conduct of these programs. Consideration should be given, therefore, to techniques used in quality circles which utilize worker participation and peer engagement to achieve common goals. In this case, the goal is to establish and maintain accident free work places and prevent equipment damage wherever molten aluminum is handled.

# III

# GENERAL INFORMATION AND DESIGN CONSIDERATIONS

# Section 4
# Hazards in Handling Molten Aluminum — General

This section of the *Guidelines* presents general information useful in understanding and avoiding hazards in operations involving molten aluminum.

## 4.1: Molten Aluminum is a Hot Liquid

Pure aluminum melts at 1220°F (660°C) and is typically handled at 1350-1450°F (700-790°C) to avoid premature solidification. In addition, molten aluminum arising from reduction operations (potrooms) can be in the range of 1800°F (1000 °C) due to the nature of the temperatures required for the alumina/cryolite reactions to occur. Molten aluminum contacting any part of the human body can cause serious burns. If extensive, these burns can be fatal. Where there is the possibility of splash or other direct exposure, personnel working with molten aluminum must wear eye and face protection and protective clothing. See Section 11: Personal Protective Clothing and Equipment.

Molten aluminum contacting other materials may set them on fire. Clothing made of the commonly available synthetic materials or synthetic blends can ignite or melt, providing little or no protection against molten metal, and should not be used. While molten aluminum tends to not adhere to untreated cotton, it can set the clothing on fire if caught in a crease or fold.

Proper design of equipment and facilities, as well as observance of good housekeeping practices, can significantly minimize the chance of fires and explosions due to splash or leaks of molten aluminum. See Section 10: Housekeeping.

**Note: Entrapment of water or moisture by molten aluminum can cause explosions. Contact and mixing of molten aluminum with a number of other substances can also lead to explosions. See Part IX which deals with explosions.**

# Section 5
# Physical and Chemical Properties of Molten Aluminum

## 5.1: Emissivity

Molten aluminum has low emissivity. Aluminum does not significantly change color as it gets hot. For this reason, the temperature of molten or solid aluminum cannot be determined by looking at it. Superheating may not be detected visually, and high molten metal temperatures greatly increase the chemical activity of aluminum and the potential for explosions.

## 5.2: Viscosity of Molten Aluminum

Molten aluminum has low viscosity, or high fluidity, enabling it to flow easily through small openings and cracks. In fact, the viscosity of aluminum at normal casting temperature is about the same as the viscosity of water at room temperature. This characteristic increases the danger of leaks and run-outs. This fluid nature contributes to molten aluminum's splashing characteristics when its movement is blocked or reversed, and also contributes to the sizable skin burns that can result from splashes.

## 5.3: Heat of Fusion and Shrinkage during Solidification

Aluminum has a high heat of fusion, which is why large amounts of heat are released when aluminum goes from the liquid to the solid state, i.e., freezes. For example, molten aluminum will give off about twice the amount of heat in freezing compared to an equal weight of molten copper. Aluminum shrinks in volume about 12% as it cools from the liquid to the solid state at room temperature. The solidifying metal tends to stick tightly to materials it encounters, including human skin. Because of the high heat release and sticking, burns from molten aluminum tend to be deep, slow to heal, and extremely painful.

### 5.4: Chemical Reactivity

Molten aluminum is a highly reactive material. Its chemical reactivity increases with increasing temperature. It combines chemically with many substances resulting in the release of large amounts of energy as heat. As an example, aluminum powder is added to rocket fuels and explosives to increase the release of energy.

Molten aluminum readily converts to aluminum oxide in reaction with a wide variety of oxygen containing materials. It should be noted, however, that aluminum oxide formed in the reaction between aluminum and oxygen in air or oxygen from other sources immediately covers and "protects" the surfaces of the aluminum metal. Water, of course, is an obvious and well-recognized reactant. But of equal, if not greater, concern are contaminants inadvertently charged into a furnace, present in transfer vessels, or added as alloying elements during melting. These include:

a. Nitrates, such as ammonium nitrate fertilizer and other materials containing nitrates. Ammonium nitrate is a component of industrial and military explosives.

b. Sulfates, phosphates, chromates, and other salts containing oxygen.

c. Metal oxides such as iron oxide (rust), copper oxides, and other heavy metal oxides; also hydrated lime.

Some appreciation of the magnitude of the release of energy when aluminum is converted to its oxide can be realized by noting that the energy release in this reaction per pound of aluminum is about three times that from a pound of trinitrotoluene (TNT).

## Section 6
## Suggested Purchase Specifications for Charge Materials

Purchase orders offer the first opportunity to control the presence of harmful contaminants in materials to be added to melting furnaces. It is suggested that purchase orders specify in writing that aluminum, aluminum scrap, alloying materials, and fluxes be as free of water as possible, be free of debris, and contain no volatile materials, nitrates or other oxidizing agents which can cause an explosion when charged into a melting furnace.

An exception is the purchase of aluminum scrap in the form of borings, turnings, saw chips, fines, pit cleanings, etc. which can contain oil and water. Extreme care must be taken in processing these forms of scrap.

## Section 7
## Receiving, Inspection, Storage, and Drying of Scrap and all other Components of the Furnace Charge

As in the case of the proposed purchase specifications noted in Section 6, the goal in Section 7 is to provide guidance for each facility to devise and implement a system that covers all plant functions and cast shop related activities to anticipate and prevent water and other hazardous contaminants being present on and in materials added to the melting furnaces.

Recommended actions are given in Sections 12-19. For more detailed descriptions, refer to Aluminum Association Publication GSR, "Guidelines for Aluminum Scrap Receiving and Inspection," Third Edition (2009).

# Section 8
# Melting, Melt Treatment and Transfer, and Casting Processes

This section provides general information on these processes for those readers not closely associated with or directly involved in handling molten aluminum. More detailed information and recommendations on melting and casting operations are given in Parts V and VI.

Since the initial *Guidelines* were issued, a large number of improvements have been made in controlling and automating melting and casting operations. Also, new systems have been devised for removing dissolved gas (hydrogen) and non-metallic particles from the liquid metal. In general, these new controls, systems, and equipment are proprietary; details are available from the owners and, frequently, in the open literature such as the Light Metals volumes published by The Minerals, Metals and Materials Society (TMS).

## 8.1: Melting

Large scale melting of aluminum is usually done in reverberatory or “open hearth” refractory-lined furnaces, with capacities that in some cases exceed 200,000 pounds (100 Metric Tonnes (MT)).

Some furnaces are topcharged, in which case the charge falls directly into molten metal that may be in the furnace or onto an unmelted charge of metal. Some furnaces are charged from floor level, through doors or into a side well adjoining the hearth. In the latter case, the charge does not fall into the main body of molten metal but into a small well or connecting pool of metal.

In some installations, the aluminum is melted in one furnace (melting furnace), and transferred to a second furnace (holding furnace) for further processing such as composition adjustments, fluxing and close control of temperature prior to casting.

In the primary aluminum industry, it is usual to find melting/holding furnaces where metal from the potrooms (or cell lines) is transferred into the furnace together with process metal scrap. These furnaces are frequently of the tilting variety to provide good control over temperature and flow of metal to the casting machine and to permit rapid and complete draining.

In the secondary aluminum industry, rotary salt furnaces, side well furnaces and induction furnaces are used to melt lighter gauge secondary scrap. Drosses are typically processed in a rotary salt furnace where salt is used to separate metallic oxides from the molten metal.

**8.1 Figure 1 - Charging a Furnace from a Transfer Crucible**

## 8.2: Transfer of Molten Aluminum

For direct chill (DC) casting, molten aluminum is usually transferred by gravity from the melting furnace to the holding furnace and then on to the mold.

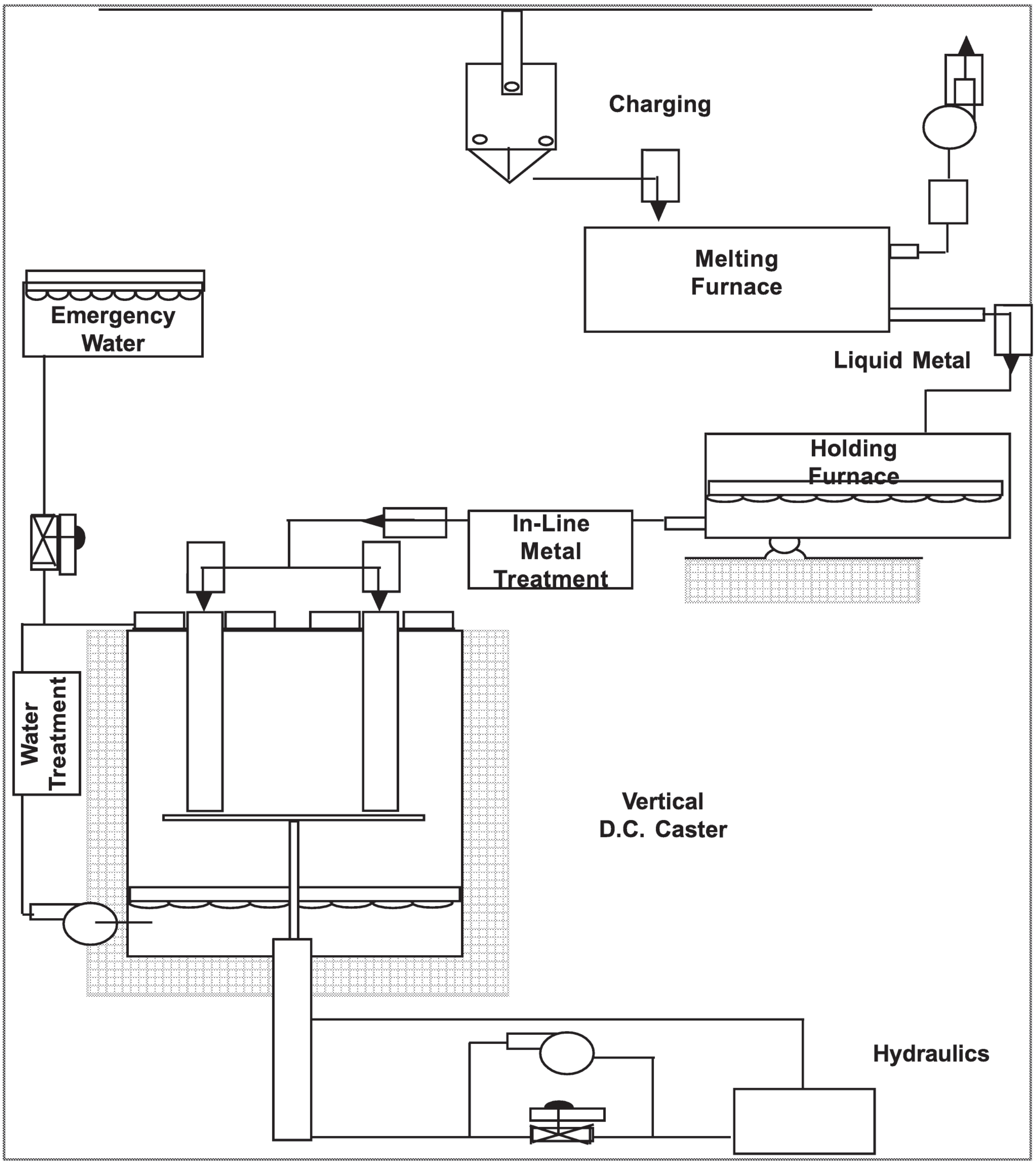
In stationary furnaces, the metal flow rate from a tap hole in the furnace is controlled by tapered plugs, whereas with a tilting furnace the flow rate is a function of tilt rate. After leaving the furnace, the metal flows through slightly sloping refractory lined troughs, or launders, toward the casting machine. The system usually includes one or more flowrate or molten metal level control devices. In some instances, special pumps may be used to move the liquid metal.

To process the metal, the melt may be treated in the furnace with a fluxing agent. Processing may also be accomplished by “inline” systems as the metal flows from the furnace to the casting station. Examples of metal processing include removal of hydrogen, trace alkali removal, inclusion removal and alloying.

A typical melting, holding and casting process is shown schematically on the flowsheet in 8.2 Figure 2.

Molten metal may also be moved from one furnace to another or to a casting station by means of crucibles and ladles. When the distance is such that excessive cooling may take place, the metal is moved in insulated containers that can be carried by trucks through the plant and over public roads.

In the case of rotary salt furnaces, the metal is usually tapped directly into crucibles or sow molds located beneath the furnace, although some salt furnaces have intermediate launders. In these cases the flow rate is controlled by the tap hole position (furnace rotation). Some rotary




**8.2 Figure 2 - Typical Melting, Holding , Casting Process Flow Sheet**

furnaces tilt and pour the molten metal out the front opening.

## 8.3: Casting

Molten aluminum is cast into process ingot in semi-continuous vertical DC and horizontal DC casting machines, and in various types of proprietary continuous casting machines. Other forms of aluminum and its alloys are cast in open, cast iron molds or sand, plaster, or steel molds.

Details of sand casting, permanent mold and die casting operations are not covered in these *Guidelines*.

### *8.3.1: Vertical DC (Direct Chill) Casting Process*

The most common method of casting process ingots is by the vertical DC casting process. In the conventional system, the molten metal flows from the furnace into a transfer trough, through a filter, through a downspout, a level control device, and a distributor into a water-cooled mold. Several ingots are usually cast at the same time.

At the start of casting, the lower opening of the mold is closed by a starting block (also referred to as a starting block, starting head, stool cap, or dummy block) typically attached to a base plate. As molten aluminum flows into the mold and as the mold fills up, the starting block is lowered at a controlled rate, as required for the size and alloy of the ingot being cast. Metal flow is adjusted to keep the mold filled. A relatively thin shell of solidified metal is initially formed by cooling through the mold wall. Additional water cooling is provided from the water jacket surrounding the mold or from another source, which flows against the hot ingot shell as it is formed, providing the "direct chill" cooling necessary to achieve complete metal solidification.

Once the ingot has reached the desired length, the flow of metal into the mold is terminated. The downward movement of the ram is stopped to allow the ingot head to solidify. The stop time depends on the cross section of the ingot and the alloy being cast. If there is still molten metal in the ingot head, the cooling water must be shut off before the ingot is dropped below the mold to avoid the possible mixing of the water and molten metal.

### *8.3.2: Hot Top / Level Pour Casting Process*

Hot Top (also called level pour) casting is a variant of the vertical DC casting process. The molten metal flows from the furnace into a transfer trough configuration and directly into the mold without the use of a downspout or individual level control device. A refractory collar is provided at the top of the mold which serves as a reservoir of hot metal to the mold during casting.

### *8.3.3: Electromagnetic Casting Process*

Electromagnetic casting (EMC) is also a variant of the vertical DC casting process. The molten metal flows from the furnace via a transfer trough through a downspout into an electromagnetic field in the shape of the product being cast. Under normal operating conditions there is no contact with the mold wall; rather, the aluminum is contained by the electromagnetic forces while simultaneously being water-cooled and solidified into an ingot. Metal level control in the mold is critical to prevent bleed outs.

### *8.3.4: Horizontal DC Casting Process*

In this process, the solidified ingot is withdrawn from the mold in a horizontal direction. At the start of casting, liquid metal enters the mold through a tundish and starts to solidify. There are a number of proprietary horizontal casting systems with differing withdrawal mechanisms, however, in many systems the metal solidifies around clinches (bolts fastened to the starting block) and, in so doing, the metal becomes attached to the starting block. At this moment, the starting block is pulled horizontally, slowly at first, then increasing to a faster and steady rate. As in the vertical process, metal flow is adjusted to suit the casting rate required. As the ingot forms behind the moving starting block, it is cooled by water. When the ingot has reached the desired length, the ingot may be sawed or the supply of molten metal may be shut off.

### 8.3.5: Continuous Casting Processes

Vertical DC and some horizontal DC casting processes are classified as batch or semicontinuous systems since ingots are cast to a predetermined length. In a truly continuous casting system, the product form is continuously "pulled" from the mold and cut to length "on the fly" and coiled in the case of sheet and rod. One such system for continuous strip casting is shown in 8.3.5 Figure 1.

### 8.3.6: Casting Pigs, Sows, and Shapes

The casting of aluminum for remelting is done in open top pig molds, usually holding 50 pounds (23 kg), or into ingot molds, usually holding 20 to 30 pounds (9-14 kg) or less of metal. The cast iron or steel molds are usually mounted on a turntable or on a continuous chain belt. Molten metal is brought to the molds through a transfer trough. A simple metering system controls the quantity of metal poured into each mold.

Sows usually weighing 700 to 2000 pounds (315-900 kg) each are typically cast by pouring molten metal into large open top molds on a turntable or rack. Sows may be cast directly from large ladles into molds. Pigging and sowing operations are shown in 8.3.6 Figure 1 and 8.3.6 Figure 2 nearby.

In foundries, molten aluminum is poured into sand, plaster, or steel molds to form a final shape. Die casting is performed by a machine that introduces the molten metal into a mold or die under pressure to produce the desired shape.

More details on the various types of casting systems, including schematics, are found in Part VI – Casting Operations.

**8.3.5 Figure 1 – One Type of Continuous Strip Casting Machine**

**8.3.6 Figure 1 – A Robotic Pig Ingot Casting Machine with Skimming and Metal Filling Control**

**8.3.6 Figure 2 – A Modern Sow Casting Operation**

# Section 9
# Considerations in Design of Equipment and Controls

To minimize risks in melting, melt treatment, and casting of aluminum, designers and installers of equipment and facilities must be aware of the hazards involved in these operations.

## 9.1: Major Hazards

The following are major hazards to be considered in design and installation of equipment and operation of facilities to handle molten aluminum:

a. Water and other contaminants on or in the furnace charge.

b. Water and other contaminants in or on the surfaces of crucibles, ladles, transfer troughs, filter boxes, furnace ledges, etc., to which molten aluminum is added.

c. Wet or rusty casting equipment, unprotected DC casting pit walls, or shallow pools of water in the bottom of casting pits.

d. Areas near furnaces, in and on casting equipment and along DC casting pit walls which allow water, aluminum fines or contaminants to accumulate.

**Note: Because of the above, automatic sprinkler systems should not be installed where molten aluminum is processed.**

e. Inadequate protection of the melting/casting plant against strikes of lightning.

f. Inadequate guarding of open pits such as DC, tilting furnace and ladle pits.

g. Overly cramped arrangement of furnaces, metal treatment and transfer equipment and casting stations and any items that can block escape routes in the event of an emergency.

h. Location of controls, shutoff devices, gas, and other service lines in places which make it difficult for the workers to respond quickly to emergency situations. Relatively small spills and leaks, if not controlled or stopped promptly, can grow and have serious results.

i. Insufficient drain pan capacity for troughs full of metal under emergency shut-down conditions.

j. Failure to calibrate critical gauges and control devices such as for drop speed and water flow rate.

k. In the case of an emergency abort, the casting system should fail in a safe manner to allow an orderly shutdown.

Each plant and its individual processes, equipment, controls, and layout presents specific requirements and challenges to the design engineer with respect to safe and efficient operations. The design engineer must also be familiar with operating characteristics of and hazards associated with proprietary processes and equipment employed or to be installed in his/her plant.

## 9.2: Standard Operating and Job Safety Practices

The designer should be intimately familiar with industry practices established for melting and casting operations. A project safety review with the operating and maintenance personnel is recommended prior to design finalization and construction.

## 9.3: General Design Considerations

Following are some suggested considerations:

### *9.3.1: Plant Layout and Equipment Design*

Facilities must be arranged and space provided for adequate escape routes in the event of an emergency. Provisions should be made for placement of tools and materials so that these escape routes can be kept clear. Additionally, auxiliary or emergency lighting should be provided to assure continuous lighting.

Controls and shutoff devices should be provided in easily accessible places and should be clearly marked.

Gas and oil lines should have provisions for remote shutoff, which should be clearly marked.

Equipment should be designed to be "fail safe" so that loss of utilities, such as air pressure, electricity, hydraulic pressure or even human energy, will permit safe termination of casting.

**Note: Warning devices should be employed to alert personnel to conditions which could adversely affect safe operations, e.g. water flow, casting speed, metal level, loss of air, loss of water.**

Hydraulic systems should be designed with remote shut off protected from molten metal spills. All units should have manual shut-offs clearly marked to be used in case of emergencies. These systems should be shielded to prevent high pressure leaks from spraying hydraulic fluid onto hot surfaces, such as molten metal or furnaces. The use of fire resistant hydraulic fluid is recommended. Some plants use water/glycol mixtures, water-soluble oil mixtures (10% oil), or phosphate esters. Fire resistant synthetic hydraulic fluids can also be used.

Electrical systems should be designed and located to protect them from heat, water, metal splash or spills from furnaces or metal treatment boxes and fumes which could adversely affect them. Air systems should also be designed to protect them from heat which can damage hoses, seals and gaskets. Some plants having basements or mezzanines put electrical switchboards and hydraulic power units at these levels so as to leave the operating floor less congested.

Wherever possible, all services to the furnaces and casting equipment should come down from above; otherwise, metal spills on the floor may surround conduit and piping and burn wiring. This may make equipment inoperative and hinder the cleanup of spills. If ground level service trenches are required in areas of potential metal spills, they should be backfilled with sand or some other insulating material to prevent molten metal penetration. Ground level openings should be protected with a curb to prevent molten metal penetration.

Screws, bolts, clamps, brackets, and other hardware requiring operator use should be designed to be handled with "fingerless hot gloves" and should be placed in a position away from metal splash. Solidified metal splash encases parts and prevents movement of components. No floor drains with traps should be located in areas where molten aluminum can accumulate in the event of a furnace or trough leak.

Whenever possible, process controls should be automated for critical functions such as metal temperature, casting speed, cooling water flow rate, trough metal level, mold metal level and process gas flow rates in order to ensure consistent safe starts and to minimize the opportunity for operator error. In designing such systems, great care must be taken to ensure process control logic and interlock devices function properly and safely. Fault tree analysis or similar methodology should be deployed to discover possible errors in process logic, especially under emergency conditions. Dry runs are recommended to test controls and alarms prior to actual casts with molten metal.

**Note: Automation for hands-free start of cast and cast shutdown is recommended as these are high risk times for personnel exposure to explosions.**

In 1986, a catastrophic explosion occurred in a plant casting aluminum process ingot that was attributed by the company to a lightning strike. Based on this incident, the company recommended that plants check their lightning protection against applicable building codes.

One organization has recommended that casting plant stacks should be connected directly to ground with two driven rods, and then interconnected to the building counterpoise system. If necessary, jumpers should be installed across any stack joints to ensure electrical continuity.

However, each facility should consider its own protective system.

### *9.3.2: Provisions for Drying/Preheating of Furnace Charge*

The provisions for drying and preheating must reflect the nature, size, etc., of the charge material. The preferred means of preheating sow, ingot, or T-ingot, which may be wet and which may contain voids, is to provide a separate preheating furnace. In one organization where gasfired ovens are used for this purpose, material to be dried is held in the oven for four hours at an air temperature of 750°F (400° C). However, each organization should develop its own drying and preheating practices reflecting the material being charged and equipment employed. See Section 15.3 for more information. Adherence to defined practices and sufficient data collection are necessary to assure that the organization's requirements are followed. It is recommended that drying/preheating ovens be surveyed at regular intervals to insure proper dry-out of the charge material.

### *9.3.3: Melting and Molten Metal Transfer Facilities*

Plants should establish an emergency plan to contain and deal with furnace run-outs. Some companies design reservoirs to receive inadvertent run-outs of molten metal from furnaces and troughs. These reservoirs may be a large crucible or a pit and must be kept dry, coated and free of debris. While the volume of the reservoir may be limited, it should provide time for corrective action to contain the metal spill.

Foundations should be designed to block the flow of runout metal to pit areas containing water or moisture if a leak or spill develops.

**Note: Concrete can spall and "explode" on contact with molten aluminum. Areas subject to frequent minor spills should be protected with materials such as firebrick or special concretes.**

Tapholes and related plugging or metal flow control equipment should be designed to minimize the possibilities of runaway type spills from these openings. Orifices should be of minimum size to meet metal flow requirements. Bath depths should be limited to reduce the metal or pressure head for plugging or control operations. Mechanically assisted tap hole systems should be considered to protect personnel. Metal detection systems for early monitoring of metal leaks should also be considered. Tap blocks should be designed and constructed of suitable materials to ensure that they will not be subject to rapid deterioration. Transfer troughs should be sized for maximum metal flow required. Spare plug rods and oversize tools should be on hand to allow plugging of the tap hole in the event of an emergency. The furnace tap hole should be located for good employee access and egress to perform the needed work.

Tilting furnaces afford an easier and safer means of controlling metal flow in transfer systems.

Combustion systems should be designed to meet the requirements of the National Fire Protection Association, Factory Mutual Insurance Companies, or Industrial Risk Insurers. Insurance companies have information on safety devices to prevent explosions involving furnace fuel and combustion systems. Furnaces used for the melting of charges coated with materials which release hydrocarbon vapors should be designed to prevent explosions as well as handle the fumes from this source.

Watercooled components, such as doors, door frames and dampers, should be designed to reduce the potential for water leaks into the furnace. These systems should be provided with open drains with no restrictions that could trap water and lead to an explosion. Care should be used to ensure that all sections of these components are water filled and that siphoning does not occur in some sections. Where possible, water cooling components should be replaced by designs where use of water has been eliminated.

Furnace components or supplementary equipment should be designed to avoid, as well as to withstand, metal splashes. Specially designed internal sills used for drying / preheating of sows or scrap should be engineered to prevent unstable stacking of the charge or unstable conditions as the sill surface deteriorates so that wet charge components do not enter the bath prematurely and give rise to molten metal splash or an explosion.

### *9.3.4: DC Casting Facilities General Considerations*

Studies with 50 pounds (23 kg) of molten aluminum at about 1400°F (760°C) dropped into water in bare steel containers indicate that, under those conditions, water depths of between three to about 30 inches (75 to 760 mm) can lead to explosions. At water levels of two inches (50 mm) or less expulsion of molten metal can occur which could cause burns. Accordingly, the design of pits beneath the casting equipment should provide for a minimum depth of three feet (915 mm) of water at all times. This should be interpreted to mean the depth of water over any residual material in the pit bottom including metal chips, aluminum sludge from bleed outs, or other debris. Many plants provide for a depth of six to ten feet (1.8 to 3 m).

All concrete and metal surfaces below the bottom of the mold that may be struck by molten metal should be properly coated and maintained with a protective layer of suitable organic material. The only surfaces that are not normally painted are sliding or rolling surfaces and the sides of starting blocks. See Part VII, Protective Coatings for Casting Pits and Equipment.

Platen assemblies (platen, base plate, and pedestal) should be designed and maintained such that water cannot accumulate. See 9.3.4 Figure 1.

