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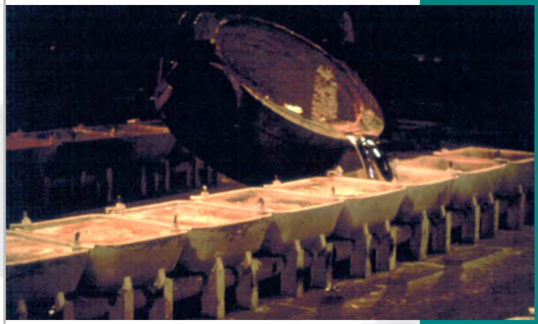
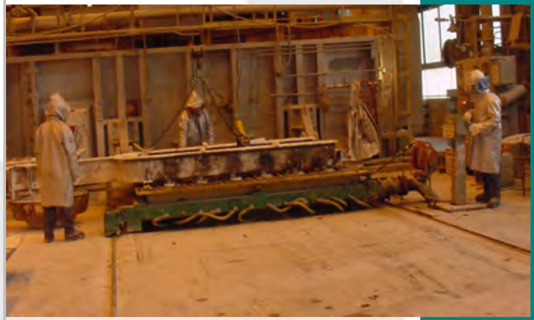
Guidelines For Handling Molten Aluminum





Third Edition
July 2002

The Aluminum Association
www.aluminum.org

Guidelines for
Handling Molten Aluminum
Third Edition

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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 may arise, have been 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 and 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 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 initial *Guidelines* were first issued in 1980, revised in 1982 and a second edition issued in 1990 as new information came to light. However, practices and equipment for melting and casting aluminum are continually being modified or changed for a variety of reasons. In addition, new information is being generated in reporting programs and research efforts implemented by The Aluminum Association.

Major improvements have been made in protective clothing and equipment for workers. New coatings for direct chill (DC) casting operations have been evaluated for prevention of explosions resulting from bleed-outs necessitated by the disappearance of the long-used Tarset Standard. Based on incident reports received by the Association, new guidelines for receiving and inspecting scrap and for casting and charging sow have been developed and promulgated. In particular, contamination of purchased scrap has been shown to be a major concern in view of the ever-increasing recycling of aluminum.

This third edition of *Guidelines for Handling Molten Aluminum* 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. The sections have been updated and considerably expanded to incorporate the new information available since publication of the second edition.

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I. Introduction

Section 1
General

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

Millions of pounds of aluminum are melted and cast safely every day in cast shops, foundries, recycling and reclamation plants all over the world. However, there are inherent hazards in handling molten aluminum, just as there are inherent hazards in virtually every activity. These hazards can be minimized or 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 destruction of equipment and plant facilities. Examples of catastrophic explosions that occurred in the aluminum industry are shown in Figures 1 and 2.