Pedestals and base plates should be sloped to allow water to run off readily. A slope of 20° or greater is generally used. No flanges should be present on edges or other configurations which will allow retention of water. Some pedestal and base plates are designed with an open lattice to minimize areas of metal build-up and potential for water accumulation. In either case, metal debris that occurs after a bleed out or spill should be removed.

**9.3.4 Figure 1 – Billet Base Plate with Starting Blocks**

The design of the table top and platen assembly should be such that it prevents cooling water (and molten metal from a bleedout from an ingot, if that occurs) from running or splashing onto the shop floor.

The operating clearance from the descending platen or anything supported by it, including the ingot, should be no closer than three inches (75 mm), and preferably six inches (150 mm), from the wall or fixture. This provides space for water and molten metal to flow freely into the casting pit and prevents metal that may solidify and accumulate on the pit wall from interfering with or stopping the movement of the platen.

Additional clearance can be beneficial, and some companies provide clearances of about 12 inches (305 mm).

Vertical DC casting is done in pits with both high and low levels of water. Low level is a minimum of three feet depth (1 m) of water above the bottom of the pit or any debris that has accumulated in the bottom of the pit. The entire base plate should remain above the water in the bottom of the pit during the entire cast when the pit is operated with a low water level.

9.3.4 Figure 2 and 9.3.4 Figure 3 show typical arrangements of casting equipment in these two situations.

With the High Level Water System, overflow of water should be by gravity and designed and maintained so that overflow of water onto the shop floor does not occur. The water level above the base plate should be three feet (1 m) minimum at all times.

With the High Level Water System, provision must be made for lowering the water level regularly to allow inspection of the protective coatings on the platen assembly and the walls of the casting pit.

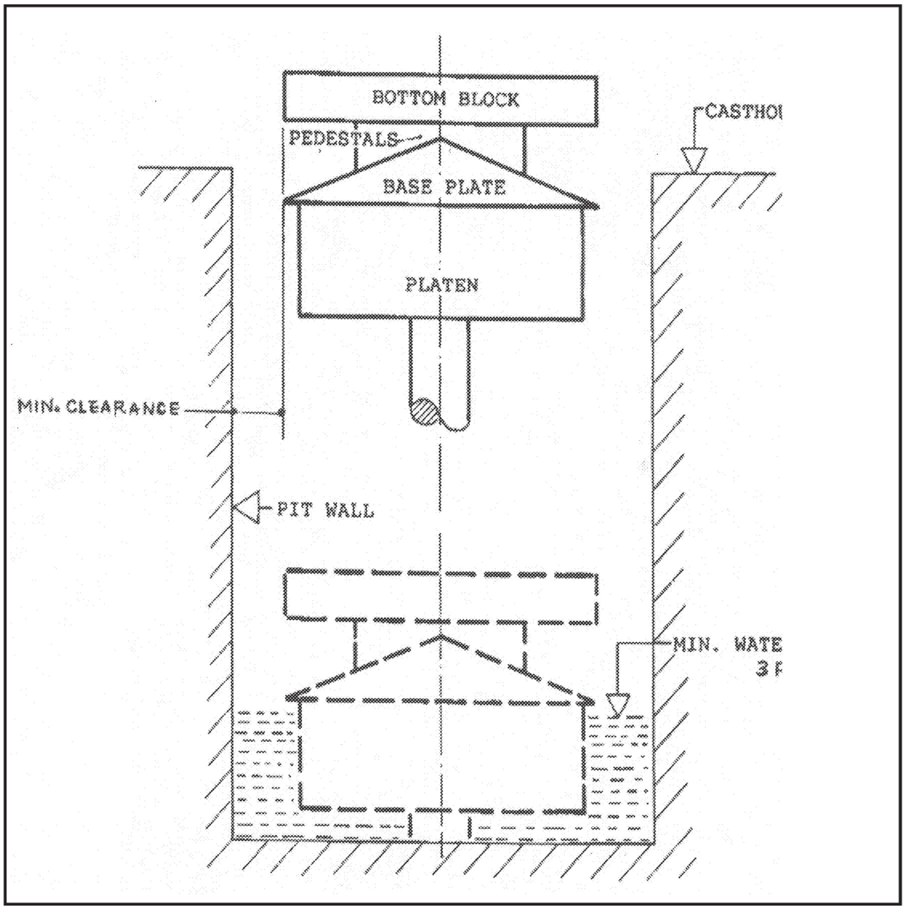
Design, installation, and operation of Hot Top/Level Pour and Electromagnetic Casting (EMC) systems require additional special consideration. See Part VI, Sections 23 and 24.

In many casting systems, the downspouts from the pouring or distribution trough are equipped with flow control pins. The design must be such that the flow of metal from the transfer trough into the mold can be closely controlled and shut off completely when necessary. When flow control pins are not used, plug rods should be available to shut off the flow in the case of an emergency.

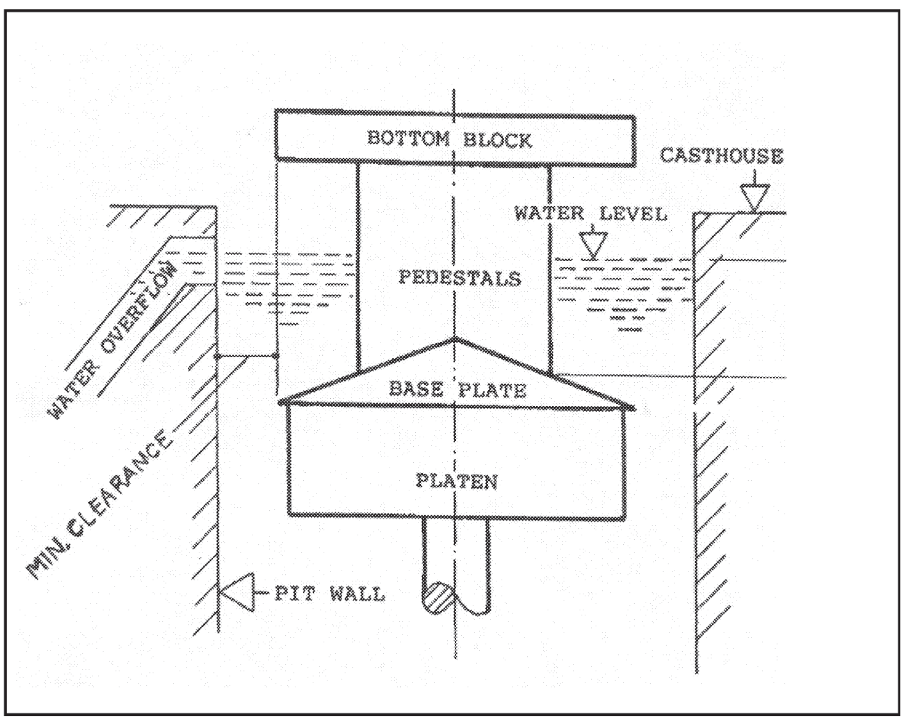
Molds should be well maintained and free of conditions that could cause ingot bleed outs or hang-ups. These include:

a. Deposits, scratches or cracks which could promote weaknesses or tears in the ingot surface.
b. Plugged water holes or slots.
c. Damaged mold bores that are 'toed-in' and would cause an ingot to hang-up.
d. Inadequate lubrication.

The phenomenon of "bumping" is caused by a steam buildup between the starting block and the butt end of the ingot. This mechanism can be minimized by adoption of drained starting blocks so as to avoid the potential problem caused by a partly solidified ingot moving up and down in the mold.




9.3.4 Figure 2 – DC Casting Pit with Low Water Level in Pit




9.3.4 Figure 3 – DC Casting Pit with High Water Level in Pit

If wipers are used for stress sensitive alloys, metal frames of wipers must be properly coated and maintained with a protective layer of suitable organic material. See Part VII, Protective Coatings for Casting Pits and Equipment. Additionally, the design and installation of wiper frames should minimize any accumulating water depth, preferably to depths two inches (50 mm) or under and ensure that the rubber wipers cannot fold double to form a pocket. If a bleed out does occur, molten metal and water might be trapped in the pocket.

The setup for casting hollow (cored) ingots is particularly critical and must be designed to ensure correct alignment between the molds, cores, and starting blocks.

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**Note: Design of equipment and operation should minimize the possibility of the metal being cast adhering to the core, causing the ingot wall to tear and the water and molten metal to mix in the interior of the hollow ingot.**

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If expendable cores are used, special attention should be given to core permeability to ensure that all moisture present in the core material is readily vented to air rather than trapped in the interior.

The factors which have the greatest influence over avoidance of bleed outs are:

a. Water distribution: This should be uniform around the mold perimeter and uniform mold to mold. This is influenced by mold and table design, but especially by mold and water system maintenance.

b. Metal Temperature: This should be within the set range for the alloy being cast and should not fluctuate outside prescribed limits.

c. Starting Procedure: The ability to control mold fill rate, casting speed, water flow and metal temperature to prevent excessive butt curl is an important aspect of equipment design. Proper starting block engagement into the mold is also an important part of the starting procedure.

d. Mold condition / lubrication: Mold surfaces need to be maintained properly. Damaged mold bores that could cause an ingot hang-up need to be repaired or replaced. Good lubrication must be maintained.

e. Mold to starting block clearances: Proper tolerances need to be maintained between the mold and starting block before starting the cast. The required gap will depend upon a number of factors including ingot size, starting block material and starting procedure. If this gap is excessive, appropriate packing of the gap should be performed. If too small, the starting block can expand against the mold and prevent lowering of the platen.

### *9.3.5: Horizontal DC Casting Equipment*

In general, this equipment involves proprietary systems with proprietary design features. However, the previously stated design considerations for safe operations apply.

The design of the drive (whether sled, pinch rolls and conveyor or other device) is critical to this process. It should provide a smooth transition from stopped to running condition. It should start and stop without jerking or pulsing. Preventive maintenance is important.

### *9.3.6: Cooling Water Systems*

Water systems need to be designed considering items such as maximum required water flow, water temperature and other factors that affect heat transfer. These include water hardness, turbidity, contamination by oil or grease, pH, and deterioration of mold heat transfer surfaces by scaling and corrosion.

The equipment should be designed for conditions that can be maintained over the operating lifetime of the facility and not for the initial facility. Since the bulk of the ingot cooling is done by the direct chill contact of water, it is essential that the flow of water at all points around the mold surface be sufficient for uniform cooling, so as to avoid bleed outs.

Cooling water piping and valving should be such that the water comes on smoothly, without surging.

Cooling water systems should be designed so that water cannot flow, spray, or otherwise leak onto areas around the furnace and casting operation where molten metal might spill. All water should go into the casting pit.

The design should provide for an emergency water supply to enable a "safe stop" of the cast in progress if the primary water source fails. If cooling water is supplied by electrically driven pumps, a power failure presents a serious hazard. In all cases, means must be provided to continue water flow with no interruption until the cast can be terminated safely. When designing the emergency supply system, consideration should be given for a worse case scenario if all casting pits were in operation simultaneously.

**Note: Emergency water supply and pressure regulation at the casting station may both be provided by using an overflowing elevated tank. Cooling water supply is pumped into the tank. The pressure of the emergency shutdown water is determined by the elevation of the tank. In case of source failure, the water in the elevated tank is the emergency supply allowing orderly and safe shutdown of the casting station.**

All water systems should incorporate visual and audible alarms to indicate abnormal conditions so that the proper precautionary steps can be taken immediately.

The emergency water supply system, including alarms, should be tested semi-annually at a minimum.

The regulator controlling the water pressure at the casting station should be capable of handling the variations in supply pressure while maintaining set-point pressure within the desired range. Ease and consistency of setting and reliability are all important considerations when selecting the regulator that controls the water pressure at the casting station.

### *9.3.7: Once Through Cooling Systems*

In this type of system, cooling water is taken from the plant water supply, through a pressure reducing station, to the casting equipment and then discarded. Environmental considerations regarding the water discharge are beyond the scope of these *Guidelines.*

Depending upon the water source and seasonal changes, provisions may have to be made for removal of solids so as to avoid blocking mold orifices. Since the water is not recirculated, there should be no increase in hardness nor pickup of oil and solids in water used for cooling.

Follow the Emergency Water Supply guidelines in the section above.

### *9.3.8: DC Casting Control Systems Safety*

It has been previously noted that in the event of hydraulic, compressed air, or electric power failure, or the operator's discretion, it must be possible to stop the cast safely. The control system failure should also be considered and should be safe in the event of any of the elements malfunctioning, i.e. sensors, actuators, communication links, controllers, etc.

This could involve:

a. dual measurement of critical variables (e.g., water flow),
b. verification that on critical actions, components will work as expected (e.g. emergency water flow),
c. in the case of malfunction, freeze control action and diverts to the failsafe condition,
d. verification that all controls are operating properly before allowing the start of a cast,
e. easy to understand operator interface with proper alarms,
f. routine regular testing of the safety control system.

Bleed outs can occur if the temperature of the metal fed to the casting machine is too high. Accordingly, a system of regulating, or at least indicating, metal temperature at the caster should be provided and the metal kept within prescribed limits.

# Section 10
# Housekeeping

## 10.1: General

Poor housekeeping can lead to serious employee injury and possible molten aluminum explosions.

A housekeeping plan should be devised and assigned to the various operating personnel. Planned inspections must be scheduled on a regular basis to identify potential problems, equipment deficiencies, and improper employee actions and to follow up on corrective actions from previous inspections. Management must demonstrate commitment and assign clear responsibilities for program enforcement.

The work area should be clean and well lit. Emergency lighting should be installed over critical areas to allow orderly shutdown in case of emergency and safe evacuation of personnel. Aisles should be open and clear, and tools should be kept in their proper places. A disorderly workplace can create an environment that generates hazards potentially resulting in injuries and accidents.

**Note: Beverage containers of all types (metal, glass, plastic), glass bottles and jars, aerosol containers and butane lighters should be banned from the melting/casting area.**

All trash must be removed from the furnace charge. Cans, bottles, and other materials can hold sufficient moisture to produce an explosion when submerged in molten aluminum. Iron scrap contaminates the melt, and rusty surfaces of casting equipment increase the risk of an explosion. Trash should be discarded only into properly identified containers. Metal drain pans must be kept free from any trash at all times.

Casting pits should be cleaned frequently. Accumulated metal reduces the effective depth of the water level in the pit.

Working floors should be kept dry. The floors should provide for proper drainage.

Aisles should be kept clear. Work floors and passageways should be kept free of protruding objects, temporarily stored material, etc. Anything that interferes with movement of personnel may prevent rapid escape during an emergency and may lead to an accident.

Furnace tools should be kept coated, dry and stored off the floor in suitable racks.

Hoses, electric cords, etc. should not be stretched across the floor areas.

**Note: Holes should be drilled in the bottoms of scrap hoppers so that water and oil cannot accumulate. Drain racks should be provided for oily scrap.**

Cylinders containing gases, such as chlorine, must not be exposed to heat. These cylinders contain a fusible plug which will melt when the temperature reaches about 150° F (65°C). Cylinders should be chained in position, the pressure on the regulator relieved, and the valve cap kept on when not in use. Cylinders should only be transported in proper carriers.

## 10.2: Cleanup of Metal Spills

Metal spills should be cleaned up immediately. Great care must be taken in using an oxygen lance in cutting up large spills of aluminum in the casting pit area or other area where water may be present. Very high temperatures are developed and superheated streams and globules of molten metal formed in the cutting operation can contact the water, which may result in an explosion.

Measures must be taken to prevent molten metal from traveling onto equipment such as electrical cables, flexible hydraulic lines, oil and gas fuel supply lines, all of which are very susceptible to fire and explosion.

More information on the management and cleanup of molten metal spills is contained in Section 27.

### 10.3: Management and Cleanup of Accumulated Fine Metallic Residues

Oxide and metal dust fines should not be allowed to accumulate over or around equipment. Periodic cleaning must be scheduled to remove and avoid risk of oxide and metal fines fires and ensuing risk of explosions. Finely divided aluminum is one of the most explosive dusts known.

Another common hazard comes from particulate generated by in-line degassing: proper design, maintenance and cleaning practices for this residue are a must to prevent fires and explosions.

See Part X for more information on the management of accumulated fine metallic residues (dusts) in aluminum casting operations.

# IV

# PERSONAL PROTECTION

# Section 11
# Personal Protective Clothing and Equipment

## 11.1: Introduction to Personal Protective Equipment (PPE)

New and improved protective clothing and personal protective equipment has been developed since the *Guidelines* were first issued and both continue to be improved throughout the aluminum industry. Severe injuries and fatalities have resulted from use of clothing that was not designed or intended for molten metal exposure. For example, synthetic fabrics like nylon and rayon will ignite and continue to burn when splashed with molten metal. It is therefore critically important to protect employees using clothing and PPE specifically designed and constructed for potential exposure to molten aluminum and radiant heat.

Although wearing the proper protective clothing and equipment will not guarantee an injury free event, it has been shown that the severity of the injury can be significantly reduced or even eliminated with the use of properly selected, designed, constructed and worn PPE.

Melting, transferring and casting of molten aluminum are all operations that involve radiant heat sources as well as molten metal. In these operations there is an ever present possibility that a worker may be contacted by molten aluminum from a splash or explosion. Since it is impossible to remove all radiant heat sources as well as molten aluminum from the casting workplace, it is essential that personal protective equipment be available and used based upon the potential exposures present.

## 11.2: Protective Clothing and Equipment (PPE)

PPE for molten aluminum operations can be grouped into two general categories: clothing and other equipment. Flame resistant (FR) clothing is described in Section 11.2.2. Various types of other protective equipment are covered in Section 11.2.3 through 11.2.7.

### *11.2.1: Selection of Personal Protective Equipment (PPE)*

The selection of Personal Protective Equipment involves:

a. an analysis of the type of hazard and the degree of exposure.
b. consideration of any mandatory standards or guidelines issued by regulatory or standard setting agencies such as OSHA, MSHA, ANSI, ASTM, ACGIH, NFPA, etc.
c. consideration for employee comfort and health.
d. an evaluation of the types of PPE available that will effectively protect the worker.

When considering protective clothing for workers exposed to molten metal and other ignition sources, many factors should be weighed. These include flammability, heat transfer, melting point of the fabric material, sticking of substances to the fabric material, durability (life of the garment), retention of the desirable protective properties of the material, ability to withstand laundering or cleaning, wearability, comfort, worker acceptance, aesthetics and costs. Even the design and construction of the garment can contribute to the severity of an injury or the degree of protection.

### *11.2.2: Protective Clothing*

The body, arms and legs must be protected against cuts, punctures, abrasions, extreme heat, extreme cold and harmful chemicals. Ordinary work clothing, if clean, in good repair and suited to the job may be considered safe in many exposures. However, "ordinary" work clothing will not protect employees from the hazards of molten aluminum.

**Understand that most normal street and "ordinary" work clothing can ignite (catch on fire) when contacted by molten aluminum. The burning clothing can cause burns to the body which are extremely painful, slow to heal, and can be fatal.**

Burns are one of the leading causes of workplace injuries in molten aluminum operations. The most serious injuries are the disabling burns that involve a major portion of a worker's body. Such serious burns are generally a result of inadequate or improper protective clothing and personal protective equipment.

Protective clothing for workers is divided into two categories.

<u>**Secondary protective clothing**</u> is protective clothing designed for continuous wear for work activities in designated locations in which the potential for intermittent exposure to molten metal splash, radiant heat or flame sources exists. Secondary protective clothing is designed so that it will not continue to burn after exposure to and removal of a source of ignition. Protection against metal splash and radiant heat are secondary in intent. Secondary protective clothing replaces "ordinary" work clothing. It may not eliminate all burns, but it should significantly reduce the number and severity of burns in the event an incident was to occur.

Secondary clothing may be made from specially treated cotton such as Banox, specially treated wool such as Zipro, wool blends such as AluSafe, or a special type of nonmelting, synthetic fabric such as Vinex. Research and development by fabric manufacturers and aluminum producers into fabric types and performance is ongoing and new materials/fabrics are constantly being introduced.

Workers should also be encouraged to wear natural fiber undergarments such as long johns, t-shirts, and socks since they will provide additional protection against burns. Most synthetic materials or synthetic blends and 100% cotton offer little or no protection against molten metal and are not recommended for use as secondary clothing.

**11.2.2 Figure 1 – Secondary Protective Clothing**

**Designed for continuous wear for work activities in designated locations in which intermittent exposure to molten metal splash, flame and/or radiant heat source is possible.**

<u>**Primary protective clothing**</u> is protective clothing designed to be worn for work activities during which significant exposure to molten metal splash, radiant heat and flame is likely to occur. Such work activities include charging, tapping, and casting, and other work which is carried out in close proximity to molten metal and hot surfaces.

Primary protection clothing consists of additional personal protective apparel such as jackets, pants, aprons, shrouds, leggings and spats that are designed and fabricated from materials capable of withstanding contact with molten metal. It is worn by workers actually working with molten metal. Primary protective clothing is worn over secondary protective clothing, thereby providing a layering effect and greater protection to the worker. Depending on the specific application, this clothing can be made from aluminized fabrics, specially treated wool, leather, or non-melting synthetic fabrics.

It is recommended that workers directly exposed to or working with molten metal in melting, transfer and casting operations wear secondary protective clothing that extends to the wrist and ankle below their primary protective clothing. Each facility should determine the area in which workers are considered exposed. Some facilities require secondary clothing whenever entering any area in the casthouse. One member company has defined "exposed" as being within 25 feet (7.5 m) of furnaces, open troughs, casting pits, pigging wheels or conveyors and similar operations involving molten metal.

During the periods of greatest molten metal exposure, primary protective clothing and equipment should be worn and where possible, exposure should be reduced or eliminated by adequately designed barrier shields that protect against frontal, side and overhead exposures.

**11.2.2 Figure 2 – Aluminized Primary Protective Clothing**

**Designed to be worn for work activities where "significant exposure" to molten metal splash, radiant heat and flame are "likely" to occur.**

When choosing or designing PPE consider the use of high visibility or reflective components so employees are more readily visible by others, especially mobile equipment and crane operators.

Once PPE requirements have been defined and implemented, any changes or modifications in the PPE system must be properly evaluated so that its intended performance is not reduced. In addition to clothing changes, this includes changes in gloves, spats, face shields, etc. Even the addition of a reflective or high visibility stripe or panel needs to be properly evaluated before being adopted for use and wear.

A cautionary note on personal protective equipment is in order. Wearing multiple layers of protective clothing, some of it heavy, in the vicinity of heat sources can contribute to the potential for a worker to experience heat stress. Employers and workers must be aware of this potential. With proper evaluation of each exposure, careful selection of protective equipment and training of employees to recognize heat stress, the potential for heat stress can be drastically reduced. Sometimes, work practices and procedures can be modified so as to reduce the length of time a worker is required to wear primary protective equipment. Other possibilities include changes in work schedules, adequate rehydration with water and/or electrolyte replacement fluids, more frequent rest breaks and use of coolout rooms.

**11.2.2 Figure 3 – Zirpro Wool Primary Protective Clothing**

**11.2.2 Figure 4 – Aluminized Primary PPE in Casthouse Use**

#### 11.2.2.1: Clothing Testing

Burns from a molten metal incident are often the result of employees' clothing being set on fire from molten metal splash. While the aluminum industry has not eliminated the occurrence of molten metal explosions, it has made considerable progress in protecting its employees. In the 1970s the Aluminum Association cooperated with the Industrial Safety Equipment Association in a series of tests in which two pounds of molten aluminum were poured on a variety of fabrics; more than 100 samples were tested in this manner. The Association then worked with the American Society for Testing and Materials (ASTM) on the development of industry standards and specifications for clothing fabrics and test methods. This led to the publication of *ASTM Standard Test Method F955-07, Standard Test Method for Evaluating Heat Transfer through Materials for Protective Clothing Upon Contact with Molten Substances.*

Beginning in 1992 the Association has held regularly scheduled workshops on casthouse safety including distribution of information on personal protective equipment (PPE) worn in casthouses and in potrooms. The Association has also sponsored an industry program to evaluate fabrics for exposure to molten metal and bath splashes without giving rise to discomfort or heat stress to the employees. Working with member companies, fabric producers and clothing suppliers, 30 fabrics for primary and secondary protective clothing were selected for testing. Splash and comfort tests were conducted under the supervision of Dr. Roger Barker of the North Carolina State University School of Textiles. The secondary protective clothing fabrics were tested both as-received (new) and after 25 laundering cycles. The results of this and subsequent testing can be found in the following reports that are available in the Aluminum Association bookstore at www.aluminum.org/bookstore –

- *Resistance of Protective Fabrics to Molten Aluminum and Bath Splash and their Comfort Properties – RPF-1*
- *Evaluation of Fire Resistant Fabrics – Molten Aluminum and Cryolite Fabric Tests*

### 11.2.3: Head Protection

For hazards of impact and penetration from falling or flying objects and electrical shock, suitable head covering should be worn. Additionally, they should have high heat resistance properties if worn in areas where high heat is prevalent. Safety headgear must meet the specifications of American National Standard 289.1, Requirement for Protective Headwear for Industrial Workers. Hard hats also have a maximum lifespan and should be replaced according to recommendations provided by the supplier.

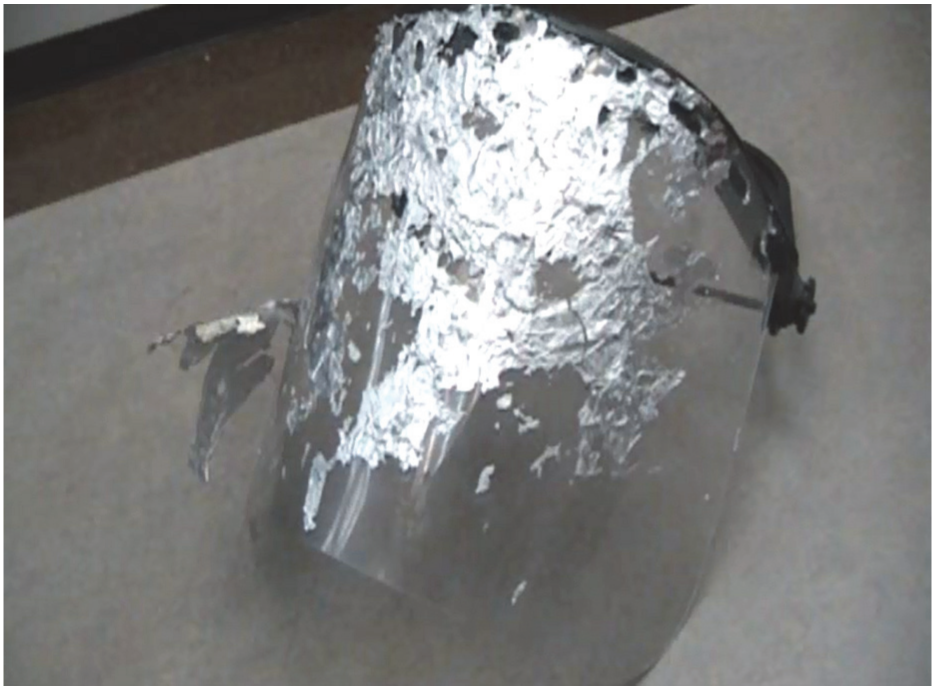
All personnel working around molten aluminum should wear a head covering. Industrial safety hard hats are required where an overhead hazard exists. Where an overhead hazard does not exist, a hat, cap, or other head covering of flame retardant material should be worn.

### 11.2.4: Eye, Face, and Neck Protection

Due to the possibility of splash and molten metal explosions, personnel working with molten aluminum must wear eye, face, and neck protection. Safety glasses meeting the ANSI 87.1 standard with side shields should be considered minimum protection against molten metal splash. Eye glass frames must be non-metallic, since burn severity will be increased when molten metal attaches to the metal frame which is in contact with the skin.

During periods of greatest exposure, such as charging, opening or closing a tap hole, starting or terminating a cast, addressing non-standard / emergency casting situations, metal sampling and skimming molten metal (e.g. during casting of billet, ingot, sows and foundry ingot), it is recommended that workers wear a face shield in addition to the safety glasses. Similarly, during these times a neck shroud made of a fabric consistent with that of a primary coat should be utilized.

Additional guidelines on eye and face protection may be found in American National Standard 287.1, Practice for Occupational and Educational Eye and Face Protection.



**11.2.4 Figure 1 - Face shield that protected employee from eye damage and facial burns during a drain pan molten metal explosion**

## 11.2.6: Hand Protection

During operations that have a potential for burn injury to the hands, industrial type, heat resistant and/or flame retardant gloves should be worn. Although cotton hot mill gloves are recommended as a minimum, there are better options available that are not cotton as it can flame-up upon contact with molten metal. Under most circumstances, gloves that minimize the opening at the wrist where molten metal might enter should be selected. Radiant heat and the overall insulating properties of gloves should always be considered when selecting gloves for use for molten metal and consideration can be given to gloves made with heat resistant fabrics such as Zetex or Para-aramid (Kevlar).

## *11.2.5: Footwear and Leg Protection*

Protective footwear should be worn where exposure to dropped objects and/or molten metal may occur and must meet the requirements specified in ASTM F2412 11 and F2413-1. Laceless safety toe boots or pourer's (molders) boots are recommended for molten metal exposure. These shoes can be removed easily and rapidly in an emergency because they have no fasteners.

Laced footwear worn around molten metal should be covered with spats to prevent them from collecting the molten metal. As a precaution, laces, if permitted, should be constructed of materials that will burn through rapidly allowing for quick removal of the footwear if contact with or submergence into molten metal occurs.

Where there is a potential for molten metal to enter the top of the footwear, or where lower extremities are exposed to molten metal splash, leggings with spats should be worn.

Safety toe footwear with metatarsal guards should be worn where there is danger of falling or rolling objects striking the top portion of the foot.

## *11.2.7: Respiratory Protection*

Normally, respiratory protection is not necessary in casthouses or foundries. Occasionally, however, there may be a leak of chlorine gas which is used in the degassing of molten metal. Where the chlorine concentration is less that 5 ppm, an air purifying respirator equipped with the appropriate cartridges or canister may be used. In situations where exposures exceed this level or repairs are being made and the concentrations are unknown, employees should be provided with full face piece self-contained breathing apparatus operating in the pressure demand mode.

Each employee who might be required to wear a respirator must be medically qualified to wear a respirator and trained regarding the proper fit, use, and care of the respirator. (See OSHA Standard 29CFR 1910.134.) In addition, all emergency use respirators (e.g., SCBAs) must be inspected monthly and records kept of the results.

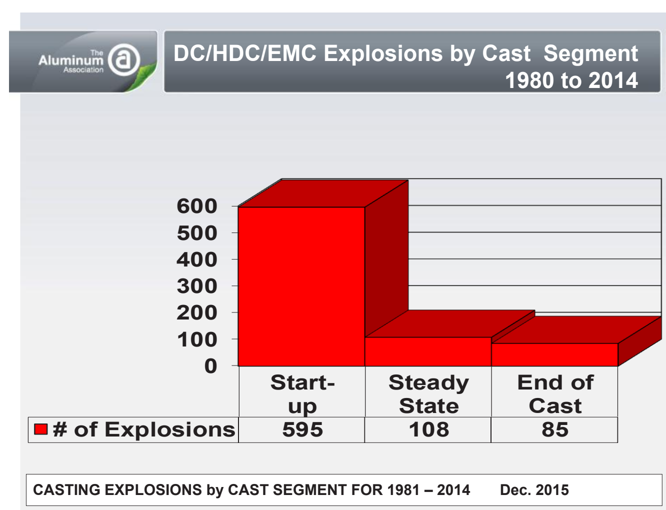
**11.3 Figure 1 - FR garments worn by employee exposed to molten metal from a drain pan explosion. Use of FR garments minimized the extent of burn injuries.**

## 11.3: General Recommendations Regarding Casthouse PPE

a. Know and follow your company requirements (safety rules) in regard to head protection, eye, face and neck protection, foot and hand protection, and protective clothing as applied to casthouse operations and also when performing or being in close proximity of operations that directly involve molten metal and molten metal contact.

b. It is important that all the primary and secondary PPE be worn when working directly with molten metal in operations such as melting, fluxing, skimming, transferring, sampling and casting. This should also include all personnel that are in close proximity to these activities, not those just directly working with the molten aluminum. It is also important that this PPE be in good condition and worn properly (e.g. clothing free from burn holes, wearing shirts closed around the neck and having face shields in the down position).

c. Wearing the primary and secondary PPE is important during casting operations, especially at the start and end of the cast and whenever addressing an emergency or non-standard casting condition, even if that occurs during the "steady state" portion of the cast. The start of cast is the period in casting operations when most explosions occur and therefore when the most protection is needed. At a minimum, primary

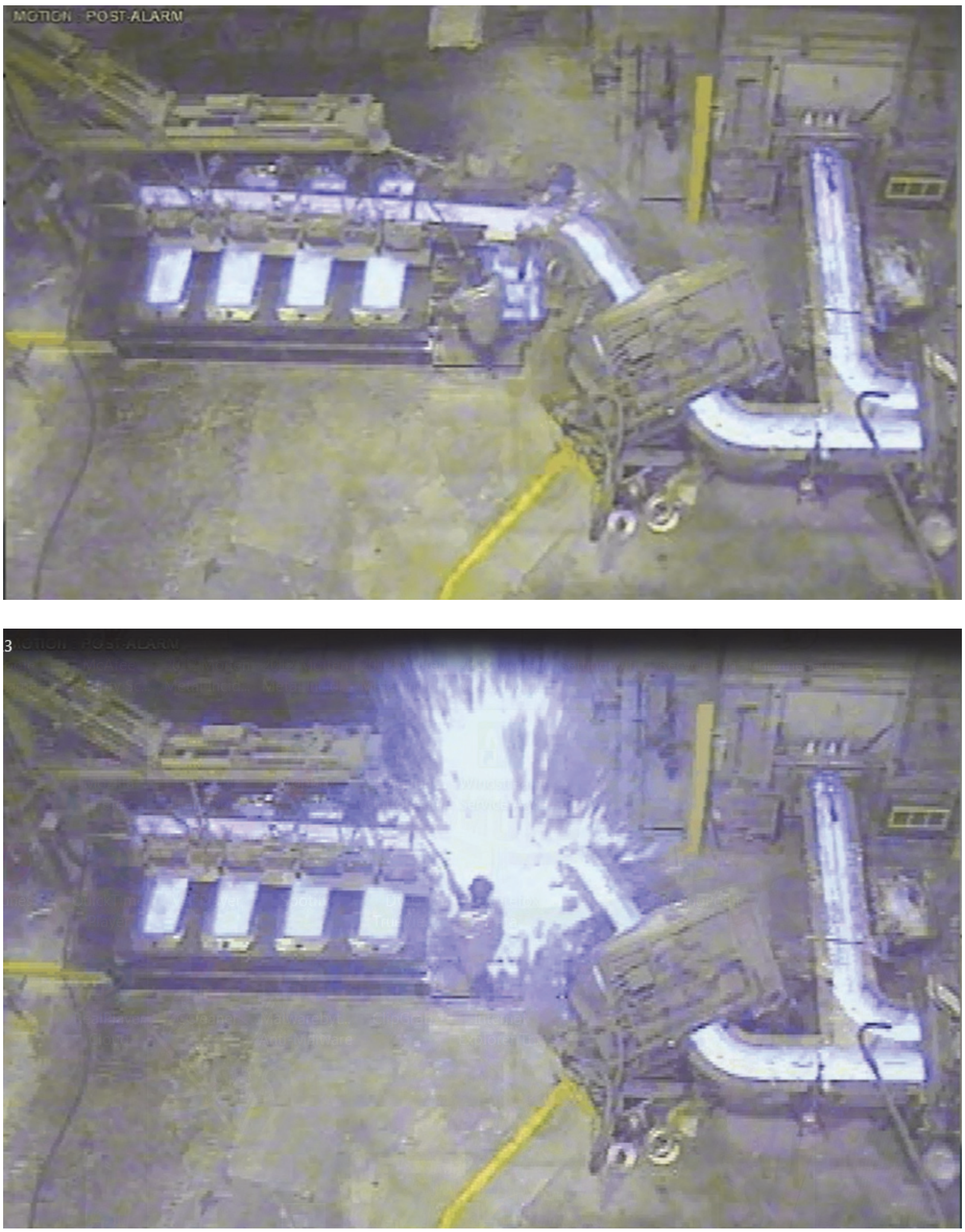


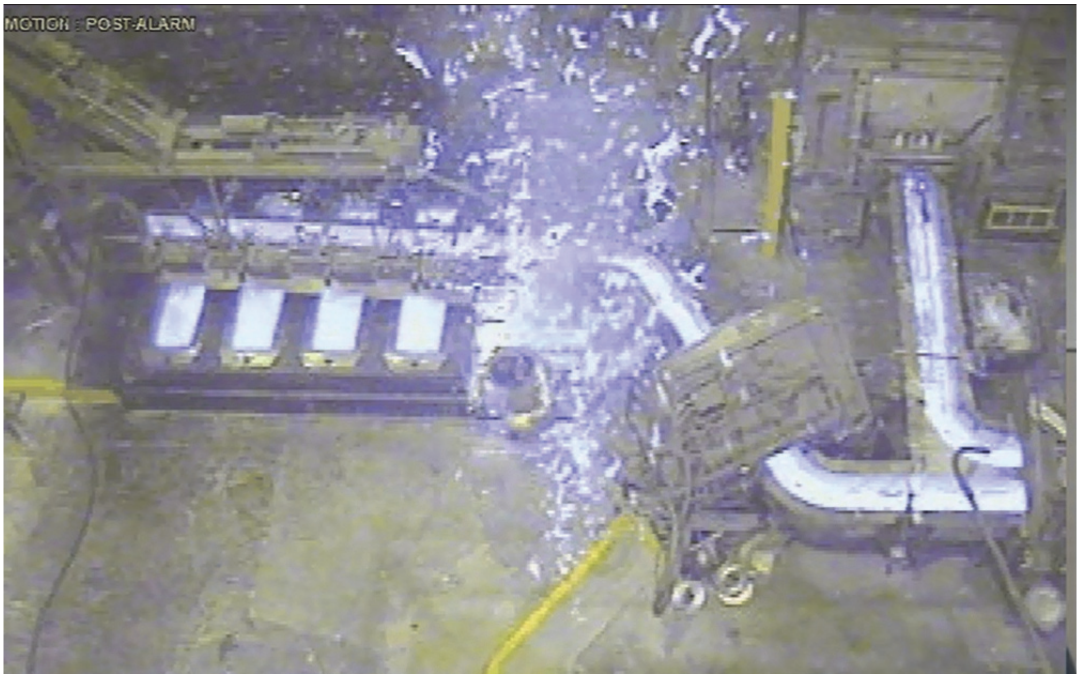

**11.3 Figure 2 – Graph of Casting Explosions by Casting Segment**

protective clothing should not be removed until the cast is considered to be in "steady state." The importance of PPE protection at the start of the cast is supported by Aluminum Association explosion data as shown nearby. From 1980 to 2014, there were 595 explosions reported during casting start. Additionally, there were 108 steady state and 85 end of cast explosions. Of those reported explosions, 66% resulted in minor injuries, 30% resulted in serious injuries and 4% were fatalities. Since employees are typically very close to molten aluminum during the start and end of cast, the risk of injury is great.

d. All visitors entering the plant work areas should be required to wear personal protective equipment appropriate for the exposure they will experience. The plant should maintain an adequate supply of personal protective equipment and clothing for loan to visitors.

**11.3 Figure 3 - Photo sequence showing an end of cast drain pan explosion in progress. Use of proper PPE prevented significant employee injury.**







## 11.4: Establishing a Personal Protective Equipment (PPE) Program

Steps to developing and implementing a PPE program to protect workers against job hazards include:

a. defining the areas and/or operations where the protective equipment must be worn;

b. determining the type of PPE suitable for the various exposures;

c. establishing procedures for issuing and replacing damaged or defective equipment;

d. establishing procedures for cleaning, maintaining, sanitizing and servicing of the equipment;

e. training employees in the proper use and care of the protective equipment;


f. establishing procedures for obtaining and maintaining an adequate inventory of the proper equipment;

g. auditing and amending the program as necessary to accommodate changes in the operation, the hazards or the exposure.

# V

# MELTING, MELT TREATMENT, AND TRANSFER OPERATIONS

# Section 12
# Receiving, Inspection, and Storage of Materials to be Melted

## 12.1: Receiving and Inspection

Upon receiving materials to be melted and/or added to molten metal, inspect the materials and shipment containers, including trucks and railroad cars, for signs of contamination. Materials to be melted include aluminum ingot, sow, RSI, all forms of scrap including billet, cast slab or ingot, alloying elements and master alloys, grain refining alloys, and salt fluxes. Suspect all foreign substances in any of these materials as being harmful. For a more detailed explanation, refer to Aluminum Association Publication GSR, *"Guidelines for Aluminum Scrap Receiving and Inspection Based on Safety and Health Considerations"* Third Edition (2009).

Particularly hazardous contaminants are:

a. Residual fertilizers (ammonium nitrate for example), dry fire extinguisher powder, chemicals such as nitrates and sulfates and all "oxidizing materials." Oxidizing materials are those which readily release oxygen in contact with molten aluminum, such as nitrates, chlorates, perchlorates, permanganates, chromates, and phosphates. Any powdery material should be suspect.

b. Water or other volatile substances whether in solid or liquid form.

c. Heavy grease and oils.

d. Garbage / trash such as cans or bottles that may contain some residual liquids.

e. Salt fluxes which contain nitrates, sulfates, and oxidizer chemicals.

f. Corroded or oxidized material.

g. Crimped or closed end pieces of tubing, extrusions or containers which may contain water.

h. Scrap contaminated with hazardous or toxic materials such as PCBs, selenium, lead, cadmium and radioactive materials.

i. Miscellaneous contaminants such as batteries, butane lighters, live ammunition, airbag detonators, fire extinguishers, medical waste (hypodermic needles, syringes, IV bags, etc.) and aerosol cans. Some of these can be explosive in shredders as well as in furnaces.

If any contamination is found, the material lot should be properly tagged and isolated until the contaminants can be identified and removed, or the material should be rejected. Immediate contact with the supplier and/or freight company may help identify unknown substances.

The use of an incoming inspection check list containing the factors noted in a-i above by trained and experienced receiving personnel is recommended.

## 12.2: Storage of Materials to be Melted

After incoming inspection, materials should be stored inside and under conditions which keep it dry and prevents contamination, including accumulation of moisture. Storage facilities should be designed to allow ready access to all scrap and other materials for melting and to prevent unusually long holding periods for materials that may be susceptible to substantial oxidation. Magnesium and magnesium alloys are especially susceptible to oxidation.

Ensure that inside storage structures are kept in good repair to prevent water contamination of charge materials by rain, snow, leaks, etc. Materials should be stored away from exterior walls and open doors. Additionally, moisture can condense on stored materials due to changes in atmospheric conditions. Stored material needs to be monitored for this potential hazard.

If material must be stored outside, it should be thoroughly inspected prior to charging and measures must be taken to ensure the material is dry prior to charging. See Section 14 for more details on drying practices.

# Section 13
# Pre-melting Precautions

## 13.1: Pre-melting Precautions

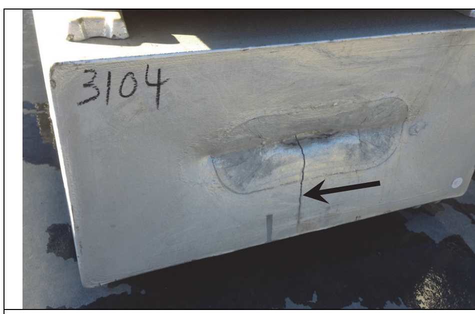
Water and other materials on or in the charge are known to cause explosions when submerged below the molten metal surface. This is also true of moisture or foreign material on tools inserted into molten metal. Do everything possible to guard against this situation.

### *13.1.1: Scrap, Remelt Scrap Ingot (RSI), Billet, Cast Slab, Ingot or Other Material That May Have Cracks/Cavities*

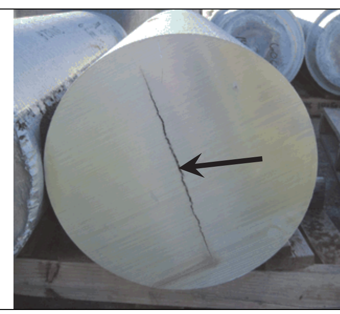
Inspect all scrap prior to charging for contamination such as foreign materials and moisture. Moisture in shrinkage cavities and cracks is not necessarily obvious; therefore suspect all material as potentially contaminated. Ensure that company procedures for inspection, drying and/or storage are followed. Purchased scrap of all varieties (bulk, baled, boxed or loose) should be considered contaminated due to its unknown storage, handling and origin and because visual inspection is difficult. Look for ice, snow, condensation or deposits of grease and oil. Lubricants used during the sawing of T-bar, billet or other ingots may reside in cracks. Remove all pieces of ferrous scrap, other metals and non-metal contaminants. Do not charge scrap or ingot that is suspected of foreign material contamination or moisture. Crimped tubing, extrusions, containers, etc. can be a hazard if they contain moisture or other contaminants. Ideally, tubing and other suspect scrap should be shredded and dried prior to charging. Double or multiple poured RSI should be rejected or melted in a dry hearth. Double poured or multiple poured sows may contain moisture that cannot be removed by a drying process. Never charge double or multiple poured sows into molten metal.

If salt has been used in the production of RSI, salt contamination on the tops of the sows is likely to be present. It is important that these sows be checked prior to charging to ensure that no moisture is present since salt fluxes tend to be hygroscopic in nature (they absorb water from the air). RSI produced by a salt process should not be charged into molten metal without first being dried according to company procedures and subsequently kept at an elevated temperature to prevent salts from absorbing moisture. For more information regarding hygroscopic salts and RSI see the following: *"Evaluating RSI Sows for Safe Charging into Molten Metal"*: Niedling, Jake J. and Scherbak, Michael, TMS 2003.

Remove all cans and bottles from the charge. If they contain water or other liquids, these containers are likely to cause explosions when submerged in molten metal. For additional information regarding safe charging into melting




Cracked sheet ingot



Cracked Billet

High profile sow with shrinkage cavity


Double poured low profile RSI

**13.1.1 Figure 1 - Examples of cavities, cracks and double poured sows that can contain moisture.**

furnaces see: *"Safe Charging of RSI (Remelt Secondary Ingot) and Other Ingot Shapes into Melting Furnaces"* Zeh, J. L, TMS 2005.

### *13.1.2: Primary Sow, Ingot and T-Ingot*

Primary sow, ingot and T-ingot should always be considered 'wet' when received by a plant. Moisture in shrinkage cavities and cracks in these products are not generally obvious and must be recognized as potential sources of hidden moisture. Primary sows that are being used by the producing plant can be considered 'dry' provided they have always been stored indoors under the required conditions that maintain them as 'dry' (See Section 12.2 above; Storage of Materials to be Melted). Ingot and T-ingot being used by the producing plant may potentially have cracks with moisture and need to be treated as such. Lubricants used during the sawing of T-ingot, billet or other ingot may reside in cracks. Additionally, changes of indoor atmospheric conditions can produce moisture condensation or "sweating" on any metal surface.

Primary sow, ingot and T-ingot can be charged safely into molten metal if they have been dried properly and stored indoors properly after drying (See Section 12.2 above; Storage of Materials to be Melted and Section 14, Drying Of Material Charged into the Furnace). Primary sow, ingot or T-ingot that have cracks that have been closed by hammering are particularly dangerous and cannot be dried properly for charging into molten metal and should always be considered 'wet'.

Details on primary sow handling and melting are provided in Section 15 and in Aluminum Association Publication GSC, *"Guidelines for Aluminum Sow Casting and Charging".*

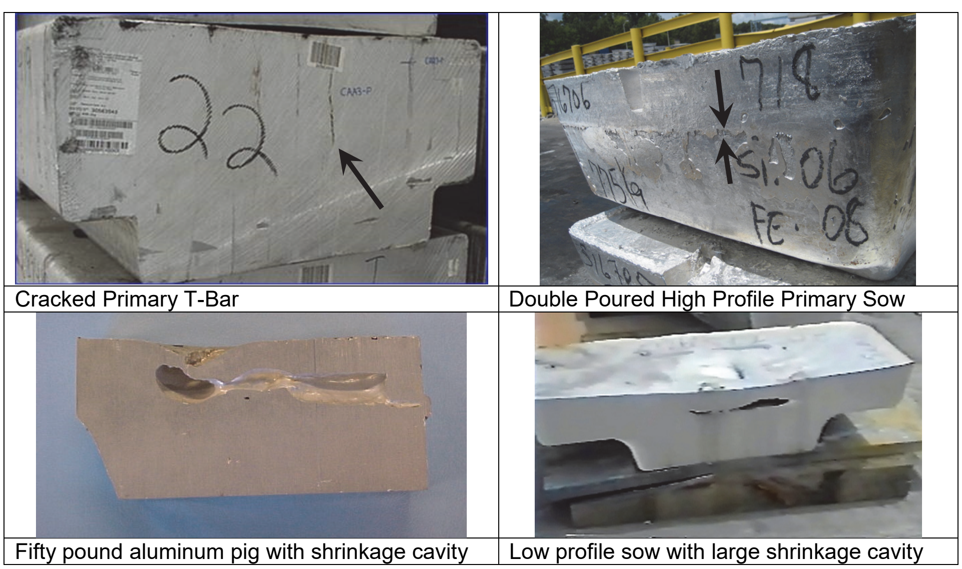
### *13.1.3: Alloying Material*

Ensure that alloy additions are clean and dry. Some of these materials may have heavy surface oxides and other contaminations that can produce a thermite reaction on contact with molten aluminum. Heavily oxidized copper, iron, steel, lead, bismuth and magnesium are all capable of a thermite reaction with molten aluminum.

Alloyed sow has the same potential to contain shrinkage cavities as noted above for primary sows, RSI and magnesium. Therefore this material needs to be charged into a dry hearth or dried and stored properly to avoid recontamination before being charged into molten metal.

Magnesium ingots should be free from oxide and corrosion which may contain moisture. Since magnesium is added directly to molten aluminum, it is imperative that it be dry and clean. All magnesium ingots should be dried as specified in the supplier Safety Data Sheet (SDS). Just as with other charge materials, water vapor will condense on the surface of a metal if the temperature of the metal is below the dew point of the surrounding air. Beware of desiccant packets or heavily oxidized ingots that may be inside bundles of small magnesium ingot.

Light gauge copper scrap, when heavily oxidized, can be particularly dangerous because it is difficult to dissolve and may be dragged from the furnace when skimming; this may result in a thermite reaction followed by an explosion outside the furnace. Even unoxidized light gauge copper wire or other fines can cause a thermite reaction explosion if it floats on top of the bath and oxidizes.




Cracked Primary T-Bar | Double Poured High Profile Primary Sow | Fifty pound aluminum pig with shrinkage cavity | Low profile sow with large shrinkage cavity

**13.1.2 Figure 1 - Examples of cavities and cracks that can contain moisture and a double poured sow.**

Zinc ingots may contain significant shrinkage cavities. Zinc ingots must be dried and stored at a temperature that prevents recontamination by water. As with other materials, water vapor will condense on the surface of a metal if the temperature of the metal is below the dew point of the surrounding air.

Alloying materials should be examined for the presence of fluxes that may contain sulfates, nitrates, or other oxidizing chemicals which can react explosively with molten aluminum.

### *13.1.4: Furnace Tools*

Keep alloying, skimming, stirring and sampling tools clean and dry. Preheating of furnace tools is especially important in processes where salt fluxes are used (see Section 13.1.6) or in processes that generate salt. Salts adhering to furnace tools can absorb moisture between uses and explode when re-inserted in molten metal. Keeping tools clean, dry and heated before use will minimize the chance of explosion. The best practice is to store all furnace tools off the floor. For more information regarding hygroscopic salts and skim tools see: *"Preventing Molten Metal Explosions Related to Skim Tools and Salt":* Williams, E, Richter, R., Stewart, D., and Niedling, J. - TMS 2005.

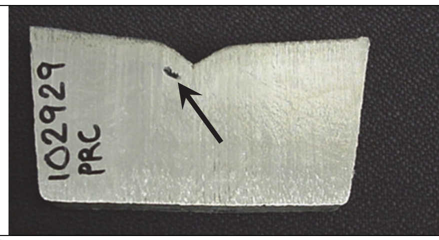
If coated with a refractory wash, apply the coating while the tool is hot so that the tool itself does not oxidize; **never coat furnace tools with lime.** Dry the tool completely after applying the wash. If tools are allowed to stand after coating they may pick up moisture; always preheat tools before use. A new tool that has never been used or one that has recently been coated with a wash should be preheated thoroughly.

Furnace tools with hollow components must be vented.

Particular care should be used with phosphorizers and tools used to add lead and bismuth because the oxides of these metals can cause a thermite reaction with molten aluminum. Avoid build-up of lead and bismuth on the tools.

Remove all aluminum and skim from furnace tools before any welding repair on the tool, otherwise a thermite reaction could take place.

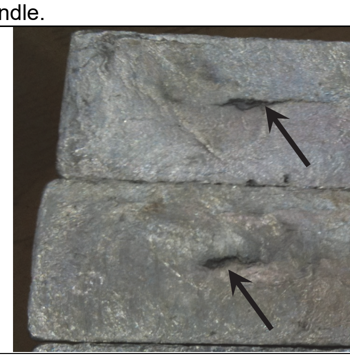
**Note: Welders should wear the appropriate PPE which will provide protection to the hands, face and body.**




Seventeen pound magnesium ingot slice showing a shrinkage cavity.

Corroded magnesium ingots inside a bundle.

Corroded / oxidized copper wire.



Corrosion around shrinkage of 25 pound magnesium ingots.

**13.1.3 Figure 1 - Examples of oxidized copper and magnesium, magnesium shrinkage cavity.**

Zinc ingot showing shrinkage cavity.

**13.1.3 – Figure 2 Example of a zinc ingot with a shrinkage cavity**

### *13.1.5: Melting and Holding Furnace Temperature Controls*

Experience has shown that aluminum becomes increasingly reactive with other materials, including air, water, refractories, etc., at temperatures above 1450°F (785°C). Higher metal temperatures can also result in furnace lining failure and molten metal leaking out of the furnace. Do not overheat metal in the furnace and maintain the refractory lining to the original design thickness.

Routinely audit temperature control devices for proper operation. Always keep the metal temperature under control and as low as practical.

Overheating of metal in the furnace can occur if temperature control is accomplished by a thermocouple placed at the bottom of the furnace. Top to bottom temperature gradient may be reduced by mechanical stirring, flux gas diffuser stirring, electromagnetic stirring or metal pumps. Beware of time delays and ensure that metal does not overheat because of delays. A basic PLC controller should be used to control the burners, monitor the molten metal temperature and provide an alarm when it exceeds the programmed temperature set point.

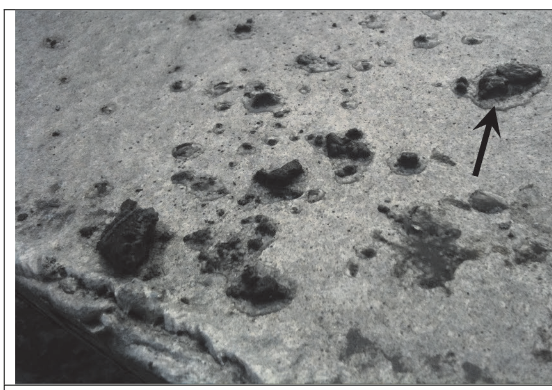
### *13.1.6: Salt Fluxes*

Salt fluxes are almost always hygroscopic, meaning that they will absorb moisture from the atmosphere. Therefore, flux bags that have been broken or damaged such that they have been exposed to the atmosphere should be discarded. Charging opened bags of salt flux into molten metal has the potential for producing an explosion. Make sure that salt fluxes do not contain nitrates, sulfates, and other oxidizer chemicals. This is particularly important in reclamation operations where large amounts of fluxes are used and mixed with molten aluminum. Make sure that workers can read and understand the labels describing the contents of containers in which fluxes are received. Do not store fertilizers or other oxidizers with flux materials.

## 13.2: Pre-melting Check List

a. Scrap & RSI, Billet or Other Material with Cracks or Cavities

1. Remove all foreign material. Be suspicious of all material.
2. Ensure that scrap material was dried and/or stored according to company procedure. Scrap that has been dried and allowed to cool below the dew point may pick up moisture.
3. Examine scrap material for moisture, water, ice, snow or heavy deposits of grease and oil.
4. Remove all pieces of iron, steel and other metals.
5. Examine crimped tubing and extrusions for moisture or other contaminants.
6. Inspect RSI sow for salt contamination and moisture. Salts can absorb and attract moisture quickly after cooling. See 13.2 Figure 1 Salt flux on the surface of an RSI sow. See also 13.1.1 regarding charging RSI produced by a salt process.
7. Double or multiple poured RSI should be rejected or remelted in a dry hearth.



Flux salts on top of RSI. Water is pooling around the salt

Flux salts imbedded in the end surface of RSI

**13.2 Figure 1 Salt flux on top of and imbedded into RSI. The dark material identified by the arrow was found to be flux salt.**

8. Remove all trash, cans and bottles and crimped tubing.
9. Do not charge scrap coils with fiber cores as unseen moisture in the fiber core can become trapped, explode, and propel molten aluminum from a furnace.

b. Primary Sow, Ingot and T-ingot,

1. Look for moisture on the surface.
2. Look for contaminants on the surface.
3. Ensure the material has been dried and stored properly.
4. Double or multiple poured primary sows should be rejected or remelted in a dry hearth.

c. Alloying Material

1. Alloy additions should be clean and dry without heavy surface oxides and other contaminants.
2. Ensure that the alloying material is dry and stored according to company procedures.
3. Avoid dragging oxidized copper from the furnace when skimming because thermiting could occur.
4. Avoid alloying material coated with or contaminated with fluxes which can contain water or oxidizer chemicals.
5. Avoid alloying, including alloy dilution operations, into a furnace with a molten metal temperature of 1500°F (810°C) or greater.

d. Furnace Tools

1. Keep tools clean, dry, and stored off the floor.
2. Never coat tools with lime.
3. Dry tools after coating if a refractory wash is applied.
4. Always preheat tools prior to use and submerging them into molten metal, especially when used for the first time and after a refractory wash is applied.
5. Avoid the buildup of oxides on tools from metals such as lead and bismuth.

e. Salt Fluxes

1. Make sure that fluxes do not contain nitrates, sulfates, and other oxidizer chemicals.
2. Keep fluxes dry. Sealed plastic bags should not be opened prior to charging.

f. Furnace Temperature Control

1. Do not overheat metal in the furnace because of increased explosion potential and the risk of lining failure. Avoid alloying and charging into a furnace with a molten metal temperature of 1500°F (810°C) or greater.
2. Routinely audit temperature control devices.
3. Always keep metal temperature in the furnace under control.
4. Avoid high temperature gradients through the metal bath.
5. Beware of delays and the impact on metal temperature.
6. Metal bath thermocouples are preferred for furnace temperature readings.

## Section 14
## Drying of Material Charged into the Furnace

The capability to dry scrap or other charge materials such as primary sow, T-ingot and alloying agents (especially magnesium) possibly containing moisture is a critical feature of a safe operation. The drying practices utilized by different facilities vary greatly with varying equipment and procedures. Follow your company's practice.

Any material to be melted which has been exposed to outside weather conditions should be dried, if possible. If drying is not possible, one of various options for safe charging should be followed. These include:

a. Charging into a dry hearth (no molten heel)
b. Charging onto a molten heel that has been solidified by either cooling the furnace or by charging known dry material to freeze the molten heel.
c. Charging wet material onto a sufficiently large bed of dry scrap that has been previously charged into a molten heel; provided the charging is performed in a manner so that the wet material will not fall or tip over into the molten heel when charged and will be dry prior to entering the molten heel during the melting process. **It is important to note that this method of charging has risks associated with it which have been noted on a number of occasions when explosions have occurred due to wet charge material falling prematurely off the dry scrap bed and coming in contact with molten metal.**

Even material that has been dried some time before melting can be hazardous if the material is not stored in a warm area. Water vapor will condense on the surface of a metal if the temperature of the metal is below the dew point of the surrounding air.

Severely oxidized or corroded sows should be rejected, melted in a dry hearth or charged on top of other charge material so that they do not contact molten metal. The corrosion products may seal off the original vents between the shrinkage cavity and atmosphere and prevent proper drying. Additionally, the corrosion product may pick up and hold moisture from the atmosphere. Oxidized or corroded RSI, sows, or ingot must not be charged into molten metal.

### 14.1: Drying Systems

There are numerous types of drying systems utilized in the industry. The systems include dryers that are separate structures just for that purpose, heat treatment furnaces utilized as dryers as required, portable burners on stands, and many other methods. It is up to the individual operation to select the best drying alternative for their application.

### 14.2: Drying Criteria

Regardless of the drying system utilized, the material type and its loading pattern are important considerations in the drying process. Adequate spacing and surface exposure are important to assure proper drying of all of the material. Practices should be developed and utilized with these considerations in mind.

The practice of using the ledge inside the melting or holding furnace as a means to dry the charge material is not recommended. The material can easily fall over into the melt during the loading process or during preheating. If this practice is used, then extreme care should be taken to prevent the material being dried from being charged too soon or prematurely falling into the molten metal bath. This is particularly important in the case of sows, RSI, T-ingot and ingot bundles. This process will actually result in moisture initially condensing on the materials surfaces due to the products of combustion and the high dew point in the furnace.

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**Drying material on the furnace ledge has been identified as one of the primary causes of molten metal explosions.**

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Routine audits, maintenance and drying furnace surveys using production load configurations and actual practices is recommended to be performed on a regular basis to ensure all material in the load is being dried to minimum standards. All material that has been dried needs to be clearly marked and identified.

**14.1 Figure 1 - Example of a commercially available sow drying system. The system shown is a natural gas fired dryer with positive pressure and recirculation fans.**

# Section 15
# Handling and Processing of Sow, T-Ingot and Billet

The term sow is applied to large castings of aluminum produced when molten aluminum is solidified in heavy steel or cast iron molds. Sows usually range in weight between 700 and 2,000 pounds (315 and 910 kg). The most common size is 1500 pounds (680 kg).

Because of the considerable contraction when aluminum goes from the liquid to the solid state at room temperature (about 12%), these large castings tend to contain internal shrinkage cavities; see Figures in Section 13.1. The size of the shrinkage cavity usually increases with the thickness of the sow. Further, these internal voids tend to be connected to the exterior top surface of the sow by cracks or other fissures. Water can enter these voids in a variety of ways so special handling and storage or heating is required to ensure that the sows are not wet or contain moisture in internal cavities.

T-ingots and billets are produced using the DC or HDC casting process. They do not have the large shrinkage cavities that are common in sows, but they frequently contain cracks which may contain water or water-based saw lubricant. T-ingots and billet generally range in weight between 200 and 2000 pounds (90 and 907 kg).

### 15.1: Storage and Shipment of Sows, T-ingot and Billet

The presence of water or ice on the surface of or in internal cavities or in cracks in sows, T-ingot and billet presents a major hazard in the melting operation. Accordingly, it is vital that all materials are dry at the time they are charged into molten aluminum.

Sows, T-ingot and billet are frequently stored outdoors at the producing plants due to space limitations. They are transported in ships, railroad boxcars, enclosed trailers or flatbed trucks covered with tarpaulins to the customers and during transit are exposed to temperature changes which may form condensation on the aluminum. Therefore, all sows, T-ingot and billet shipped from one location to another must be considered wet.

Materials that are produced in a plant and stored indoors where the plant interior experiences temperature variations below the dew point should be considered wet. The only storage environment that can maintain this product in the dry condition is one that maintains the temperature above the dew point at all times.

### 15.2: Inspection of Primary Sows, RSI, T-Ingot, and Billet

Ultrasonic testing may reveal voids, but grain structure and porosity make this technique unreliable. Water in sow cavities frequently is not detected by ultrasonic inspection. Cracks in T-ingot and billet can readily be detected ultrasonically. As indicated previously, if salt fluxes have been used in RSI operations, the sows will often contain salt on the surface or in the shrinkage cavity. This salt can pick up moisture from the air and cause an explosion when charged into molten aluminum. Therefore, it is essential that all RSI be carefully inspected for surface moisture prior to charging. The preferred practice is to charge RSI into a dry hearth.

All shipments of sow, RSI and T-ingot should be inspected for contamination with ammonium nitrate or other oxidizers. Ammonium nitrate is a white powder often used as a fertilizer. Any material contaminated with a white powder should be quarantined until the powder can be identified by chemical means. Ammonium nitrate is extremely explosive in molten aluminum.

### 15.3: Drying of Sows, T-Ingot and Billet

If water is present on or in an internal cavity or crack of a sow, T-ingot or billet submerged in molten aluminum, an explosion of some magnitude will most probably occur. Therefore, water must be removed by drying the sow, T-ingot or billet for a period of time and at a temperature which will completely evaporate the internal and external water before the sow, T-ingot or billet is charged into molten aluminum. Since there are many sizes and shapes of these materials it is impossible to specify a time and temperature that will guarantee complete dryness for all sizes and shapes. However, **furnace drying for 4 hours after the internal metal temperature has reached 400°F (204°C) should adequately dry 1500 pound (680 kg) sows. Furnace drying of all sizes of T-ingot should be accomplished in 4 hours once a metal temperature of 300°F (150°C) is reached.** Although billet remelting is not as common, it can present hazards in the melting process as well and requires adequate drying.

Individual companies should develop safe, effective practices for drying sows, T-ingot and billet appropriate for their operations.

### 15.4: Modification of Sow Molds

Numerous studies have been conducted on the solidification of aluminum in a sow mold with the objective to develop a mold design which will eliminate shrinkage cavities. Although improvement has been made in minimizing shrinkage cavities by reducing the thickness of the sow, the elimination of the cavity has not been achieved on a production basis. Therefore, it should be assumed that all sows have shrinkage cavities.

### 15.5: Charging Sows, T-Ingot, and Billet

Sows, T-ingot, and billet in the following conditions may be safely charged into a molten aluminum heel:

a. Furnace dried sow, T-ingot and billet that are properly stored (temperature maintained above dew point).

b. Furnace dried sow, T-ingot and billet that were immediately placed in heated indoor storage.

c. Sow produced in-plant that is properly stored (temperature maintained above dew point).

Sows, T-ingot or billet in the following conditions may be safely charged into a dry hearth or on top of a bed of scrap that has completely solidified any molten heel that was present:

a. Sow, T-ingot, and billet produced at another plant that has not been furnace dried.

b. Sow, T-ingot, and billet stored outdoors that has not been furnace dried.

c. Sow, T-ingot, and billet stored indoors in an area without temperature controls even if they were previously furnace dried.

Molten metal should not be added to a furnace charged with undried sow or T-ingot until the sow or T-ingot show significant signs of melting.

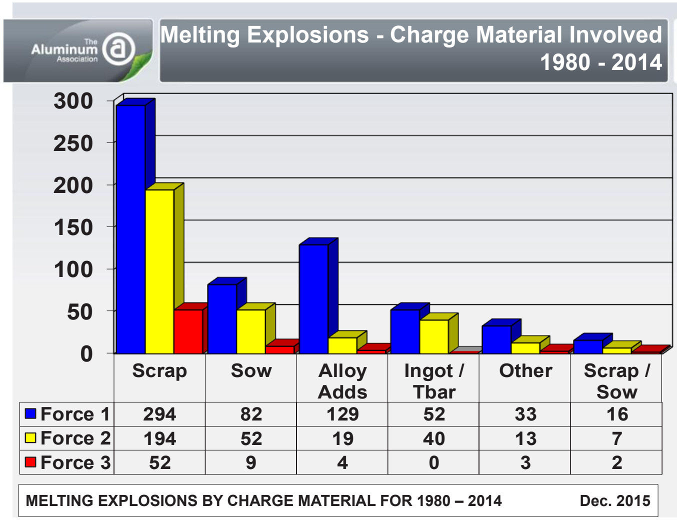
Charging wet material onto a sufficiently large bed of dry scrap that has been previously charged into a molten heel can be done safely provided the charging is performed in a manner so that the wet material will not fall or tip over into the molten heel when charged and will be dry prior to entering the molten heel during the melting process. **It is important to note that this method of charging has risks associated with it which have been noted on a number of occasions when explosions have occurred due to wet charge material falling prematurely off the dry scrap bed and coming in contact with molten metal.**

## Section 16
## Melting Operations including Treatment of Metal in the Furnace

Particular care and attention should be exercised in the aluminum melting operation. Data gathered by The Aluminum Association show that the majority of severe explosions involving molten aluminum occur during furnace charging. Warning signs, audible alarms, warning lights, etc. should be provided to alert personnel that charging and melting are taking place.

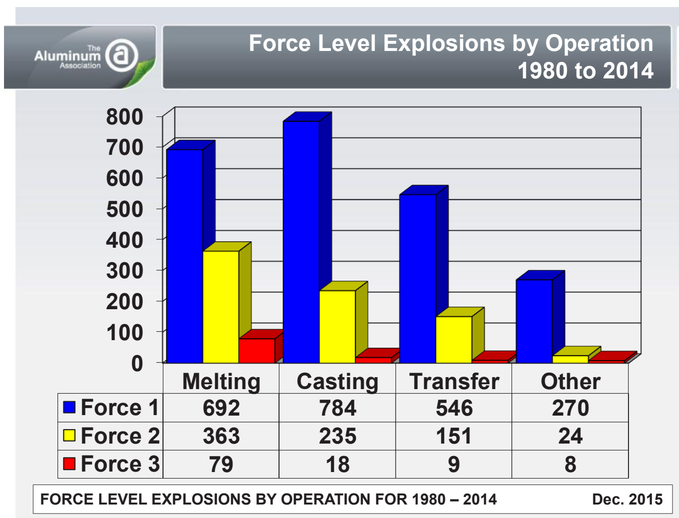
**Note: Care must be exercised to ensure melting and holding furnaces are not overcharged. Overcharged furnaces can overflow the door sill and onto the cast house floor.**

Based on information reported to The Aluminum Association, 16 Figure 1 provides a compilation of the melting explosion data over the years 1980 thru 2014 for the various types of charging material involved. Wet or contaminated scrap problems continue to be the area where most of the melting explosions occur. Scrap charging is where the majority of Force 2 and Force 3 melting explosions have occurred. The melting operation generates the most Force 2 and Force 3 explosions. See 16 Figure 2. Force 3 explosions are the most devastating; for a detailed explanation of Force levels see Section 34. Contact The Aluminum Association for the most recent Molten Metal Incident Report data, only excerpts of which are presented here.




| | Scrap | Sow | Alloy Adds | Ingot / Tbar | Other | Scrap / Sow |
|---|---|---|---|---|---|---|
| Force 1 | 294 | 82 | 129 | 52 | 33 | 16 |
| Force 2 | 194 | 52 | 19 | 40 | 13 | 7 |
| Force 3 | 52 | 9 | 4 | 0 | 3 | 2 |

**16 Figure 1 – Melting explosions data**




| | Melting | Casting | Transfer | Other |
|---|---|---|---|---|
| Force 1 | 692 | 784 | 546 | 270 |
| Force 2 | 363 | 235 | 151 | 24 |
| Force 3 | 79 | 18 | 9 | 8 |

**16 Figure 2 - Force Level Explosions by Operation**

## 16.1: Charging Sequence

It is important to take care when adding the charge to a furnace with a molten heel and, particularly, to a sidewell or topcharging furnace. With these types of furnaces, the charge tends to submerge more quickly below the molten metal than with a conventional door charged furnace, which significantly increases the risk of an explosion from moisture or contamination.

Plan the charging sequence which will avoid molten metal contact of sow, RSI, T-bar, small ingot, cracked ingot, or any scrap not certain to be totally free of moisture. Ensure that all of the charge components have been added (with the exception of some alloying components) prior to achieving a complete molten bath.

Charging the furnace following a complete drain presents significantly less of an explosion hazard from moisture on or in the charge; however, an explosion caused by foreign material such as ammonium nitrate fertilizer may not require a "bath" of metal to occur.

Take particular care when adding a solid charge to molten metal in the furnace. Use the following sequence of charging:

a. Dry light scrap (including dry chips or scalpings).
b. Dry medium scrap.
c. Dry heavy scrap.
d. Sows, coils, ingots.

Saw chips and scalpings containing up to 2-3% moisture and oil may be charged into the furnace provided no immediate effort is made to submerge this material with heavier scrap. Do not add aluminum fines that may fall into the category of combustible dust into a charge bucket. Aluminum fines in the bottom on a charge bucket added to a furnace with a minimal heel has caused explosions in the past.

**Note: If moisture or coolant collects in the bottom of the container holding the chips and scalpings, it is reasonably certain that the moisture/oil content is greater than 2-3%. If the chips are less than 10% of the total charge weight, wait for 10 minutes before charging heavier scrap on top of the chips.**

## 16.2: Addition of Alloying Materials

Many alloying materials (metal elements and alloys called "hardeners") are added with the cold charge. Heavy elements such as lead, bismuth, zinc, and copper should be added after meltdown. Magnesium also should be added after meltdown. If hand charging of alloying materials must be performed, personnel should be aware of the possible surface moisture on the alloying material and always recognize the potential for explosions caused by surface moisture.

Avoid alloying, including alloy dilution operations, into a furnace with a molten metal temperature of 1500°F (810°C) or greater.

Adding alloying materials to transfer troughs is not recommended because of the possible close proximity of employees if there were to be an explosion and the high potential for wet alloy material to prematurely fall into the melt or dam up the transfer and overflow the trough. There have been numerous transfer trough explosions caused by the addition of alloying materials contaminated with surface moisture. Addition of corroded materials, such as corroded magnesium in the trough, is also problematic. Therefore, alloying in the furnace is always the preferred method.

## 16.3: Degassing (Fluxing)

When processing the metal in the furnace with flux tubes or with spinning nozzles and other systems, ensure that the tubes or nozzles or other components which are immersed in molten metal are dry and in good repair. Preheating the components which will be immersed into the molten metal is required to eliminate the potential for an explosion.  Give special care to removable processing equipment because components that were previously immersed in the molten aluminum may pick up moisture as a result of surface buildup of salt products of reaction, such as magnesium chloride.

## 16.4: Skimming

Use only warm, dry tools. Never coat the tools with lime. Pull skim into warm, dry containers which are free of rust. Do not dump the skim when its internal temperature is above 1000°F (540°C), and do not probe the container with a steel tool because of the danger of a thermite reaction. Never skim directly onto a Portland Cement based concrete floor as the concrete floor can contain embedded moisture which can react with the skimmed material and cause an explosion.

**16.4 Figure 1 – Skimming Dross from a Furnace by Mechanical Skimmer**

**Note: Skim/Dross managment practices including cooling equipment and processes are not covered within the scope of these *Guidelines*.**

### 16.5: Use of Compressed Air

Do not add compressed air into molten aluminum for stirring or other purposes. Plant compressed air usually contains moisture.

# Section 17
# In-line Melt Treatment Operations

There are numerous proprietary in-line melt treatment systems for fluxing and filtering molten aluminum. Follow manufacturers' instructions carefully to ensure safe operation. Consideration must be given to potential overflow or leaks from such systems. Ensure that the surrounding area does not contain water and other hazards in the event of spills of molten metal.

In-line metal treatment systems are commonly found in continuous and DC casting operations for removal of hydrogen gas, non-metallic inclusions, and alkali metals such as sodium. These devices may be generally classified as follows:

- Packed bed media filters.
- Rigid media filters.
- In-line degassing devices utilizing spinning nozzles, stationary nozzles or porous plugs.

In-line metal treatment units come in numerous configurations and from a variety of manufactures. These devices are for the most part proprietary and have been patented. Manufacturers' recommendations should be consulted for safe operating practices and specific hazard information.

### 17.1: Packed bed media filters

A packed bed media filter will most commonly consist of a refractory lined box filled with alumina mesh and/or balls. Since these devices contain molten metal even when no casting is in progress, normal precautions observed with any molten metal transfer vessel apply. Additionally, heating systems and temperature control systems must be maintained in good working order to assure safe start-up of casting operations. If the metal contained in these devices is either too hot or too cold, unsafe conditions such as excessive butt-curl, bleed outs, freeze-ups or overflowing troughs can occur (see Section 18).

When re-charging packed media filters, precautions must be taken to minimize exposure to metal splashing and radiant energy.

### 17.2: Rigid media filters

Rigid media filters come in a wide variety of types and sizes. For units that hold molten metal between casts, refer to the section above (17.1) for heating system and temperature control precautions. Each time a rigid media filter is replaced, care must be taken to ensure that the new filter has been adequately preheated. Otherwise the filter may not prime and metal could overflow the filter box or troughing system. Each time a trough connection to a filter box is broken, care must be taken to ensure that the connection is properly sealed again.

### 17.3: In-line degassing devices

The most common in-line degassing devices are of the "spinning nozzle" variety. Traditional spinning nozzle reactors consist of a refractory lined box containing any of a number of reaction zones. Molten metal remains in the box between casts. For these types of devices, the same care with respect to heating and temperature control systems apply as described in Section 17.1 above. Additionally, care must be taken to ensure spinning nozzles are pre-heated to remove moisture before submersion in molten metal. This is especially critical if the nozzle has been previously used and has the potential for surface salt that may contain moisture. It is best to keep the spinners heated between uses. Rotating nozzles at higher than recommended speeds may also result in metal splashing.

A newer generation of more compact in-line reactors do not hold molten metal between casts. When these units require draining of metal at the end of a cast, make certain the drain tub has been pre-heated to remove all moisture. All seals and connections must be properly made so that metal does not leak out when re-filling with metal.

Skimming tools used with in-line degassing devices should be kept dry and preheated before submergence into molten metal. If the tools contain hollow components they should be vented. The above comments regarding possible moisture pick-up due to salt also apply to skimming tools.

**Note: Specific safety instructions issued by the manufacturers must be followed when operating in-line metal treatment devices.**

# Section 18
# Melt Transfer Operations — General

Spills and leaks should be avoided when molten aluminum is moved from one location to another. These spills and leaks can cause explosions as well as burns, fires, and damage to equipment. The most common occurrence is a small explosion accompanied by flying metal and debris that can take place when molten aluminum spills onto a freestanding puddle of water or onto a damp concrete floor.

The following items can be incorporated into a check list for pre-transfer activity:

## 18.1: Crucibles, Troughs and other Containers

a. Inspect all bails of transfer vessels periodically for fatigue cracks, damage, excessive wear, etc.

b. Make certain all refractory linings are dry and warm.

c. Carefully follow drying and curing schedules recommended for the refractory used. Ensure a procedure is in place to prevent use of noncured linings.

d. Inspect all refractory linings regularly. Make certain the containers are in good condition.

e. Heat empty vessels before reuse to remove moisture absorbed from the atmosphere.

f. Keep pouring spouts clean so nothing interferes with the smooth flow of the metal out of the vessels.

g. Equip vessel heaters with low and high pressure cutoff switches and flame monitors to prevent fuel gas explosions. Follow appropriate standards of the National Fire Protection Association (NFPA).

h. Do not leave containers under nonflaming gas heaters. Gas can accumulate and explode when the burner is lit.

i. Set up and maintain safe metal levels or "freeboard" for each vessel (for example, 8 inches (200 mm) from top, or 2 rows of brick).

j. Clean vessel edges of buildups to prevent splashes if pieces fall or break off.

k. Keep foreign materials, trash, etc. out of all vessels to avoid unexpected splashes and runovers when pouring. Remove such matter prior to filling with molten metal.

l. Position spouts to keep the freefall distance between vessel and receiver at a minimum when pouring metal.

m. Use a lid when practical in transporting metal.

**Note: Lids not only reduce the chance of metal spills but will also reduce heat lost.**

## 18.2 Transport of Vessels by Crane

a. Cranes handling molten metal should meet ANSI requirements for hot metal cranes.

b. Evaluate in detail the path to be followed, traffic flow, pedestrian flow, obstructions, etc., to ensure right of way for molten material.

c. Carry the load a minimum distance from the floor to reduce the potential of spills and splashing.

d. Provide visual and audible warning devices on hot metal cranes.

e. Crane controls and speed ratios between bridges and trolley movements should be the type that will prevent surging of the metal in the vessel.

f. Do not engage crane auxiliary (tipping) hoists when the vessel is in transport.

g. Provide crane operators special training for molten metal transfer operations, emphasizing the special hazards.

h. Establish and maintain crane transport speed limits.

i. When multiple cranes are utilized on the same set of rails, consider the use of anti-collision devices or similar collision avoidance devices are used to prevent contact between cranes.

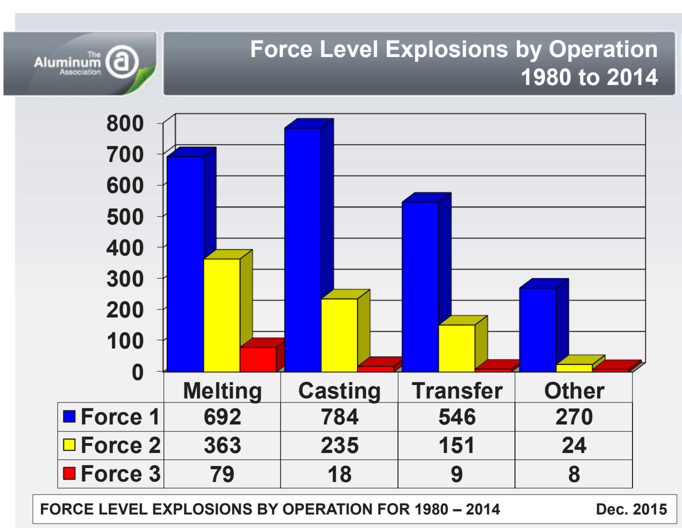
See Section 33 for more information on crane safety in the casthouse.

## 18.3: Pumps for Molten Aluminum

If pumps are used to move metal from the furnace or within the furnace, their installation, care, and use should be strictly in accordance with the recommendations of the pump manufacturer and, of course, company practices. Metal level detection is important to prevent metal spills out of the pump well or the furnace door.

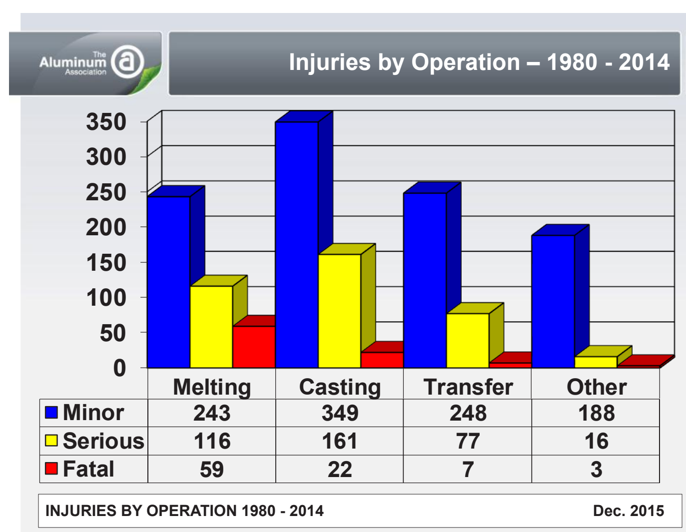
## 18.4: Industry Statistics for Metal Transfer Operations

Numerous explosions have been reported to The Aluminum Association which occurred during metal transfer operations. See 18.4 Figure 1, 18.4 Figure 2 and 18.4 Figure 3 below showing The Aluminum Association data on reported Metal Transfer Explosions. A total of 706 metal transfer explosions have been reported between 1980 and 2014, with 151 and 9 being Force 2 and Force 3 explosions respectively. As a result of these explosions, 248 minor injuries, 77 serious injuries and 7 fatalities have been reported. So although metal transfer would seem to be a rather mundane



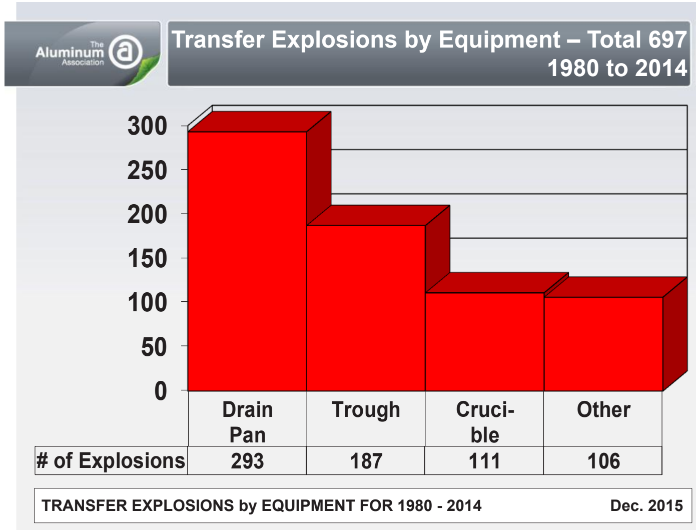

| | Melting | Casting | Transfer | Other |
|---|---|---|---|---|
| Force 1 | 692 | 784 | 546 | 270 |
| Force 2 | 363 | 235 | 151 | 24 |
| Force 3 | 79 | 18 | 9 | 8 |

**18.4.Figure 1 - Force Level Explosions by Operation**




| | Melting | Casting | Transfer | Other |
|---|---|---|---|---|
| Minor | 243 | 349 | 248 | 188 |
| Serious | 116 | 161 | 77 | 16 |
| Fatal | 59 | 22 | 7 | 3 |

**18.4 Figure 2 – Injuries by Operation**




**18.4 Figure 3 – Transfer Explosions by Equipment Type Involved**

operation, it has resulted in numerous explosions, injuries and even fatalities. The major causes of transfer explosions involve drain pans, troughing and crucibles.

# Section 19
# Metal Transfer during Casting of Process Ingot

Many of the same guidelines in Section 18.1 apply to the transfer of molten aluminum during casting. The majority of these explosions have resulted from wet or damp drain pans as well as wet or damp troughing.

a. When possible, use refractory materials in trough linings, etc., which do not require water in their installation. However, when materials that contain water are utilized, ensure that they are adequately cured according to manufacturers' recommendations or company policy. A procedure should be in place to prevent the use of noncured linings.

b. Make certain refractory linings are completely dry and warm before use.

c. If coatings are utilized on troughs or pouring pans, ensure that they are adequately dried before use. **Never use lime as a wash or protective coating.**

d. Check the linings and coatings regularly for cracks, wear, etc. Keep trough joints and connections tight and sealed with appropriate gaskets and sealants. Preheat troughs prior to use to eliminate moisture from humidity or other possible sources.

e. Troughs should be designed to prevent overflow of metal onto the floor. Freeboard of one to two inches (25 to 50 mm) should be designed into the troughing system. Consider an overflow notch cut into the top edge of the trough where metal could flow into a drain pan. The variability of your metal level control system needs to be taken into account when designing the trough freeboard. Develop and follow company practices when leaks occur in the transfer system.

f. Provide one or more containers for molten metal drained from systems. The containers must always be in place before the furnace is tapped and must be empty, clean of debris and rust and hot or oiled. The containers (drain pans) should be capable of holding all the molten metal in the transfer system when the troughs are full.

g. Drain pans should never contain trash of any kind. This includes floor sweepings, trough skulls, paper or plastic cups, garbage, lunch remnants, etc.

h. The containers should be emptied after each use to allow maximum filling in emergencies. Utilize care in the removal of drains from containers since the metal may still be liquid in the center if removed before complete solidification.

i. Keep emergency taphole plug bars close at hand to prevent trough overflow in the event of taphole or casting station problems. Oversized plugging devices should be on hand to allow plugging of the taphole in the event of tap block failure.

j. The taphole and related plugging on control equipment should be designed to minimize runaway type spills from these openings. Tap blocks should be designed and constructed of suitable material to ensure they are not subject to rapid deterioration. Routine cleaning, inspection and replacement of tap blocks is recommended.

k. Ensure that troughs are not located where molten metal overflow might allow molten metal to fall into sumps or depressions which might collect water.

l. Remove all residual dross and metal from troughs and spouts prior to reuse. Take care in removing residual metal from troughs; the metal may still be liquid underneath the crust.

m. When making trough repairs it is critical that the materials used are cured as recommended by the supplier before molten metal is transferred. Develop and follow company procedures to prevent transfer of metal prior to curing refractories.

n. Drain pans should be inspected for cracks and may be coated with a release agent periodically. The pans and release agent coating must be heated prior to use. Cracked pans should be repaired or replaced.

o. Drain pans should be clean, dry and warm before the cast is started. If a cold pan must be used in an emergency, the pan should be oiled first. The oil should coat the entire surface uniformly. Particular attention should be paid to proper drain pan condition after the casting unit has been down for an extended period, such as after an outage.

### 19.1: Cleanup of Metal Spills

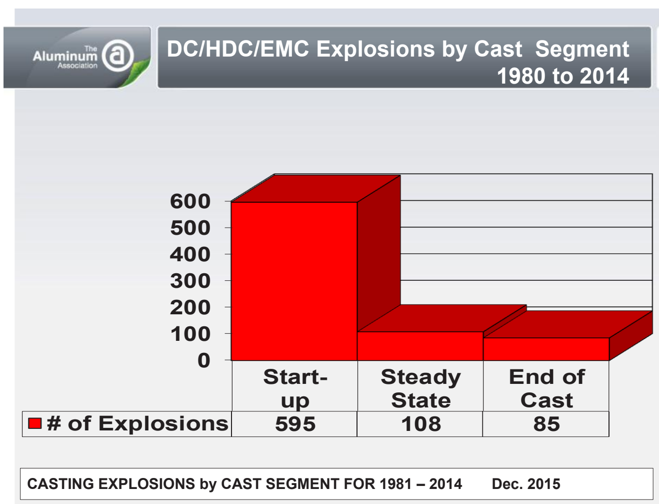
See Section 27 for hazards to avoid in cleanup of metal spills.

# VI

# CASTING OPERATIONS

# Section 20
# SOP's for Casting and Precasting Precautions

Operators with experience in direct chill (DC) casting of aluminum know that most casting problems (bleed outs, hang-ups, explosions, etc.) occur during the start of the cast. This is substantiated by The Aluminum Association incident report data as shown in 20 Figure 1. The potential for injury at this time is compounded by the fact that it is at the start of the cast when the largest number of personnel are around the casting equipment, thereby increasing exposure and the risk for injury.




**20 Figure 1. DC/HDC/EMC Explosions by Cast Segment**

A Standard Operating Practice (SOP) for casting describes how to cast products – including output quality requirements, machine settings, and how to operate the equipment. The casting SOP should describe in detail the settings for the casting machine – i.e. cast / drop rate, ingot cooling water flows, temperatures to maintain, etc. Casting SOP's should also describe and prohibit unsafe operations to save a cast, e.g. paddling in the corner of a slab, forcing an actuator, plugging a bleed out or crack with solid material, hitting a hanging slab with a hammer, etc.

Know and follow the steps in the facility casting SOP for starting the cast, including checkout of equipment in advance. Also, know what to do when there is a bleed out, lose an ingot, or have an ingot hang up in the mold. Memorize emergency shutdown procedures. To facilitate smooth emergency shut-downs, all emergency valves should be located close to the casting pit, easily accessible and properly identified (e.g. emergency down valves for tilting holders, emergency casting cylinder platen valves and emergency water valves). All casting systems need to be designed and operators need to be trained to address a 'loss of power' emergency. Depending upon the design of the system, this could include back-up power supplies which need to be part of regular preventive, maintenance programs. Emergency lighting should also be available to facilitate a safe controlled shutdown.

The facility Standard Practices Manual should be developed specifically for the equipment in the plant. The following general guidelines are in no way to be considered a Practices Manual; rather they are intended to be used in training and safety programs to help perform the job safely.

A precast checklist should be used with all casting systems (DC, hot top, EMC, horizontal DC, etc.) to insure that the cast can be safely started, operated in steady state, and completed.

Items in this list should include the following:

a. Make sure all instruments are working properly. This includes thermocouples, water flow meters, casting rate indicators, metal level sensors, furnace tilt control, cast length indicator, etc.

b. If a bleed out occurred on the previous drop, check the depth of the water in the pit to ensure that it is at least three feet (1 m) above any debris, check the pit walls for clinging frozen aluminum, check the base plate or platen cover for the presence of aluminum debris and check areas for burned off protective coating. Remove aluminum debris from pit walls and base plate. Recoat areas where the protective coating has burned off. Either raise the level of water in the casting pit or remove debris from the bottom of the casting pit to ensure that at least 3 feet (1 m) of water is present in the pit at all times.

c. Keep aisles and passageways around the casting pit open and free of clutter. Ensure that there are at least two open exits from the pit area. Two exits are also recommended from the operator booth if one is used.

d. Keep employees not directly involved in casting out of the casting area when molten metal is present.

e. Verify that all machinery guards and covers are in place.

f. Ensure that the metal to be cast is at the proper temperature (this includes metal contained in degassers and filters). Ensure that all refractory materials are properly dried and preheated, including the ceramic foam filter, flow control equipment and other devices, if used. Molten metal that is either too cold or too hot can create serious hazards during casting. It is important to follow the temperature range specified in the plant standard practice.

g. Inspect spouts, control rods, headers, transition plates, etc. for cracks and chipped areas. Replace defective components. Ensure that control rods are set to the proper gap for proper fill rates and that emergency plug-off equipment is hot, dry and readily available.

h. Check the condition of molds. Look for cracks, gouges and excessive surface roughness. Then check the water and oil pattern on molds to ensure uniformity. Replace molds that have been damaged or have a poor water or oil pattern. For molds with non-continuous lubrication, ensure the molds are properly lubricated before starting. Note: it is best to inspect the logs or slabs after a cast to identify mold problems to be addressed before the next cast.

i. Inspect the condition of troughs. Ensure that all trough dams are properly positioned to prevent leaks. Repair and thoroughly dry damaged refractory areas before subjecting them to molten aluminum. Bare steel should not be exposed in the launders.

j. Ensure that drain pans are empty, hot or oiled and of adequate size to hold the entire contents of a full trough in the event of an emergency shutdown.

k. Ensure that tools and other devices which may come in contact with liquid metal are clean and warm and have had their working ends stored off the floor. Tools with hollow handles must be vented. Ensure plug off devices are clean, warm and in close proximity to the casting table.

l. Check starting blocks for cracks, oxidation and/or rust. Based on plant or company acceptance criteria, replace all unacceptable cracked blocks immediately. Clean oxidized or rusty blocks. Ensure that all starting blocks are dry before starting the next drop. Oiling the blocks prior to casting is the recommended procedure. A light coating of oil on all block materials (steel, cast iron, aluminum) helps reduce the potential for explosions due to damp or wet conditions. Typically, oils used for casting will work for this purpose. It is recommended that low viscosity oils such as kerosene not be used.

m. If there are any plugged off mold positions, ensure that the starting blocks for the plugged positions are either covered with a shield that is coated with protective paint or completely oiled or greased. If the starting block is 2” deep or greater then greasing is preferred instead of oiling. If possible, water to the plugged off mold positions should be turned off.

n. Check the functioning of the emergency water supply at regular intervals, and at least semi-annually, to ensure proper operation. This should include the warning system to the operator as well.

o. Ensure that the water is on and at the required flowrate for the start of the cast. Control systems will generally be designed to automatically check for the ability to achieve both the required minimum and maximum flowrates. Note that in typical HDC systems the water is not turned on until the metal enters the mold.

p. Ensure that the correct practice has been entered in the control system.

q. For slab casting, ensure that butt curl control equipment and systems are functioning and set properly.

r. Ensure that the pit air exhaust system is functional.

s. Make sure that all personnel that are to be present for the start of the cast are wearing appropriate primary and secondary protective clothing and safety equipment for the start of the cast. (Refer to Section 11)

t. If a new casting table and or bottom block base has been installed, ensure that all structures have been properly bolted / fastened together and secured. Note that it is difficult to check this after the table / bottom block mounting base is set up to cast. Other equipment that could be propelled off of the casting table in the event of an explosion should also be fastened to the casting structure.

u. All objects, tools, etc. on casting tables are either removed or securely fastened down prior to the start of the cast.

v. Ground connections on all fixed and mobile equipment should be confirmed visually as a means of lightening effects prevention.

w. Verify the adequacy and proper operation of equipment and mechanisms in place to provide fall protection at the casting pit. This is particularly critical at the end of cast when the casting table is absent and the ingot/billet is being removed or has been removed leaving the pit open.

# Section 21
# Casting of Process Ingot – General

The "basics" of recommended design and engineering of the equipment and processes used to cast molten aluminum into process ingots are described in Sections 8 and 9 of Part III of these *Guidelines*.

The following sections present procedures for operating common casting systems with emphasis on safety. In spite of the marked increase in the use of automated systems and controls, it is recognized that the operator continues to be the most important factor in the production of aluminum process ingot from the standpoint of quality, cost and safety.

# Section 22
# Direct Chill (DC) Casting – Conventional

## 22.1: DC Casting – Vertical

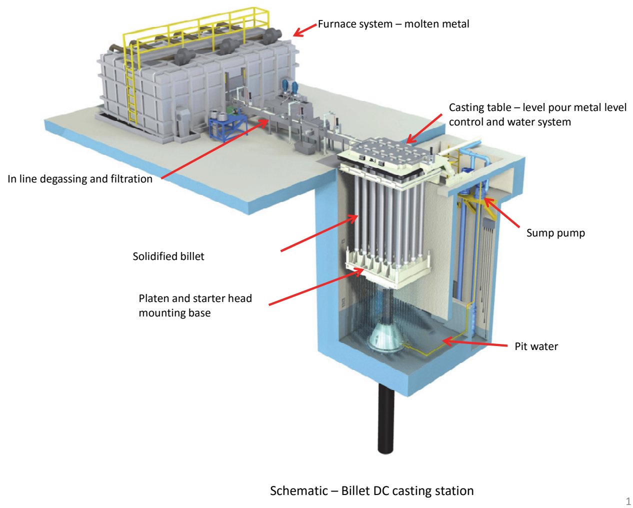
This method of casting is depicted in 22.1 Figures 1 and 2.

### *22.1.1: Before Starting the Cast*

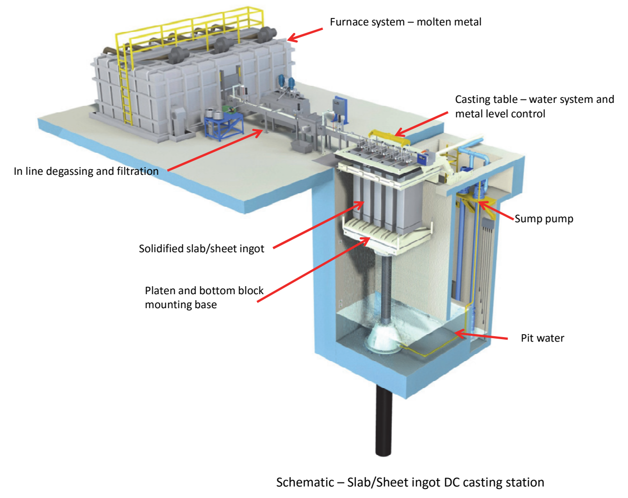
a. Review and follow the precasting Check List (Section 20).

b. Ensure that the molds are centered over the starting blocks.

c. Check the starting block / bottom block elevation prior to casting. It is very important that the starting blocks are in the correct position in the mold prior to cast start. Each tooling set has the correct position specified in the standard operating practice or casting practice. Failure to use the correct starting position for the starting blocks can result in the starting blocks being flooded with water before they are covered by molten metal and cause an explosion. In addition, platen drift (down)




**22.1 Figure 1 – Typical DC Casting Station - Billet**




**22.1 Figure 2 – Typical DC Casting Station – Slab/ Sheet Ingot**

can cause a similar condition. If the platen drifts down excessively in the stationary position prior to start of cast, stop and repair before casting.

d. Position the starting blocks at the proper engagement into the mold per the plant practice.

e. If the gap between the starting block and the mold is larger than 1/8 inch (3 mm), it is suggested that the gap be filled with an appropriate packing material after the starting blocks are positioned for the start.

f. Ensure that the required mold metal distribution systems (e.g. spouts, mini-bags, control pins) are in place and properly positioned.

g. Inspect the manual or automatic metal flow control devices for proper positioning and working order.

h. If a new casting table and/or bottom block base has been installed, ensure that all structures have been properly bolted / fastened together and secured. Note that it is difficult to check this after the table / bottom block mounting base is set up to cast.

### *22.1.2: Starting and Steady State Casting*

a. Ensure that only required personnel are present during start of cast and steady state casting.

b. Best practice at some DC casting operations includes automation, equipment and procedures that allow all personnel to be away from the casting station in a protected control room from the start of the cast until steady conditions have been achieved.

c. Maintain constant surveillance over the casting operation. This includes metal flow, metal levels, metal temperature, gauges, controls, indicators, ingots being cast, ingot length, mold lubrication, etc. Follow the plant practices for any necessary adjustments or alarms.

d. In the event of a bleed out of metal from an ingot, an ingot hang-up or failure of the metal flow control system to one or more molds, immediately **abort** the entire cast using prescribed plant procedures unless your specific equipment and procedures allow for continued casting and permit safe operation. It should be recognized that when bleed outs occur during casting of sheet ingot/slab, T-bar and large diameter billet there is the potential for a high volume of metal to bleed out and therefore a higher potential for an explosion.

e. If metal flow to one or more ingot positions "freezes off" in the distributor or downspout and the platen continues to descend, stop the flow of molten metal immediately to that downspout. If casting sheet ingot or large extrusion billet (greater than 15 inch (380 mm) diameter), the recommended procedure is to stop the platen, consider aborting the cast, stop the metal flow from the furnace, drain the metal in the trough into drain pans and move a safe distance away from the casting unit until the ingot is solidified. When plugging is allowed (e.g. only billets with a diameter <380 mm) a max percentage of plugged strands should be defined in the plant casting SOP. Under some circumstances it may be necessary to stop the water flow to the molds as well if there is danger of water being submerged into the molten head of the ingot.

**Note: Never manually hammer on an ingot that is hung-up in a mold. The impact from hammering may cause an explosion!**

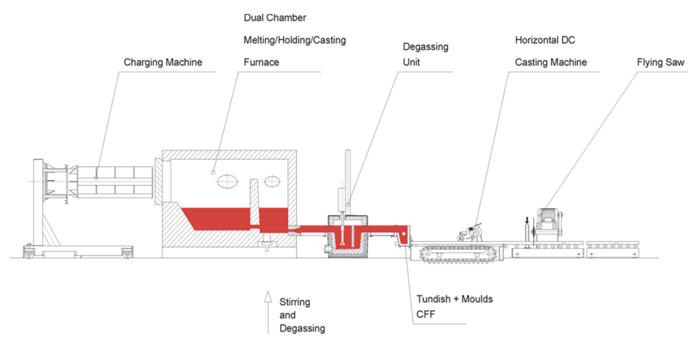
### *22.1.3: When Cast is Completed*

a. When the cast is complete, stop the lowering of the platen before the heads of the ingot reach the bottom of the mold. Allow the water to flow down the ingots until they are 100% solid. When end of cast explosions occur, it is very frequently due to the molten ingot head dropping below the bottom of the mold bore and water entering the ingot head. For large ingot, completely solidifying the entire ingot head may require 10 to 15 minutes. After the ingot head is sufficiently cool, turn off the cooling water, allow the water to drain out of the molds and then lower the ingots below the molds. Retract the mold table and blow all water off the heads of the solid ingot. In some plants the ingot will be dropped below the mold with the water still on after solidification to continue ingot cooling, however this must be done after the ingot head is completely solidified.

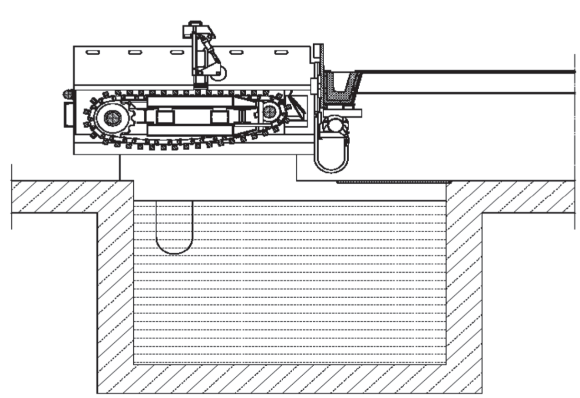
**Note: Failure to follow the above procedure can result in an explosion.**

b. When high levels of water are maintained in the casting pit, never lower the top of the ingot below the level of the water at the end of the drop until all the metal in the ingot head is 100% solidified.

c. Pit or personal fall protection should be employed whenever removing cast billet or slab from the pit. The fall protection should comply with OSHA or appropriate international standards for elevated heights and/or open floors.




**22.2 Figure 1 - Schematic of Horizontal DC Casting Station**



**22.2 Figure 2 - Section of Horizontal DC Casting Station and Water Basin**

## 22.2: Direct Chill Casting – Horizontal

This method of casting is depicted in 22.2 Figure 1 and Figure 2.

A number of proprietary horizontal DC casting systems have their own specific design and arrangement of components, takeaway mechanism, etc. Each has a specific mode of operation all of which cannot be covered in these guidelines. As with all equipment, for safe operation understand and follow the steps outlined in the Standard Practices Manual.

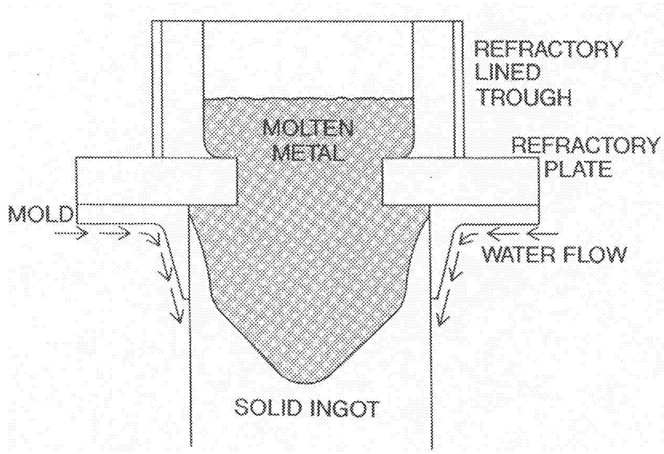
a. Follow an established checkout system covering the operating conditions of the instruments and equipment, cooling water system, depth of water in the sump or pit, protective coatings for equipment and walls of sump or pit and molten metal temperature to be used for safe operation. Many of the items in Section 20 also apply to horizontal DC casting.
b. Check the speed of the drive or takeaway mechanism to verify that it is correct.
c. Ensure that the drive mechanism can be started and stopped smoothly and without jerking.
d. Inspect starting blocks and molds to be sure they are in good operating condition.
e. Center the starting blocks in the molds and align horizontally. Similarly, align the takeaway mechanism, conveyor or sled.
f. Inspect starting blocks to make sure anchor bolts or other pullout devices, if used, are present.
g. Follow established practices for sealing joints and openings in the system to prevent escape of molten metal.
h. Ensure that molds and troughs are clean and dry.
i. Lubricate graphite molds (if used) following established practice.
j. Verify that the water flow and applications are operating properly and in accordance with standard practice.
k. Have equipment and tools on hand which will allow emergency stops to be made including clean, warm, dry or oiled drain pans to receive metal overflow from distribution box or transfer trough.
l. Follow practices established for sequence and timing of the start of the cast.
m. Verify that the watercooling system is operating properly.
n. Stop the flow of molten metal immediately if water supply fails or alarms warn of low pressure.
o. Stop the flow of molten metal immediately if withdrawal mechanism stops or does not operate properly.
p. Follow established procedures for your system if a molten metal bleed out occurs.

# Section 23
# Hot Top Casting / Level Pour Casting

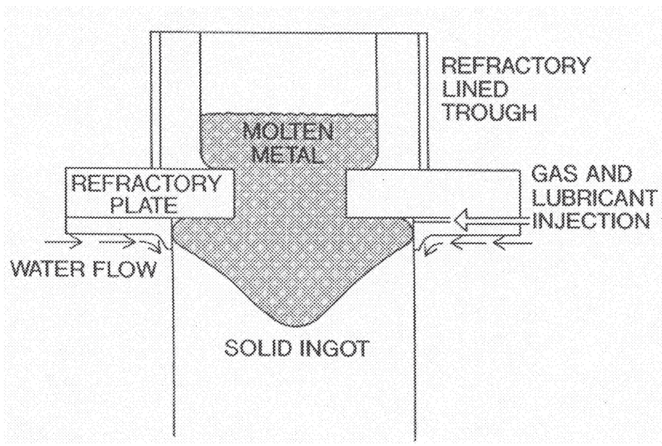
## 23.1: Hot Top Casting Systems

Hot Top generally refers to vertical direct chill (DC) casting systems in which the top of the open mold is surrounded by or made with a refractory "ring." The molds may be round to produce extrusion ingot (billet), or rectangular to produce sheet ingot. Molten metal is delivered from the furnace to the mold via a level pour trough system. The metal is distributed at a constant elevation from the refractory pan or trough on top of the mold table directly to the mold without the use of a conventional float and spout for control of the metal level. The metal "underpours" from the mold table to the mold. See 23.1 Figure 1.

Hot Top technology is most often applied to mold tables with large numbers of round molds for production of extrusion ingot. The Hot Top refractory plate is given various names in the industry such as transition plate, orifice ring, and header plate.




**23.1 Figure 1 – Schematic of a Hot Top DC Casting System**




**23.1 Figure 2 – Schematic of Hot Top Mold with Air Injection**

The refractory plate fixes the mold length by insulating the molten metal from the mold wall. Solidification begins immediately below the refractory plate. Hot Top molds typically have a shorter mold length than conventional molds. The short mold length means less heat removal through the mold wall and a corresponding increase in the relative cooling by spray water applied directly on the ingot.

More complex Hot Top systems may include one or more of the following:

a. a continuous mold lubrication system;

b. a replaceable porous graphite casting surface;

c. a gas injection system which surrounds the solidifying metal with an insulating layer of gas to further reduce mold wall cooling. See 23.1 Figure 2.

Release agents are sometimes used inside the mold to prevent metal from sticking to refractory joints.

Some plants also use the term 'hot top' as referring to the use of a ceramic paper inside a DC mold and using bi-level metal transfer.

### *23.1.1: Before Starting the Cast*

a. Review and follow the Precasting Check List (Section 20). These items also apply to Hot Top casting.

b. Check the water pattern on all molds. The Hot Top casting process requires uniform distribution of the cooling water on each ingot. If water patterns are broken or uneven the ingot will be cooled unevenly which can result in surface defects, bowed ingot and bleed outs.

c. Carefully check starting block elevation prior to casting. It is very important that the starting blocks are the correct distance up in the mold for the start of the cast. There is only one correct position for every mold set. Failure to use the correct starting position for the starting blocks can result in the starting blocks being flooded with water before they are covered by molten metal and cause an explosion. If the platen drifts down excessively in the stationary position prior to start of cast, stop and repair before casting.

d. Check all starting blocks to make certain they have been oiled and no water is present. Due to the design and construction of Hot Top molds it is difficult to inspect for the presence of water on the starting blocks. The starting blocks should always be oiled before they are elevated to the start position. After the cooling water is turned on and just before molten metal is released from the furnace, a visual inspection should be made of all starting blocks to insure that they have been oiled and no water is present.

e. Check casting speed. Casting speed is a critical variable in the Hot Top casting process. Excessively slow starting speeds can cause metal to freeze in the metal feed hole in the center of the ingot. This causes the solidified ingot to separate from the molten metal or pull the solidified ingot butt off the starting block. When the casting rate is increased the solidified butt may drop out of the mold allowing molten aluminum and water to mix and potentially cause an explosion.

### *23.1.2: During the Cast*

a. Wear the personal protective clothing and equipment specified in the plant's standard practice during the entire drop.

b. Remain alert for bleed outs or hang ins during the entire cast.

c. Bleed out - A Hot Top / Level Pour mold is fed by a much larger opening than a conventional DC spout. This means a large quantity of molten metal can be spilled into the casting pit in a small time interval. A hissing sound may typically be the first indication of a bleed out. It is frequently very difficult to identify the ingot that is bleeding out. Look for a slight surface metal disturbance, a whirlpool or a drop of metal level in a specific area. The recommended procedure for a bleed out or hang in is to stop the platen, consider aborting the cast, stop the metal flow from the furnace, drain the metal in the trough into drain pans and move a safe distance away from the casting unit until the ingot is solidified. Under some circumstances it may be necessary to stop the water flow to the molds as well, if there is danger of water being submerged into the molten head of the billet.

d. Hang in - If metal flow to one or more ingot positions "freezes off" in the mold entrance or thimble and the platen continues to descend, stop the flow of molten metal immediately to that mold position. If the billet does not hang in the mold the decision needs to be made if the cast can safely continue. The recommended procedure for a bleed out or hang in is to stop the platen, consider aborting the cast, stop the metal flow from the furnace, drain the metal in the trough into drain pans and move a safe distance away from the casting unit until the ingot is solidified. Under some circumstances it may be necessary to stop the water flow to the molds as well, if there is danger of water being submerged into the molten head of the billet.

e. Have warm and dry plug off rods or dams readily available on the casting table. Many Hot Top casting tables have a large number of ingots. It is a good practice to specify in the standard practice the maximum number of ingots that may be plugged or dammed off before the drop must be aborted. A large number of bleed outs indicate there is a serious problem that must be identified and fixed.

f. Never remove a plug or dam even if it is leaking! If the leak cannot be stopped without replacing the plug or dam, **abort** the cast.

g. Walking on top of the casting table when molten metal is present is not recommended, especially when addressing a problem on the casting table such as plugging off a position. Aborting the cast is preferred in this case.

### *23.1.3: When Cast is Completed*

Stop the cast when the trough has drained but before water is impinging on the molten ingot heads. When all ingots are totally solidified, turn off the ingot cooling water. When the water flow stops, lower the ingots below the molds, remove the casting table and blow off any water that has dropped on the ingot heads.

# Section 24
# Electromagnetic Casting (EMC)

Electromagnetic casting (EMC) systems are proprietary systems available from vendors, or developed in-house. Keep in mind that the following are guidelines only; follow the operating practices and safety rules established by your organization for these proprietary systems.

## 24.1: General Information and Design Considerations

The EMC process is a vertical casting process in which the liquid metal head of the ingot is not held by the mold wall as in the case of the conventional mold, but by an electromagnetic field. Under normal operating conditions there is no contact of molten aluminum with the mold wall; the aluminum is contained by the electromagnetic forces while simultaneously being water-cooled and solidified into an ingot. Molten metal will contact the mold when there is a power failure or when metal head control is lost. Cooling water is applied directly to the metal just below the electromagnetic field. While single ingot stations may operate successfully without automation, multiple ingot stations cannot be properly controlled without automation.

### *24.1.1: Process Controls*

Automated control systems are used to provide both safety and reproducibility in the casting operation. Care must be taken that all steps and items of equipment are coordinated in their operation in the casting system. This includes flow of metal to the system (tilting of furnace), molten metal treatment and transfer systems, and flow of metal to the casting machine for starting, casting, and ending the cast.

Automated controls must provide for response to emergency situations, whether these emergencies are triggered by the operation, the machine, or by external circumstances.

As in the use of other systems for casting process ingot, the requirements of a given EMC production facility will determine the overall design employed. The vendor / designer / installer of the EMC power supply system must design and install the equipment for safe operation and provide to the operating facility the necessary instructions on how to safely operate and maintain the equipment.

It is important that that electrical hazard inherent in EMC be recognized in the design criteria, and communicated to the Operations Group so that subsequent modifications to the equipment will not result in unsafe conditions for the operating personnel.

Another hazard to be recognized is that any conductive material close to the inductor will be heated. The distance that the conductive material must be kept from the inductor is dependent on the operating conditions of the electromagnetic field. Any conductive materials placed close to the inductors will heat and may cause severe burns when touched by the operators.

### *24.1.2: Use of Automation*

Vendors of EMC systems have different approaches to the use of automation in process control.

One vendor and user takes the stance that the control system must provide not only for automatic control over individual steps in the process, but also for automatic interfacing and coordination of these steps. In the event that a critical parameter is exceeded, the system must have the capability to shut down automatically and safely without operator intervention.

However, in the event that the operator at the casting machine observes an unusual situation or serious problem, means are provided for the operator to safely interrupt or stop the casting process. See 24.3.2 Quick Stop and 24.3.3 Emergency Stop.  Safe shutdown must occur with loss of power or failure of any component, including the convertor and process computer (PLC).  Critical portions of the automation system and the operating mechanisms that are required for a safe shutdown in the event of a loss of power or failure require some type of Battery Backup Power Supply [UPS – Uninterruptable Power Supply]. This is to ensure that these items function for a sufficient amount of time to affect a safe shutdown.

## 24.2: Casting Operations

Recommendations on steps and practices to be used provided by one vendor of commercial EMC equipment follow; a schematic of the steps and functions involved is shown in 24.2 Figure 1.

A precasting check list is used which incorporates all parameters critical to safety, product quality, and production rate. All the items on the check list must be completely complied with before starting a cast.

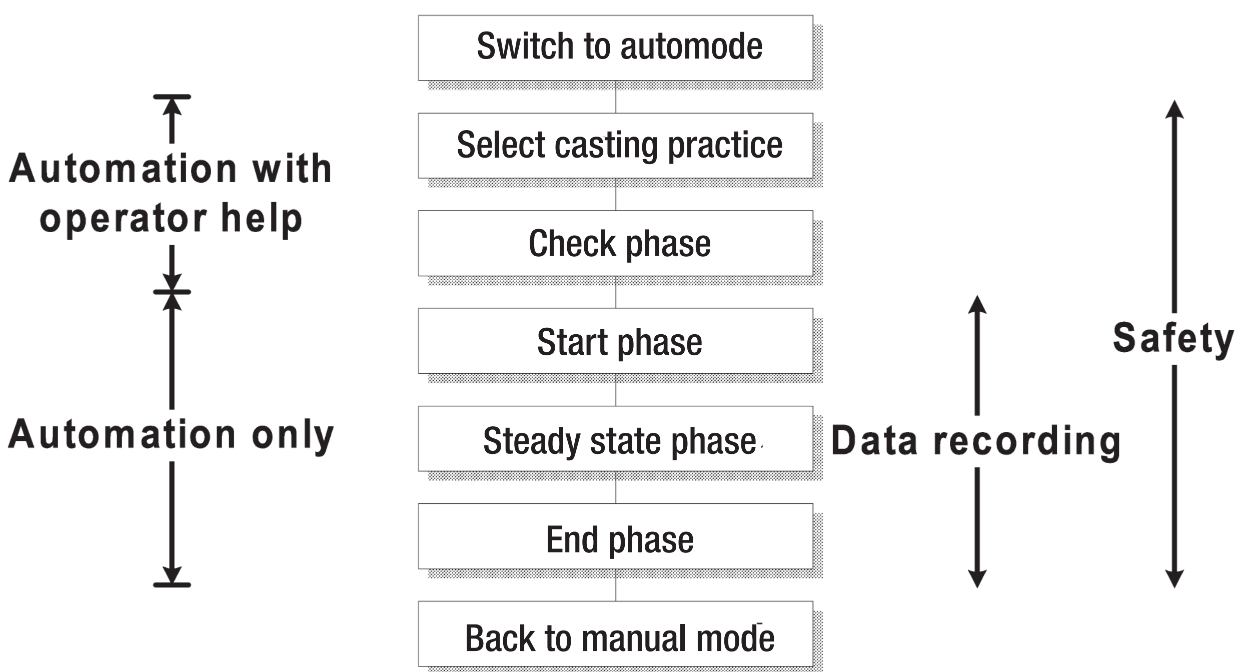
During casting, an alarm signal is heard when the first tolerance limit of the operating parameters is exceeded. In the case of particularly critical parameters such as casting speed, cooling water quantity, and aluminum level, there is a second safety tolerance limit, which, if exceeded, will lead to an automatically controlled interruption of the cast (Quick Stop).

The casting operation, controlled by four main phases and two safety phases, takes place completely automatically. Only the phase involving the preparation of the machine according to the checklist necessitates the collaboration of the operator, who in cooperation with the automation program, arranges the equipment required for the casting operation and tests the facility's principal control devices or sensors.

The start of the automatic casting operation is authorized once the checklist is completed. As soon as the system is ready to cast, a completely automatic sequence of operations is initiated beginning with the tilting of the casting furnace and ending when the ingots have reached their programmed lengths.

The cast start phase also includes all the "ramps" for the casting parameters. The steady state phase begins with the expiration of all startup curves. From that point onwards, the software has no other task than to keep the machine under surveillance, to control the process variables to the preset values, to react to alarms, to keep a log of the important events of the casting operation and to trigger an emergency stop if one of the parameters cannot be maintained within the tolerances.

Several centimeters before the desired ingot length is reached, the end cast phase begins. It enables the process to be stopped while simultaneously minimizing losses of metal in the




**24.2 – Figure 1 – Typical Automated EM/DC Casting Sequence**

troughs and arranging for ingots of the required length to be obtained.

## 24.3: Safety Considerations

The automated system needs to be designed to control every conceivable situation that may occur to end the cast.

### *24.3.1: Premature End of Cast*

The premature end of cast can either be a planned action intentionally introduced by the casting machine operator before the slabs have reached the set length or an automatic action initiated by process computer when a planned cast length has been reached or when an upset condition has been recognized by the process computer and the programming requires a premature end of the cast.

### *24.3.2: Quick Stop*

The terms Quick Stop, Rapid Stop, or Abort all refer to the unexpected termination of a drop. The quick stop is a premature interruption of the cast. It is done in order to prevent injury to people or damage to the machine. It is initiated by the casting machine operator or automatically by the process computer without any delay when the alarm of "unacceptable" defect is displayed once one or more of the critical casting parameters is outside the acceptable tolerances.

### *24.3.3: Emergency Stop*

The Emergency Stop is actuated by either: 1) the casting machine operator if it is determined there is a potentially serious situation for personnel or equipment; or 2) by the process control computer. The process control computer will typically be programmed to do this under the following situations:

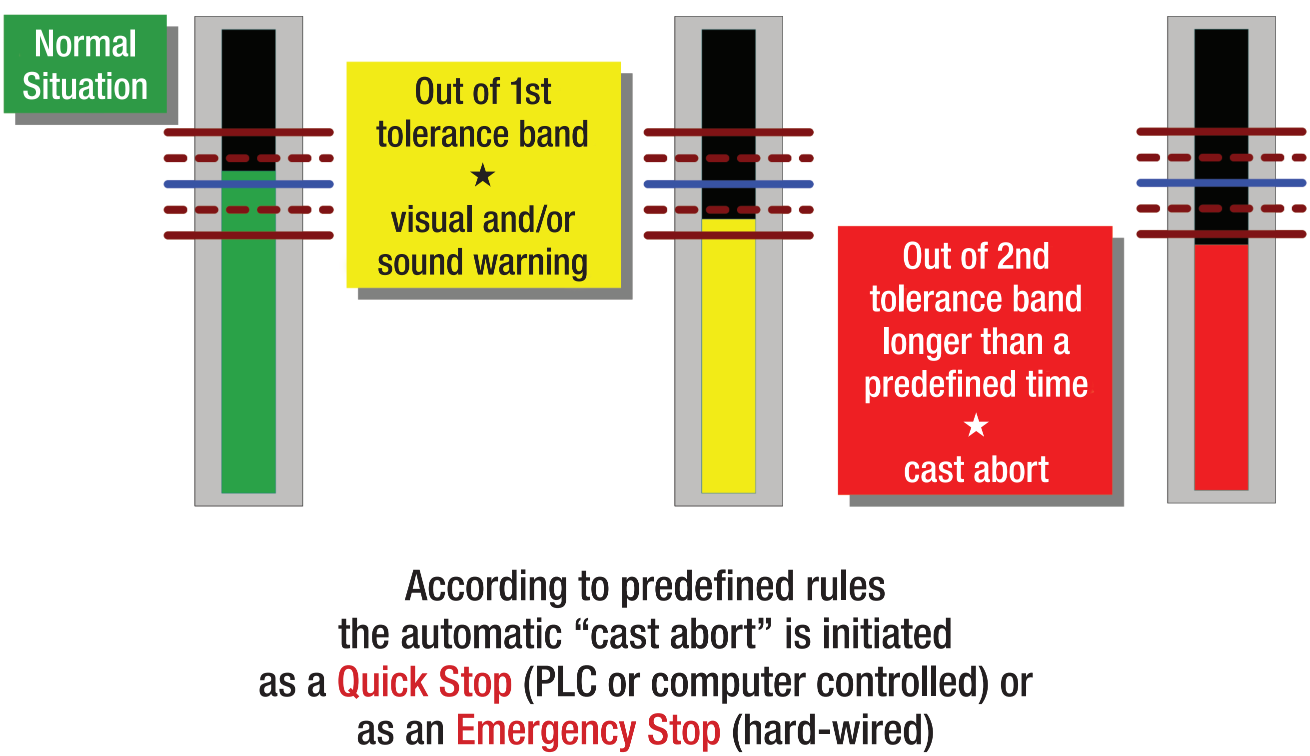
a. the supply of cooling water is interrupted;

b. the convertor shuts off (e.g. due to a power failure);

c. the process computer fails;

d. overheating of the system, which may be at various locations from the convertor to the inductor coil of any mold position;

e. the occurrence of an electric arc (e.g. against the inductor) where the EM field has gone to ground.




**24.3.2 Figure 1 – Automated Safety Stops in EM/DC Casting**

As the situation is with the Quick Stop, the Emergency Stop may be a manual stop by the operator or an automatic stop by the process computer. Quick Stop and Emergency Stop protocols are generally based on the following:

a. Molten Metal: For both situations the supply of molten metal to the casting table is stopped and the molten metal is directed back to the furnace and / or into drain pans.

b. Platen: For both situations the lowering of the platen is stopped.

c. Cooling Water: For both situations, the supply of cooling water is typically not interrupted.

Note that the most significant difference in a Quick Stop and an Emergency Stop is normally related to the correct operation of the EMC converter. EMC converters have built-in systems that will initiate a Quick Stop or Emergency Stop when the converter senses problems outside of acceptable operating conditions. Typically, both Quick Stops and Emergency Stops are caught and acted upon by the computer/PLC systems before an operator can react to any out of control condition.

# Section 25
# Aluminum – Lithium Casting

Aluminum – Lithium (Al-Li) casting is a subset of conventional Direct Chill (DC) ingot casting requiring special apparatus and procedures. It is known from several decades of experience that Al-Li alloys can be safely handled and successfully commercially cast. However, there are a number of significant differences in Al-Li casting when compared to conventional DC casting. These include the explosiveness of the alloy, the handling of lithium metal, the use of a protective atmosphere, refractory contamination, and the separation of Al-Li from the regular scrap and dross stream.

Further information on these differences and their management can be found in the Aluminum Association Publication T-4, *Safety, Health and Recycling Aspects of Aluminum-Lithium Alloys.*

## 25.1: Explosion Prevention

Previous study has shown that aluminum alloys containing lithium have a propensity to explode much more violently than non-lithium alloys. The mechanism of the violent nature of the explosions is related to the lithium interaction with water during molten metal contact. When molten Al-Li alloys come in contact with water, the following reaction occurs:

$$Al\text{-}Li + H_2O > LiOH + H_2$$

The release of hydrogen noted in the formula above creates an explosive atmosphere within the casting pit. This is in addition to the steam and chemical reactions that occur in conventional molten aluminum explosions. Common Al-Li alloys are composed of customary aluminum alloying elements with lithium levels from around 1 to 3%. The explosive nature of Al-Li alloy is increased as the lithium level in the alloy increases.

Casting operations must be established to prevent molten Al-Li spills from coming into intimate contact with casting water.

a. Al-Li alloys have molten metal spills, breakouts; etc. similar to the problems experienced in the conventional DC process. Molten metal spills create a condition where the molten Al-Li alloy and casting water come into contact with each other. A molten Al-Li spill should not be allowed to be completely submerged in water. Common techniques used to minimize molten metal and water contact are to use a dry pit or capture the spill above the casting pit water.

b. Once a molten metal spill has been detected, shut off the ingot cooling water as soon as possible.

c. Since hydrogen gas will be produced by the molten spill, an extremely efficient casting pit exhaust system must be in place to keep the hydrogen evolution below threshold ignition levels. In the confined space in the casting pit, air turnover must be such that the lighter-than-air hydrogen gas is not permitted to accumulate in the upper region of the pit. Shutting off the casting water limits the molten metal spill interaction with water, reducing the amount of hydrogen gas produced.

d. Lithium containing dust and fumes will be produced during the reaction. These are breathing irritants that require appropriate ambient air turnover and replacement.

## 25.2: Handling of Lithium Metal Prior to Alloying

Lithium is an element that is highly reactive in contact with many other substances, releasing large quantities of heat during that reaction. It can also react violently with water, the humidity in air, and the moisture in other substances, releasing hydrogen gas, which may catch fire explosively. Corrosive fumes of lithium oxide and/or lithium hydroxide are also released. In addition, lithium metal has an auto-ignition temperature of 354°F (179°C).

a. Solid and molten lithium must be kept from any possible contact with water due to the potential for a violent reaction and possible flash fire.

b. Solid lithium metal must be handled with dry rubber gloves and safety glasses or goggles. Contact causes skin burns and eye damage. Dust masks are recommended.

c. Handle solid lithium under inert gas or alternately in open atmosphere at room temperature either coated with mineral oil or where the relative humidity is maintained below 50%.

d. Store solid lithium in the original supplier's packaging. If opened, store in a dry environment containing <2% humidity, away from water, acids, and oxidizing materials. Lithium should not be stored in ambient air. Solid lithium metal should be stored in a protected and secure facility where it cannot be inadvertently used in non-lithium casting operations.

e. In case of solid or molten lithium fire, do not use water, sand, or $CO_2$. Preferentially use graphite, copper powder, or Lith-X® for firefighting.

f. Flame retardant, personal protective clothing (PPC) is required when handling molten lithium.

Reference: FMC Lithium SDS, Ref. Number QS-MSD-151 for more information.

## 25.3: Use of a Protective Atmosphere

Lithium metal can be safely alloyed with aluminum and its alloys, but specialized lithium related handling processes and equipment are needed. Typical alloying techniques include adding commercially pure solid lithium directly into the molten metal, pre-melting the lithium and injecting it into the molten bath, or use of a lithium master alloy. To eliminate auto-ignition of lithium, a protective atmosphere must be provided. Once lithium has been introduced into molten aluminum, the protective atmosphere must be maintained to keep the lithium contained in the melt. Otherwise, the lithium will oxidize into the ambient air, creating fuming, oxidation, and potential flashing.

a. Lithium must be immersed into molten aluminum through an inert protective atmosphere, typically argon. Nitrogen is not a suitable substitute for argon. The protective atmosphere must be maintained any time there is lithium present in the molten alloy. This protection is required from the melting furnace through molten metal transfer to the casting car until the ingot casting operation is completed.

b. Casting operations require more process control than typically used in conventional DC casting due to all stages of the process being covered by the hardware over the protective atmosphere. Observation of the process is typically through sight ports and feedback from instrumentation.

## 25.4: Molten Aluminum-Lithium Containment

Al-Li alloys are corrosive, damaging containment refractories that would not be adversely affected by conventional alloys. In general, higher lithium containing alloys are more sensitive to refractory damage than lower lithium containing alloys.

a. Lithium has the propensity to accelerate refractory degradation in furnaces not meant to contain Al-Li alloys. Studies have shown that even at a low concentration (a few tenths of a percent) lithium rapidly harms conventional refractories.

b. Induction, electric, and indirect reverbatory furnaces can be used, although special Al-Li resistant refractories are required.

c. Care must be taken to protect and contain molten metal spills that can occur under melting and holding furnaces from a breakout. Water must not be allowed to collect in such areas. Appropriate steps must be taken to insure that if water is present, its existence is alarmed, and corrective action immediately taken.

d. It is preferable to have an engineered air ventilation system for the Al-Li facility to reduce personnel exposure to corrosive lithium-based fumes from a molten metal spill or breakout.

e. Al-Li resistant refractories are also required for molten metal transfer systems, in-line degassing and filtration devices, and any other places where molten Al-Li alloy comes into contact with refractories. The refractories in hot-top billet casting molds are also subject to the same conditions and special requirements.

## 25.5: Tools & Equipment Used in Molten Al-Li

Molten Al-Li alloys and oxides of Al-Li alloys are hygroscopic, picking-up moisture from the atmosphere. Any hand or furnace tool that has been in contact with molten Al-Li must be properly dried and kept warm before subsequent usage. Drain and skim pans must be preheated and kept warm. Cold pans and tools enable moisture to collect, creating an explosion hazard.

## 25.6: Al-Li in the Scrap Stream

Al-Li scrap must not be allowed to intermingle with conventional alloys. Segregation of the different scrap streams must be managed such that Al-Li scrap cannot be blended with non-lithium containing alloys. If there is question, the batch must be considered to be contaminated with lithium. When a high concentration of Al-Li scrap is added to a conventional furnace operation, it can cause personnel irritation from fuming. Previous study has shown that lithium concentration as low as a few tenths of a percent in conventional aluminum furnaces can also cause premature refractory failure. Further, it can damage the refractories in transfer and casting troughs while causing unexpected and unexplained breakouts and molten metal spills.

## 25.7: Handling Al-Li Scrap

All Al-Li containing scrap, in any form from ingot to sheet & plate to chips & swarf, will oxidize. All Al-Li charge material must be properly dried and preheated prior to introduction into a molten bath. Drying Al-Li scrap and allowing it to cool to ambient is not an acceptable practice prior to charging. This includes introduction of the Al-Li scrap into molten metal either containing or not containing any lithium.

Al-Li drain scrap and dross must be kept separate from conventional aluminum scrap. Drain scrap and skulls can be reused upon proper drying and preheating. Al-Li dross should be cooled (to eliminate burning and thermitting) in a dedicated area that captures dust and fumes. Cooled dross must be stored indoors.

# Section 26
# Other Casting Systems

## 26.1: Continuous Casting

A variety of continuous casting machines produce aluminum products in a wide variety of shapes, sizes and alloys. For safe operation, understand and follow the practices received from the manufacturer or developed and written in your Casting Standard Practices Manual.

## 26.2: Casting Sow and Foundry Ingot

These general precautions for handling and transferring molten aluminum apply to these operations:

a. Keep inner surfaces of ingot and sow molds free of scale or rust.

b. Inspect molds for cracks on a regular basis and remove cracked molds from service based on plant crack acceptance criteria.

c. Preheat or oil cold molds before pouring molten aluminum in them.

d. Do not use molds as trash containers. Molds should be empty, clean and hot or oiled before molten aluminum is added.

e. If a release agent is used, dry the coating per the manufacturer's specification with applied heat before pouring molten aluminum in the mold.

f. Keep tools, skimmers, etc. dry and warm before immersing in the molten metal.

g. Never use lime as a coating for tools or molds.

h. Appropriate protective clothing and equipment must be worn during the transfer, mold filling and skimming operations. (See Section 11: PPE)

# Section 27
# Cleanup of Metal Spills

Since major spills of molten metal occur infrequently, there is a risk that workers may forget proper procedures for cleanup. Therefore, this work should be supervised closely by experienced personnel. An inspection of the area should be made before cleaning up a spill. The size of the spill and potential hazards hidden by the spill should be taken into consideration. Workers involved in cleanup should wear proper clothing and protective equipment. If a torch is used or heat applied, standby fire extinguishers should be on hand.

## 27.1: Spills from Furnaces and Transfer Equipment

When molten aluminum spills on concrete, some small but potentially hazardous eruptions of metal may result from the contact between the molten metal and residual and combined moisture in or on the concrete.

If the flow of metal cannot be stopped immediately, try to contain the flow over the floor area by using sand, bone ash, whiting or alumina as a dam. Do not attempt to halt the flow of metal with shovels or hand tools.

Before the metal is completely solidified and still in a mushy condition, under some circumstances it can be broken up into manageable sizes by the use of a rake or raveling tool. Secure footing is a must when performing this task. Workers should wear a face shield, secondary and primary protective clothing in addition to the normal safety glasses, and should have head covering, gloves, and safety shoes. Watch for expulsions and spalling of the concrete.

If the metal cannot be separated into manageable sizes while it is solidifying, it will be necessary to break or cut it up into smaller pieces. After solidification, this can be a difficult task. In some cases, a front end loader can be used to lift and break up a solidified spill.

An oxygen lance may be used to cut up large pieces of metal after solidification. Great care must be taken that molten aluminum formed by the high heat of reaction does not come in contact with any water in the area. Globules of molten metal can be formed at very high temperatures when an oxygen lance is used. A thorough safety review should be performed before oxygen lancing, which should be used as a last resort.

## 27.2: Spills in Casting Pits

Relatively small streams of molten aluminum (bleed outs and spills) falling into the casting pits are usually broken up on contact with water in the pit and solidified into smaller pieces. Normally, these pieces can be removed fairly easily. Large spills pose problems, particularly when the metal solidifies in large pieces. The problem is complicated by the difficulty of getting to the spill.

Great care must be taken in using an oxygen lance in cutting up large chunks of metal spilled in the pit area. The use of oxygen lancing over a casting pit containing water should be avoided. As indicated above, very high temperatures are developed and super heated liquid metal globules can fall into the pit water, which may cause a severe explosion.

# VII

# PROTECTIVE COATINGS: CASTING PITS AND EQUIPMENT

# Section 28
# Protective Coatings for Casting Pits and Equipment

Extensive test work has established that surfaces of metal equipment and related components* in DC casting pits, which may be struck or contacted by both molten aluminum and water, must be properly coated and maintained with a protective layer of suitable organic material. When properly maintained, protective coatings effectively minimize potential explosions from molten metal bleed outs or spills that can occur when molten metal comes in contact with coated steel and concrete.

Before being used, the surfaces of metal casting equipment* and the walls and bottom of the casting pits must be coated with a company approved organic coating. Once the equipment and pits are in use, the condition of this coating must be inspected regularly and replaced or patched whenever it is damaged or worn off. It has been demonstrated conclusively that protection against explosions is obtained only with coatings that provide 100% coverage, with no breaks or openings permitted.

Several types of protective coatings have been tested to date and found to be effective in preventing molten metal-water explosions where molten metal comes in contact with steel or concrete following bleed outs and spills during DC casting. These materials should be used on DC pit walls as well as metal casting equipment such as platens.

Prior to the early 1990's most of the test data and experience had been gained with two proprietary coatings: bitumastic material named Tarset Standard and an epoxy named WiseChem E212F. Tarset Standard was withdrawn from the market in approximately 1994. Subsequent to that withdrawal, the Association coordinated a program at the Alcoa Technical Center to test coatings as possible replacements for Tarset Standard. The effort began in mid-1995 and was supported by 14 aluminum companies including five outside the U.S., an equipment manufacturer and coating manufacturers. As a result of this program, three new coatings were identified as having the ability to prevent explosions from bleed outs into the pit during DC casting.

These coatings were:

- Courtaulds Intertuf 132HS coal tar epoxy (no longer marketed)
- Carboline Multi-Gard 955CP
- WiseChem E-115

Reference ATC Report No 97-475-18-DDL, available from The Aluminum Association, for the details regarding this testing.

In addition, further testing of the three coatings listed above was performed by ATC (Reference ATC Report No 00-121) to investigate the effect of coating cure time on adhesion and explosion avoidance and is available from The Aluminum Association.

In addition to the ability to protect against explosions, other considerations for these coatings are ease of application and, particularly, the ability to be applied to and adhere to a wet or moist surface. This is important in the case of DC casting pit walls which are difficult to dry completely.

Heavy grease coatings on surfaces exposed to contact by both molten aluminum and water have been found to minimize the potential of explosion. However, these coatings are difficult to maintain.

Research has shown that contact of molten aluminum with water on a rusty steel or iron surface constitutes a particularly dangerous situation for explosions. Therefore, all iron, steel, and stainless steel components of casting equipment* and support structures should be protected and maintained with a suitable organic coating.

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* This does not refer to molds, starting blocks or other equipment used to cast, i.e., solidify, the molten aluminum or surfaces or casting equipment such as guides which must be kept lubricated.

Diagrams of typical DC casting equipment and pit designs are available in Section 22.

Based on the results of the testing programs, it is recommended that any organic material used to coat steel and iron equipment in and around the casting pit be free of readily reducible oxides such as iron oxides and residual chemically combined water.

# VIII

# CASTHOUSE MOBILE EQUIPMENT

# Section 29
# Casthouse Mobile Equipment

## 29.1: General

Mobile equipment use in and around the casthouse is needed for a variety of reasons, including transporting molten metal, moving and charging scrap, tending furnaces, loading and unloading at docks, and to facilitate travel from one area to another. Mobile equipment movement can occur at times, and in environments, that may cause limited visibility or difficulty in hearing the approach of mobile equipment and this can place demands on both the operator and the other employees working in the area.

It is essential that all operations have robust systems in place to ensure that operators are safe to operate the equipment through information, training, supervision and medical fitness. The equipment also needs to be safe to use and fit for its purpose so that those personnel who work close to mobile equipment are not placed in danger.

# Section 30
# Pedestrian Interaction / Segregation

It is important to provide good visibility and appropriate signage, warning signals, gates, barricades, mirrors or other traffic and pedestrian controls for routine moving of mobile equipment following a formal risk assessment process. Physical segregation of pedestrians and free moving mobile equipment should be provided where feasible at crossings for normal operation, as well as during maintenance, construction or other temporary activities.

## 30.1: Risk Assessment

In order to increase the overall safety of all employees, risk assessment should be used to determine high risk mobile equipment operations–risk to both operators of the equipment and the employees on the plant floor (pedestrians).

In order to identify risks and prioritize actions around mobile equipment, risk assessments should cover the following aspects:

a. traffic participation (pedestrians, vehicles, and lifting equipment),

b. traffic flow (speed, direction, and interactions),

c. traffic density and frequency (such as peak flow).

When determining the order to assess mobile equipment and pedestrian interfaces, use past incident history, traffic flow patterns, process flow patterns, equipment layouts, employee feedback, near miss reports and measurements of the present traffic to find the high risk areas and establish the assessment order.

The relative risk of each of the mobile equipment and pedestrian interfaces should be determined using a risk assessment tool based on frequency of exposure, potential severity of a collision and the number of individuals exposed. Conduct an analysis of mobile equipment and pedestrian flow paths to analyze how raw material, finished material, rework, scrap, maintenance and administrative flow paths interface with each other and pedestrians. For example, an interface with a relative moderate risk that is heavily traveled at shift change may rank high in overall risk.

All risk assessments should be documented and revised periodically and if there are changes to the site or in the event of an incident.

## 30.2: Protection of Pedestrians

The prioritization of pedestrian protection methods from highest to lowest implementation desirability should be as follows:

1. Design of work areas, equipment, plant layout and process flow patterns can eliminate the need for mobile equipment or reduce traffic flow by establishing simple flow paths and eliminating scrap, waste and rework that increase mobile equipment and pedestrian interfaces.
2. Engineered safety features such as sensor lights, interlocks, indicators and light curtains.
3. Safety devices such as physical barriers, mirrors, motion detectors or sensors and gates. For high risk mobile equipment and pedestrian interfaces, physical separation of mobile equipment and pedestrians is preferred.
4. Warning devices such as strobe lights, audible signals, and warning lights and signals. Warning devices may be appropriate where the relative risk is less severe or as an additional layer of control.
5. Procedures, training and personal protective equipment including hazard recognition, standard operating procedures, location specific rules and high visibility vests, hard hats and other personal protective equipment. High visibility clothing including reflective vests, high visibility hard hats, reflective decals and reflective strips may be especially appropriate where long term solutions and engineering controls are being planned.

# Section 31
# Equipment Specifications

The following should be considered when specifying, purchasing or leasing free moving mobile equipment:

## 31.1: Forklifts / Powered Industrial Trucks

Forklifts that operate in molten metal areas should have a fully enclosed cab. The front shields, overhead protection and windows should have molten metal splash and impact resistance equivalent to 0.5 inches (13mm) of polycarbonate. Air conditioning should be provided for fully enclosed cabs to minimize heat stress.

If it is infeasible to have a fully enclosed cab in molten metal areas, mobile charging equipment used to charge melting furnaces should be equipped with a front shield that can protect the operator from splashing metal. In addition, openings around floor controls, etc., should be sealed and an appropriate top cover or shield employed. The shield should be constructed to minimize the possibility of any metal splash reaching the operator. Shield design should be as per above and all should be held in a strong frame.

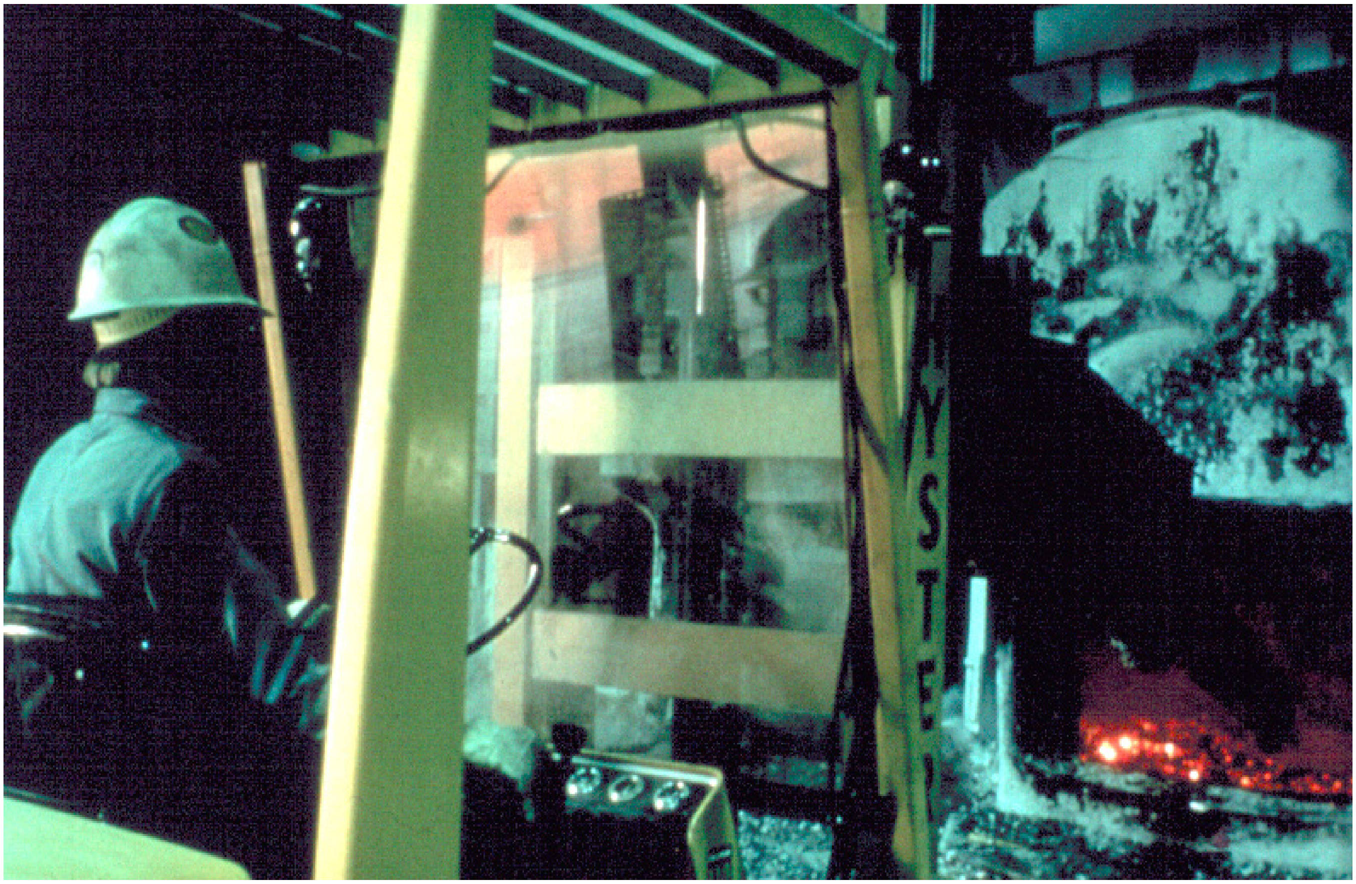
31.1 Figure 1 shows a load of scrap being charged into a furnace using a shielded fork truck. Although shields on fork trucks provide good protection against metal splash, they cannot be counted upon to protect the operator in the event of an explosion in the furnace during charging operations.

31.1 Figure 2 shows a fork truck following a furnace molten metal explosion.

As noted above, the best choice for protecting a mobile charging equipment operator is to utilize equipment that has a fully enclosed cab.

Additional considerations for forklifts used in molten metal operations include:

a. Warning devices such as special flashing lights, audible alarms, bells or horns.
b. Audible back-up alarms that can be heard above ambient background noise levels.
c. Front and rear lights; e.g. head lights.
d. Horns that can be heard above ambient background noise level.
e. Mirrors.
f. Hydraulic systems (hoses and fluids) that are designed for foundry use. To the extent possible the hydraulic fluids should be fire-resistant.



**31.1 Figure 1 – Charging Scrap into a Remelt Furnace Using a Shielded Fork Truck**

**31.1 Figure 2 – Fork Truck Following a Furnace Explosion**

**31.1 Figure 3 – Foundry Package Equipped Fork Truck in Use**

g. Solid tires–to prevent explosions if in contact with molten metal.

h. Diesel fueled equipment is preferred in molten metal operations toward the goal of keeping pressure vessels like propane cylinders and highly flammable fuels like gasoline out of casting areas.

i. In some situations, front and rear cameras and a monitor in the cab so operators can see in the direction of travel.

j. Other safety features such as blue-spot pedestrian warning lights, seat belt interlocks, back up sensors, impact/shock-detection system, tilt indicators, weight-alert, etc. as deemed necessary by local risk assessment.

Many equipment vendors can provide specification packages for fork trucks designed for foundry or casthouse use that include all or most of the above items, including enclosed cabs. 31.1 Figure 3 provides a picture of fork truck equipped with a ‘foundry package’ in use in a high temperature metal environment.

### 31.2: Overhead Cranes, Hoists, Jibs, and Other Mobile Equipment

Cranes and other mobile equipment used in cast houses need to be designed for use in the harsh environments associated with aluminum casting operations (high heat, molten metal, heavy dust, etc.). This may require more robust equipment, fixtures, wire ropes, and other special features to allow for continued safe operation in a cast-house. Inspection frequencies and replacement of parts may need to be more frequent than lighter duty applications.

## Section 32 Qualification, Training and Evaluation

Training on mobile equipment use must be conducted by competent persons who have mobile equipment knowledge, training, and experience. Training must include safety rules, operating procedures, equipment controls and safe work instructions. It should be a combination of classroom instruction and practical training.

Forklift / powered industrial truck formal retraining and evaluation needs to be conducted every 3 years or more frequently if mandated by local requirements. Other types of mobile equipment require training prior to use and periodic refresher training (frequency varies).

Personnel operating mobile equipment must be certified to safely operate mobile equipment for which they have been trained. This may require several certifications if different types of mobile equipment are to be used (counterbalanced forklift truck, 4-way reach truck, all-terrain lift, etc.).

All personnel who perform periodic and preventative maintenance and inspections for mobile equipment (to include cranes, forklifts, etc.) need be competent and receive the appropriate training.

Persons working within or around loading areas and docks need documented training on safe loading operation and use of dock safety devices and equipment.

Refresher training shall be conducted as required by local regulations and when an operator is involved in an incident, is observed to be operating in an unsafe manner, is assigned to a different type of mobile equipment, or when conditions in the workplace change that could affect the safe operation of mobile equipment.

Forklift / Powered Industrial Truck Training will typically include the following topics:

a. Operating instructions, warnings and precautions for the type of mobile equipment the operator will be authorized to operate.
b. Industrial vehicle controls and instrumentation location, what they do and how they work.
c. Engine or motor operation.
d. Steering and maneuvering.
e. Visibility, including restrictions due to loading.
f. Lifting accessory operation and use limitations.
g. Equipment capacity, stability.
h. Equipment inspection and maintenance that the operator will be required to perform including pre-use inspections.
i. Any other operating instruction, warning or precaution listed in the operator’s manual.
j. Conditions where the equipment will be operated.
k. Composition of probable loads and load stability.
l. Load manipulation, stacking and un-stacking.
m. Pedestrian traffic areas where mobile equipment will be operated.

n. Narrow aisles and other restricted places where vehicles will be used.

o. Ramps and other sloped surfaces that could affect stability.

p. Other unique or potentially hazardous environmental conditions that exist or may exist in the workplace – molten metal for example.

q. Closed environments and other areas where insufficient ventilation could cause a build-up of carbon monoxide or diesel exhaust.

r. Refueling and recharging batteries requirements.

s. Good practices such as sounding the horn when moving loads, entering and leaving premises etc.

# Section 33
# Operating Guidelines

The following information is provided to identify some safe operating practices for the use of mobile equipment. The list is not comprehensive and local conditions may be different. This should only be used as a guideline and not a substitute for detailed risk assessment and local procedures.

## 33.1: General

a. It is important to ensure only personnel with the appropriate training and certification operate or work in and around free moving mobile equipment.

b. Operating areas must use visible and appropriate signage, warning signals, gates, barricades, mirrors or other hazard controls for routine moving of mobile equipment following a formal risk assessment process.

c. Speed limits for free moving mobile equipment and overhead cranes need to be established and enforced.

## 33.2: Forklifts / Powered Industrial Trucks

a. Pre-use inspections need to be performed on moving mobile equipment before each shift that the equipment is to be used. Mobile equipment must be taken out of service if the pre-use inspection finds conditions that impacts safe operation.

b. Operator and passenger restraints must be provided and utilized on all free moving mobile equipment at all personnel seating positions.

c. Modification and retrofit of operator and passenger restraints should only be made with the written approval of the equipment manufacturer.

d. All free moving mobile equipment should be fitted with an appropriate fire extinguisher unless prohibited by local requirement or risk assessment.

e. Personnel working in close proximity to free moving mobile equipment should wear high visibility reflective clothing or other means to increase visibility.

f. Effort should be made to provide safe distance between pedestrians and running vehicles. If a vehicle is to be approached, the truck should be stopped and forks lowered to the ground.

g. If the view of a mobile equipment operator is obstructed, then methods should be used to increase safety such as operating the vehicle in reverse, use of cameras, using a signal person, etc.

h. When traveling on an incline, keep the forks pointed downhill without a load, and pointed uphill with a load. Do not attempt to turn the forklift until it is on level ground. Plans should be developed and implemented for safe methods to use free moving mobile equipment to tow or pull objects, including moving trailers, towing stuck in snow, mud, or removing stationary objects such as process equipment, hoppers, stumps or rocks. The implemented safe methods need to consider the rated capacity of the hitch, the precautionary safe distances in the event of the load becoming unstable and the trajectory of any broken pulling devices, such as chains.

### 33.3: Cranes and Hoists

a. All hoists must be fitted with an upper over-travel device to prevent the load block from passing the safe upper limit of travel. The upper over-travel device must only be used as a safety device in the event of an emergency and not be used for positioning of the hoist. A second device actuated before the upper over-travel device as the hoist moves up is needed if the operation performed by the hoist requires a positioning device to stop the upward motion of the hoist.

b. A hoist lower travel limit device needs to be incorporated in the design if the load block enters a pit or hatchway during normal operation.

c. It is extremely important that no one be allowed to walk under a load or move a load over a person or occupied area such as break rooms, control rooms, etc. (unless specially designed safety features are in place).

d. Lifting accessories such as slings, chains, beams, eye bolts etc., must be inspected periodically by a competent person based upon the workplace hazards, reported incidents, utilization rates, maintenance history and local requirements.

e. A visual inspection needs to be performed prior to the initial use of any lifting accessory during a shift.

# IX

# EXPLOSIONS INVOLVING MOLTEN ALUMINUM

# Section 34
# Explosions Involving Molten Aluminum

In general, whenever two liquids at widely different temperatures are brought into intimate contact, an explosion can result, particularly if the colder liquid has a relatively low boiling point. This is certainly the case with molten metals and water. In most instances, the water is trapped between the molten metal and a solid surface, it the water quickly turns to steam and, in so doing, expands approximately 1700 times. This rapid expansion, accompanied by a rise in temperature, is an explosion that can throw metal a large distance, injure employees and damage equipment. The water must be trapped in order to give rise to an explosion. If the molten metal is able to push the water aside or if the water contacts the metal surface but does not penetrate beneath the surface then any steam formed will dissipate harmlessly.

With aluminum there is an additional factor to cause concern. Aluminum is a very reactive chemical element with a great affinity for oxygen with which it is almost always combined in nature. Just as it requires a large amount of energy to break the aluminum-oxygen bonds and produce metallic aluminum in a reduction cell, that energy will be released if the aluminum is able to recombine with the oxygen from either water or air. From thermodynamic calculations it has been estimated that the energy release if one pound of aluminum fully reacts with oxygen is equivalent to detonating three pounds of trinitrotoluene (TNT).

Based on the many years of research into the cause and prevention of molten aluminum-water explosions, and from the many investigations of plant explosions, it is apparent that there are three different types of explosions that can occur. For purposes of incident reporting (see Section 37) the Aluminum Association has defined them as Force 1, Force 2, and Force 3 explosions. 34 Figure 1 provides a table which characterizes these three force levels by five different attributes. All five attributes need to be considered when rating an explosion.

Additional descriptions of these force levels follow:

Force 1 explosions, also referred to as "steam explosions," occur when molten metal traps water which quickly turns to steam. These explosions are characterized by metal dispersed a short distance, usually up to about 15 feet and often less than 10 pounds of metal, with little or no property damage. Employees can receive burns if struck by the molten metal but no fatality has ever been reported to the Association from a Force 1 explosion.

Typical incidents of Force 1 explosions arise from moisture in molds or starting blocks at the start of casts, moisture on scrap or ingot charged into furnace melts, moist or cold tools inserted into molten metal, moisture in trough linings and moisture in molds or pans into which molten metal is drained following a cast.

Force 2 explosions are violent steam explosions. As with a Force 1 explosion, water is trapped and turns to steam. But in this case, probably due to confinement, the steam pressure is not as easily relieved and builds up to the point that considerably more metal is thrown a greater distance. The Force 2 explosion is characterized by metal dispersed 15 to 50 feet, often to the roof of the plant, and there may be some accompanying property damage.

| Attributes | Force 1 | Force 2 | Force 3 |
|---|---|---|---|
| Property Damage | None | Minor | Considerable |
| Light | Minimal | Flash | Intense |
| Sound | Short Cracking | Loud Report | Painful |
| Vibration | Short Sharp | Brief Rolling | Massive Structural |
| Metal Dispersion | < 15 Feet | > 15 – 50' Feet | > 50 Feet |

**34 Figure 1 – Explosion Characterization**

Force 2 explosions can be deadly. Many of the fatalities and serious injuries from molten metal incidents reported to the Association were attributed to these explosions, particularly from clothing being set on fire from the large amounts of molten metal thrown by the explosion. Typically, Force 2 explosions result from wet scrap or improperly preheated sow charged into molten metal in a furnace, massive bleed outs during DC casting, and molten metal drained into wet or contaminated molds or pans.

Force 3 explosions are the catastrophic events arising from reaction of molten metal with oxygen from air, water or oxidizers such as fertilizers, etc. They are characterized by considerable property damage and metal dispersed more than 50 feet away; often the metal has disappeared and what remains is a white or gray powder, aluminum oxide. Examples of Force 3 explosions are shown in 1 Figure 1 and 1 Figure 2. In both instances multiple fatalities and severe damage were the result.

In research tests in which 50 pounds (23 kg) of molten aluminum were dropped into water tanks (see Section 36), high-speed photography revealed that, in the most severe explosions, molten metal was dispersed above the tank where it reacted with air. From this it can be inferred that many Force 3 explosions are the result of an initial explosion in the molten metal (from water or other contaminant) blowing out finely divided molten metal where it reacts with air similar to an aluminum powder explosion. This reaction is highly exothermic and, because of the large amount of surface area involved, can account for the destruction accompanying these events.

Reports of Force 3 explosions have been attributed to charging of wet scrap and non-preheated sow, massive DC casting bleed outs and, often, contamination. Other Force 3 explosions have been attributed to charging fertilizers such ammonium nitrate and when molten metal has come into contact with heavily oxidized metals and other oxidizing agents. Other sources of contamination in scrap, such as live ammunition and closed containers, have been suspected of causing catastrophic explosions.

## Section 35
## Thermite Reactions

Molten aluminum reacts with oxides of heavy metals such as iron, copper, lead, bismuth and nickel to free the heavy metal and produce aluminum oxide. These reactions, called thermite reactions, have been and continue to be noted in industry. Thermite reactions generate large amounts of heat, but not gases. In melting and casting aluminum, care must be taken to guard against contact of the molten aluminum with rusty iron and steel, heavily oxidized copper, and other oxidized materials.

In melting operations, sustained thermite reactions do not occur below the surface of the molten aluminum unless the temperature is extremely high, about 3000°F (1650°C). However, if pieces of rusty iron and heavily oxidized copper in the charge to the furnace become trapped in the skim or dross layer at the surface of the molten aluminum, thermite reactions can take place. Surface oxidation of thin films of aluminum and/or aluminum-magnesium alloys in the skim and dross can provide local temperatures high enough to initiate these reactions along with small explosions and flashes of light. These observations substantiate the occurrence of thermite reactions at the source of the melt with heating and increase in pressure of gases in or immediately adjacent to the materials which make up the dross layer.

It is not uncommon for lead and bismuth to penetrate through a furnace lining and accumulate under the furnace floor. These metals will oxidize in an ingot plant environment. If the furnace lining has a catastrophic failure and molten aluminum drops onto the oxidized lead and bismuth a thermite reaction can occur that could destroy the furnace. In plants that produce 2011 or 6262 alloys the accumulation of lead and bismuth under the furnaces should be controlled.

Violent explosions have occurred in operations where masses of heavily oxidized copper wire were added to molten aluminum to produce aluminum-copper alloys. In these instances, the oxide coating on the copper prevented dissolution of the underlying copper metal and, when the mass of wire with adhering films of aluminum and dross was removed from the furnace, almost immediately a violent explosion took place.

# Section 36
# Research on Molten Aluminum-Water Explosions

## 36.1: Background Information

When molten aluminum and water come into contact during casting operations, the resulting reaction can vary from a harmless evolution of steam to a violent explosion with extensive damage and loss of life. As a result of controls developed by the industry, only a small percentage of the spills of molten aluminum into water that occur during direct chill casting operations lead to a serious explosion even when large amounts of molten metal are involved. The situation, however, is quite different in melting and transfer operations. If water is introduced under molten aluminum in a furnace, trough, mold or drain pan, or in casting operations if water somehow is introduced under molten aluminum in a mold or starting block, an explosion of some magnitude is almost certain to occur.

As repeatedly stated in these *Guidelines*, materials added to molten aluminum must be free of moisture, volatile materials, and oxidizer chemicals, such as phosphates, nitrates and sulfates. Tools should be properly cleaned, dried, and heated before being immersed in the molten metal.

Over the years, the aluminum industry has made an extensive effort to gain an understanding of explosions that can occur when molten aluminum is dropped into water. Following a serious explosion in a pilot plant in 1949, Alcoa began research to determine the conditions leading to explosions during DC casting and to develop preventive measures. Other organizations, including other aluminum companies in this country and abroad, have spent considerable time and effort investigating explosions which have occurred during DC casting and melting of aluminum and searching for and evaluating methods of protection. Beginning in 1969 the Aluminum Association sponsored several basic studies of molten aluminum-water reactions, their initiation and prevention conducted at Battelle Memorial Institute, IIT Research Institute, Alcoa Research Laboratories, and the Sandia National Laboratory. Most recently, the Association coordinated an industry effort at the Alcoa Technical Center and Oak Ridge National Laboratory to evaluate protective coatings for DC casting operations. These efforts are summarized below in chronological order.

## 36.2: References

Published papers, reports and videos covering studies of molten aluminum-water explosions are listed in Part XI: References. The videos are particularly useful in training and safety programs directed to safe melting and casting of aluminum alloys.

## 36.3: Early Alcoa Studies

The first research program at Alcoa, conducted by George Long and published in 1957, was an empirical study in which molten aluminum was dropped into a tank containing water to simulate a bleedout during DC casting. In all, 880 tests were carried out. The bulk of these tests involved sudden discharge of 50 pounds (23 kg) of commercially pure aluminum through a 3 ¼ inch (82 mm) diameter tap hole into a 12 inch by 12 inch by 12 inch (300 mm by 300 mm by 300 mm) steel or concrete container partially filled with water at ambient temperature.

Long summarized his findings by citing three requirements for producing an aluminum-water explosion during casting:

a. Molten metal in considerable quantity must penetrate to the bottom surface of the water container.

b. A triggering action of some kind must take place on this bottom surface when it is covered by the molten metal.

c. Water depth, temperature and composition must be proper for the rapid transfer of a large quantity of heat from the metal to the water.

Of particular significance were Long's finding that (1) the critical water depth for violent explosions was 3 to 6 inches (75 to 150 mm) under these experimental conditions and (2) organic coatings applied to the interior surfaces of the water container would prevent explosions.

Subsequently, P. D. Hess and K. J. Brondyke of Alcoa conducted a study in an attempt to determine the mechanisms involved in explosions and to develop more efficient ways to prevent them.

In this program, using Long's apparatus, 50 pounds (23 kg) of molten aluminum were dropped into water under a variety of conditions and the results captured on high-speed film. Several organic coatings applied to the inner surfaces of the water container were found to prevent explosions; Alcoa's expressed preference was Tarset Standard. However, the researchers found that the coating would lose its effectiveness if it were not repaired after several drops of molten metal onto it or if there was a hole or bare spot in the coating larger than the metal stream diameter.

Hess and Brondyke concluded that aluminum-water explosions during casting could be prevented in two ways:

a. Maintain sufficient depth of water in the casting pits. Deep water probably prevents explosions by sufficiently cooling the metal to solidify it before it can trap water at the bottom surface.

b. Apply a protective coating. Organic coatings on exposed surfaces probably guard against explosions in two ways: (1) the coatings are decomposed by contact with hot metal, and gases are generated which agitate the metal, preventing a restraining crust from forming, permitting steam to escape and thereby avoiding a pressure buildup; (2) the coating prevents contact between the hot metal and surface rust or other oxides or hydroxides, and prevents wetting. However, the precise mechanism is not yet understood.

## 36.4: Battelle Studies

In 1968, the Aluminum Association funded a project at Battelle Memorial Institute to study mechanisms of initiation and propagation of explosions between molten aluminum and water. Battelle first prepared and submitted an extensive "Review of Knowledge;" experimentation began in September 1969. First the Battelle investigators attempted to produce explosions by dropping small amounts, 10 pounds (4.5 kg) or less, of molten aluminum into water in a steel container under conditions similar to those in Long's work. None of the 20 experiments run in this manner was successful.

Next, the quantity of aluminum was increased to nearly 30 pounds (13.6 kg). Even with this amount, and with metal temperatures approaching 1900°F (1040°C), the investigators still had a difficult time producing an explosion. Only when the steel bottom plate was oxidized in a certain way were explosions produced.

By constructing water containers with Plexiglas sides the initiation of the explosion within the container could be observed on motion picture film employing high filming speeds. The films showed that the most violent explosions occurred when nearly all the metal had entered the container, sometimes as much as a second after the initial contact of molten metal with the bottom.

When the molten aluminum was very hot, 1900°F (1040°C), there were visible spots of light in the aluminum-water mixture, mainly at the container bottom, on one or two frames immediately preceding the explosion. A violent explosion then produced complete whiteout of the film. At a filming speed of 5,000 frames per second, the observable explosion initiation occurred in less than one millisecond.

The Battelle investigators also determined that aluminum-water explosions could be initiated by detonating a small exploding charge either within the container or outside the container with the force of the explosion transmitted into the aluminum-water mixture by means of an aluminum bar imbedded in the container wall. In every instance, the artificial “trigger” produced an aluminum-water explosion, even with 10 pound (4.5 kg) quantities of aluminum, with various “inert” container bottoms such as glass or coated steel, and with metal temperatures as low as 1350°F (730°C). In one experiment in which 10 pounds (4.5 kg) of aluminum at 1900°F (1040°C) was dropped into a water container with a glass bottom, a length of Pyrofuse was imbedded in the container and burned in the aluminum-water mixture giving off intense heat but no pressure pulse; no explosion resulted.

The instrumentation employed by the Battelle investigators (fast responding thermocouples and pressure gauges in the water container) did not yield meaningful results. Spectrographic analysis of the explosion byproducts did reveal the presence of AlO, a form of aluminum oxide which is only stable at high temperatures. Based on this finding, and from thermodynamic calculations, the temperature of the explosive reaction was estimated as greater than 3000°F (1650°C), supporting the premise of a chemical reaction.

The Battelle studies added considerably to the existing knowledge, but did not fully provide the basic understanding of molten aluminum-water explosions during casting or their initiation which was sought.

## 36.4: IITRI Studies

During 1973-1975 a study of initiating mechanisms for molten aluminum-water explosions during casting was jointly sponsored at IIT Research Institute by the Aluminum Association and the National Institute for Occupational Safety and Health (NIOSH). Although their experimental results were for the most part inconclusive, the IITRI investigators did propose a model for the initiation mechanism. The premise for the model, which is based largely on the work of others, is that liquid water must be present in cavities (“quench pits”) of the surface contacted by molten aluminum for initiation to take place. Initially a vapor film forms which prevents intimate contact between the aluminum and the entrapped liquid water. A stimulus is needed, most likely an impact-produced shock, to collapse the vapor film. When this occurs, the resulting hot liquid-cold liquid contact gives rise to spontaneous nucleation of liquid water to gaseous water and vapor explosion.

The IITRI investigators concluded that flow of molten aluminum over the “quench pits” produced sufficient shock to collapse the vapor film. Although the model postulated by IITRI during the last days of the contract has plausibility, no repeated documentation was developed. Representatives of the Aluminum Association and NIOSH monitoring the research program at IITRI felt that the postulated model was based on inconclusive evidence. In their opinion, further basic research and hard data are needed to fully understand what initiates a violent explosion when molten aluminum is dropped into water.

## 36.5: Association Sponsored Studies at Alcoa Technical Center

In the mid-1970s new protective coatings were introduced. The Aluminum Association sponsored a study at the Alcoa Technical Center during 1977-1979 primarily to evaluate these coatings and to determine if any alloy classes were more susceptible to explosions than commercially pure aluminum. Findings confirmed the importance of providing proper protective coatings on surfaces which may be struck or contacted by molten aluminum and water, identified Wisechem E212F as a viable coating and showed that Rustoleum Red did not prevent explosions when applied alone to steel surfaces. The study showed no differences in explosion sensitivity among the alloy groups investigated (Al-Li alloys were not included in the study) with one exception: alloy 2011, a free-machining alloy with additions of lead and bismuth, which produced explosions under conditions that the other alloys did not.

After that finding, all further experimentation was conducted with the more sensitive 2011 alloy.

Information generated since issuing the report "Molten Aluminum/Water Explosions 1979" has confirmed the critical role that mechanical shock can play in explosion initiation. Violent explosions have occurred in laboratory tests with pans coated with various organic coatings, which had otherwise prevented explosions, when a 150 pounds (68 kg) weight was allowed to impact the side of the pan shortly after metal entered the water. These findings indicate that casting sites should be carefully inspected paying particular attention to the potential for impact events which could accompany a bleedout.

## 36.6: Sandia Studies

During 1986-1988, the Aluminum Association sponsored work at the Sandia National Laboratory, Albuquerque, New Mexico. Small, single drops of molten aluminum were allowed to fall through water past a short wire which could be exploded electrically to generate a shockwave of controlled strength; and the intensity required to make the drop of aluminum explode was measured.

If the aluminum was allowed to fall to the bottom of the container and then a shock of less than the critical intensity was applied, the aluminum might or might not explode, depending on the nature of the surface. The general conclusion was that water wettable surfaces led to explosions while water repellent ones did not. Unfortunately there is not enough experience to allow this generalization to be used with confidence in selecting coating materials, but it seems to be consistent with the view that organic materials (bituminous paints, grease) are safe while inorganic ones (lime, rust) are dangerous.

## 36.7: Evaluation of Protective Coatings

In the early-1990s Tarset Standard, which was used for many years by the industry as a principal protective coating in DC casting pits, was withdrawn from the market. The Association requested and received from Alcoa Laboratories a proposal to test coatings as possible replacements for Tarset. The effort began in mid-1995 supported by 14 companies including five producers outside the U.S. and an equipment manufacturer. Oak Ridge, and initially Argonne, National Laboratories participated in the program by providing basic studies of surfaces and effects of coatings through a cooperative research and development arrangement (CRADA) with the Department of Energy.

As a result of this program, three new coatings were identified as having the ability to prevent explosions from bleed outs into the pit during DC casting. These coatings were –

- Courtaulds Intertuf 132HS coal tar epoxy (no longer marketed)
- MultiGard 955 CP epoxy
- WiseChem E-115 epoxy

However, the coatings have published cure times considerably longer than plants would like to wait before putting the unit back into service after recoating or repairing the existing coating. A follow-up study, supported by 15 producers and three suppliers, to determine the minimum time after application when these three coatings become protective has also been completed. Once again, Oak Ridge National Laboratory participated through an extended CRADA with the Aluminum Association.

# Section 37
# Molten Metal Incident Reporting

In 1980, the Association published these *Guidelines* and held its first Loss Prevention Workshop for the industry, at which the *Guidelines* were distributed and discussed. It was generally felt that the task was completed and no further efforts were needed. However, during the six-month period from late 1983 to early 1984 a half-dozen explosions were reported in which eight fatalities occurred. It was then decided that a program should be set into place to monitor the molten metal incidents that were occurring in aluminum plants around the world.

Working with the Association's Safety Committee and industry technical personnel, a one-page form for reporting molten metal incidents was developed in 1985; a copy of the form is shown in 37 Figure 1. The form was submitted to companies around the world who were invited to participate in the reporting program. There was no charge for participation, but companies had to commit to reporting any incidents in their plants. In exchange, they would receive annual summaries and bulletins on particular incidents or pertinent information reported to the Association.

For most of its tenure the program has had approximately 230 participants reporting for about 300 plants located in 20 countries. The program continues to foster awareness among all levels of the industry's workforce, to provide valuable insights into present day situations and to provide needed direction for the Association's research efforts. To participate in the program, or to obtain an electronic copy of the incident reporting form, contact the Association's Health & Safety Department via www.aluminum.org or 703-358-2760.

**ALUMINUM ASSOCIATION**
**MOLTEN METAL INCIDENT REPORT**

Date of Incident ______________________ Type of Plant ______________________
*(month/year)* *(Reduction, Recycling, Rolling, Extrusion, etc.)*

Explosion Characterization* *(see explanation below)* Force 1 ________ Force 2 ________ Force 3 ________

**OPERATION:**

**Charging/Melting** Type of Furnace ______________________
*(Reverb, Topcharging, Induction, etc.)*

Furnace Capacity ______________ lbs. % Full ______________ Alloy ______________

Metal Temperature ______________ $^0$F Approximate Amount of Metal Involved ______________ lbs.

Materials Charged ______________________

Outside Storage? Yes☐ No☐ Preheat? Yes☐ No☐ Preheat Time & Temp ________ Hrs. ________ $^0$F

---

**Transfer** Type ______________________
*(Crucible, Trough, Truck, etc.)*

Alloy ______________ Temperature ______________ $^0$F Approximate Amount of Metal Involved ______________ lbs.

**Casting** Type of Unit ______________________
*(D.C. Continuous Sand & P.M., etc)*

Alloy ______________ Temperature ______________ $^0$F Approximate Amount of Metal Involved ______________ lbs.

Stage of Operation ______________________
*(Start-up, Termination, etc.)*

---

**Other** Describe ______________________

______________________

______________________

______________________

**Brief Description of Incident and Results, Including Extent of Injuries** ______________________

______________________

______________________

______________________

______________________

______________________

***Explosion Characterization**

| | | |
|---|---|---|
| Force1 | Property Damage | None |
| | Light | Minimal |
| | Sound | Short Cracking |
| | Vibration | Short Sharp |
| | Metal Dispersion | <15' Radius |
| Force 2 | Property Damage | Minor |
| | Light | Flash |
| | Sound | Loud Report |
| | Vibration | Brief Rolling |
| | Metal Dispersion | 15-50' Radius |
| Force 3 | Property Damage | Considerable |
| | Light | Intense |
| | Sound | Painful |
| | Vibration | Massive Structural |
| | Metal Dispersion | >50' Radius |

Please Return To:

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F (703) 894-4939
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**37 Figure 1 – Molten Metal Incident Reporting Form**

# X

# EXPLOSIONS INVOLVING COMBUSTIBLE DUST

# Section 38
# Combustible Dust in the Casthouse

An explosion inside a molten metal fluxing unit, a secondary fire in the rafters ignited by molten metal, an exploding vacuum truck, and a high-energy flash during a furnace repair. These are all examples of incidents caused by the presence of hazardous dusts that can happen in casthouse situations.

Many industrial processes generate small aluminum particles ranging from chips to dust as depicted in 38 Figure 1. These fines may be the product, or byproduct, of a given process. They can also come from sawing, grinding, and machining operations, erosion, or be solids formed from vapor deposition. Among the most common sources of dusts within the casthouse are: molten metal fluxing units, melting furnaces, and thin scrap conveyors.

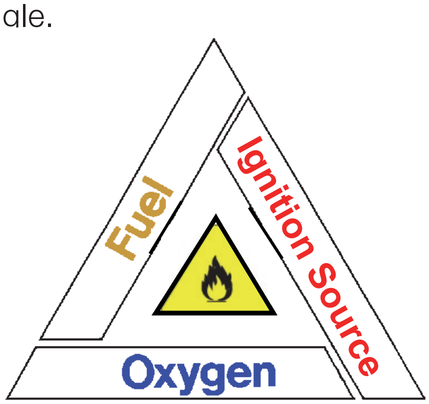
More information on the management of aluminum dusts can be found in the Aluminum Association publication, *Guidelines for Handling Aluminum Fines Generated During Various Aluminum Fabricating Operations – F-1*, (Third Edition 2015)".

**38 Figure 1 – Aluminum Dust/Fines**

Many materials, including metals, polymers and composites of these are potentially explosive in a finely divided form. Safe handling of potentially explosive dusts requires that plant staff recognize the hazards, apply proper handling techniques and be aware of explosion prevention methods and emergency responses.

# Section 39
# Hazards

The typical fire occurs due to the simultaneous occurrence of: 1) fuel, 2) an oxygen containing agent, and 3) an ignition source. These three items constitute the sides of the well-known Fire Triangle.




**39 Figure 1 – The Fire Triangle**

In the casthouse -

Common **fuels** include:

a. Flammable gases
b. Degradation byproducts
c. Finely-divided plastics and other carbonaceous particles
d. Vapors deposited during alloying, or other molten metal handling operations,
e. Aluminum or other metal dusts in layers.

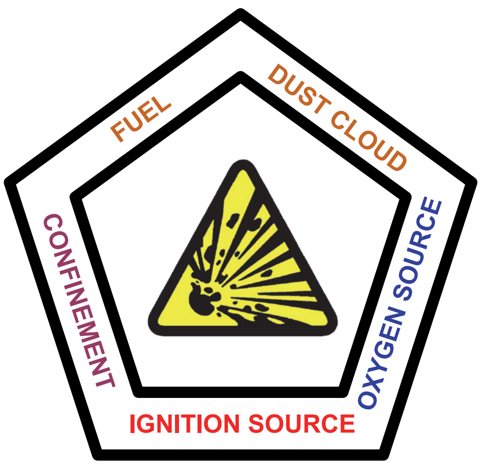
Common **oxidizers** include:

a. Oxygen-containing polymers
b. Nitrates, Sulfates and Peroxide
c. Metal oxides (like $Fe_2O_3$ and CuO)
d. Carbon dioxide
e. Water
f. Air

Typical **ignition sources** include:

a. Hot surfaces
b. Open flames
c. Electric or static arcs
d. Spontaneous combustion
e. Pyrophoric materials
f. Impact sparks
g. Thermite reactions
h. Matches and lighters.

A fire can turn into a dust explosion with the addition of two additional legs to the Triangle: 4) formation of a dust cloud, 5) confinement of the reaction, constituting the Explosion Pentagon:




**39 Figure 2 – The Explosion Pentagon**

The United States Bureau of Mines established ratings like Severe, Strong, Moderate, Weak and None to describe the ***probability*** of an explosion occurring as a function of the minimum amount of airborne material required to initiate and sustain a catastrophic reaction. These ratings do not describe the force of the reaction.

Aluminum, magnesium and lithium have Severe ratings. They are aggressive reducing agents whose reactions occur with a drastic release of energy. On the other hand, copper, stainless steel and nickel do not oxidize readily and therefore are low on the explosibility list. A comparison of selected metal powders to non-metallic materials is shown below:

| Material | L.E.L (oz/cu ft) | Rate of Pressure Rise (psi/sec) |
|---|---|---|
| Aluminum | 0.045 | 20,000 |
| Magnesium | 0.030 | 15,000 |
| Polyethylene | 0.020 | 7,500 |
| Flour | 0.050 | 3,700 |
| Coal | 0.050 | 2,000 |
| Coffee | 0.085 | 150 |

(1 oz/cu ft = 1 kg/cu m)
(1 psi/sec = 6.9 Kpa/sec)
L.E.L = Lower Explosive Limit

The Rate of Pressure Rise is the main property that separates metal powders like aluminum and magnesium from organic materials like plastics and flour. It can be understood that if flour can destroy a silo at 3,700 psi/sec, a metal dust at 5 to 6 times can do much further damage.

Explosibility is particle size dependent. One of the first rules-of-thumb used to predict explosibility potential is to characterize the amount of material finer than 200 mesh (75 micrometers) in a sample. Two things become apparent: 1) Below 10% minus 200 mesh, aluminum powders have typically shown no explosion hazards, and 2) Above the 10% level, the minimum amount required drops exponentially to a Strong hazard, above 40% fines content the explosion probability is at the Severe level.

In addition to the hazards noted above, there are chemical reaction hazards which can lead to an explosion. Aluminum fines can react exothermically with strong oxidizers (nitrates, peroxides) and halogen (F, Cl, Br, etc.) compounds.

Aluminum fines will also react violently with other metal oxides in the presence of even a weak energy source. Thermite reactions of aluminum have been documented with iron (rust), copper and lead oxides and are further discussed in Section 35.

# Section 40
# Preventive Measures:

Preventive measures must be geared at controlling and/or eliminating as many of the legs of the pentagon as possible with special focus on: the fuel, the dust cloud, the oxidizer, and the ignition sources.

A plant-wide survey should be conducted to identify and characterize any potentially combustible dusts which may be present. A review of the Safety Data Sheets provided with finely divided materials and powders used in the plant can also be useful in identifying potential dust fire and explosion hazards.

**40 Figure 1 – Aluminum Dust Cloud**

## 40.1: Dust Cloud Prevention

Engineering controls in combination with an active maintenance program designed to prevent or control the generation of fugitive combustible dusts is essential. A comprehensive inspection and housekeeping program designed to eliminate the accumulation of any fugitive dust that is generated is an important prevention method. Inspect "out of the way" areas such as elevated horizontal surfaces and areas above suspended ceilings on a regular basis. Do not use plant air to push away dust as this generates, rather than eliminates, dust clouds. Natural bristle brushes or brooms should be used to clean up accumulations of dust in work areas. Non-sparking metal dustpans or containers are preferred in order to reduce the potential for static electric dischage.

**The prevention of dust cloud formation is critical when handling potentially explosive dusts.**

## 40.2: Elimination and Control of Ignition Sources

The most obvious ignition sources include: hot surfaces, smoking, and electrical grounding of equipment. More rigorous items include: The need for special non-sparking hand tooling, dust-tight/explosion-proof electrical switches, connectors and other equipment, selective use of conductive floors, and attention to welding and torching operations. A "Hotwork" management program is essential to control ignition sources which may be present during maintenance activities.

## 40.3: Training

All plant personnel should be trained in the hazards of combustible dusts, how to recognize the accumulation of excess fugitive dusts, and in basic emergency response procedures in the event of a combustible dust fire or explosion.

# Section 41
# Dust Incident Response

Below are some simple rules for aluminum dust incident management:

- Know and recognize the hazards.
- Evacuate and let it run its course if proper training in managing the magnitude of the fire/incident is not in place.
- For small, localized fires, initiate alarm procedure **first** and then ONLY use Class D fire extinguishers or dry inert granular material (for example, sand) to smother the fire.
- DO NOT USE WATER - 1) Water reacts with aluminum and many other finely divided

metals to form highly flammable hydrogen, and 2) Water usually comes out of the hose under pressure. This in turn creates a dust cloud that may turn a simple metal fire into a dust explosion.

- Do not use ordinary ABC-type extinguishers on a metal fire, as the extinguishing agent will only accelerate the fire and the pressure used to expel the agent from the extinguisher may create a severe dust explosion hazard.

Advise the local Fire Department on the hazards associated with metal fires and develop a plant specific plan for managing dust incidents.

In conclusion, the safe handling of potentially explosive dusts requires that the industry:

- Recognize the hazards
- Apply proper handling techniques, and
- Be aware of explosion prevention methods and fire fighting techniques.

# XI

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