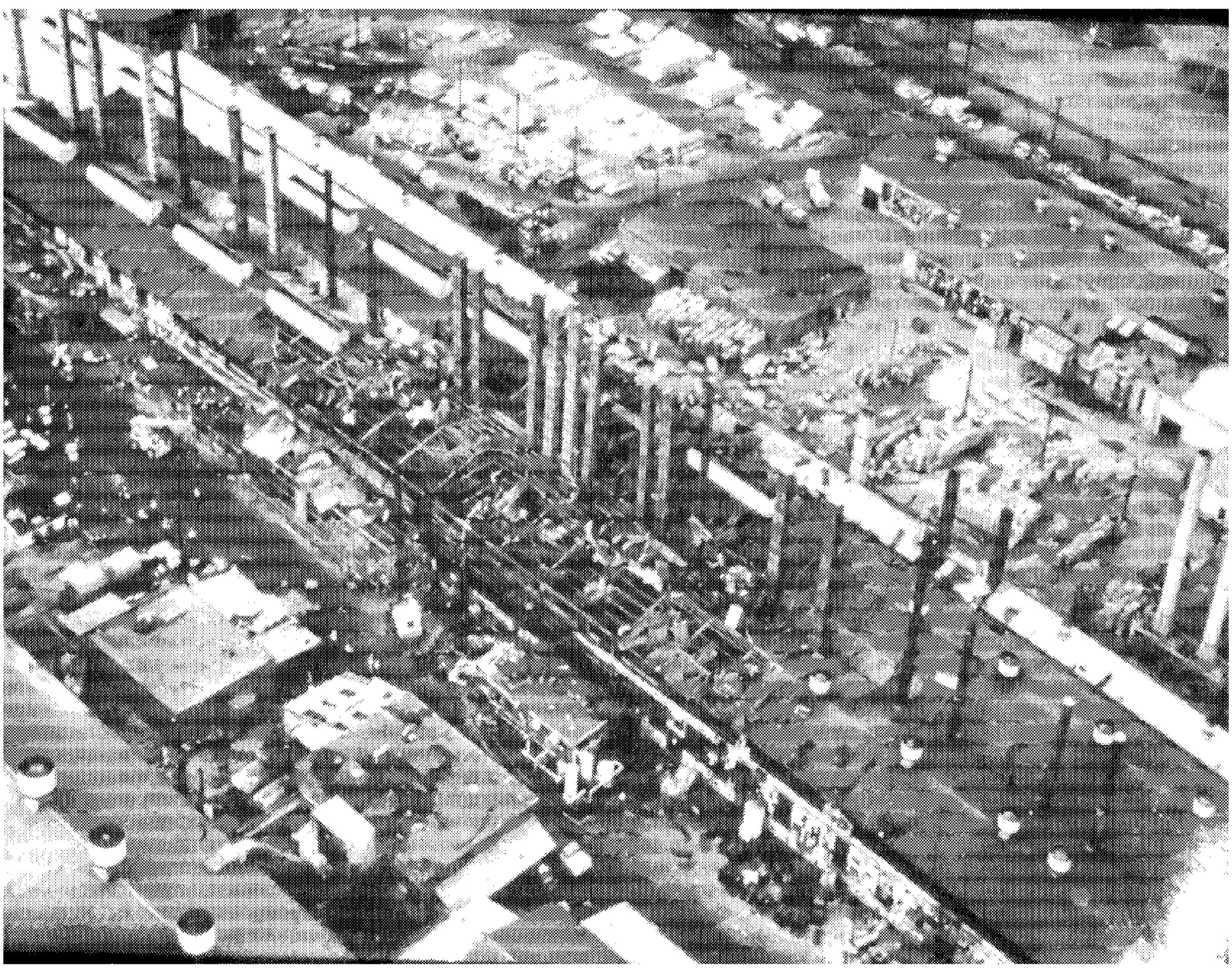

Figure 1: Casthouse Following Molten Metal Explosion

Whatever your job - operator, foreman, maintenance, engineer, supervisor, or manager - study and use these *Guidelines* to increase your knowledge and understanding of the hazards and of the ways that avoid or minimize them. Although these *Guidelines* cannot cover all circumstances and conditions which may be encountered (and which may require specialized techniques and action), they do offer sound, tested guidance.

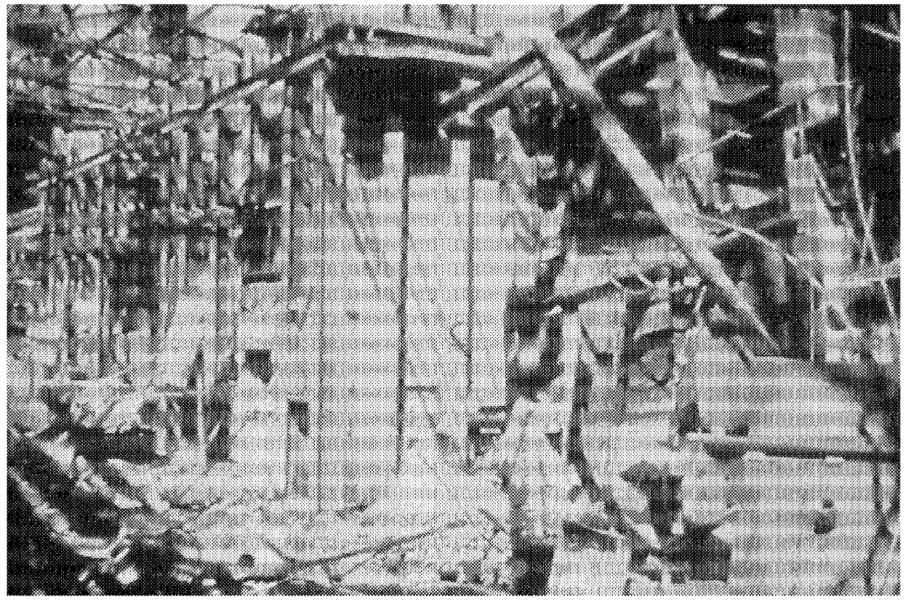

Figure 2: Results of Explosion in Remelt Furnace

Section 2
Scope, Format, and Organization of 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 melting, treating, transferring, and casting molten aluminum and its alloys (excluding pot line operations in reduction plants) are discussed.* Dross processing operations and equipment are not discussed.

Emphasis is placed on large-scale melting and casting practices for the production of process ingot. Slabs or billets are subsequently mechanically worked into forms such as sheet, plate, foil, forgings, extrusions, or T-bars, sow and Remelt Scrap Ingot (RSI). These are then remelted at another site. More attention is also given to scrap melting operations.

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

2.1.1: Aluminum-Lithium Alloys

These *Guidelines* do not cover procedures for the additional hazards involved in melting and casting aluminum-lithium alloys. For information, see Aluminum Association Publication T4, *Safety, Health and Recycling Aspects of Aluminum-Lithium Alloys.*

2.2: Format

The wire bound format of the *Guidelines* is intended to allow the publication to lie flat for easy copying of sections for safety and training meetings.

2.3: Organization

The revised *Guidelines* consist of nine parts. The presentation of material under headings of both general information and specific procedures results in some repetition. This was done deliberately in an effort to reach all concerned with, or involved in, safe handling

* Details are not given on operating practices for proprietary melting, melt treatment, and casting systems. Information on specific safety procedures should be sought from vendors of these systems. For additional details of safe practices in foundries, refer to *Safety Requirements for Melting and Pouring of Metals in the Metal Casting Industry,* prepared by the American Foundry Society.

II. Safety Management

Section 3
Safety Programs and Training

3.1: General Safety

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 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. Successful management of safety programs includes basic scientific and management principles, setting of standards, measurement of compliance and monitoring and feedback systems. The goal is to establish a safety culture where commitment to and support of a safe working place and adherence to safety rules are observed by all personnel including top management.

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 any and all suspect or unsafe conditions or equipment to their supervisors.

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 and conduct of these programs. Consideration should therefore be given to techniques used in quality circles which utilize worker participation and peer pressure 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 information useful to 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 1300-1450°F (700-790°C) to avoid premature solidification. 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, Protective Clothing and Equipment.

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 VIII which deals with explosions.

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 not to 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 on Housekeeping.

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 with the release of large amounts of energy as heat. 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 relatively free of water 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, 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*, Second Edition (2002).

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 manufacturers 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 reverbatory 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.

Figure 3: Charging Furnace from 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 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

* As indicated previously, process ingot is a casting which is subsequently mechanically worked into shapes such as sheet, forgings, extrusions, wire, etc.

machine. The system usually includes one or more flow rate 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 "in line" 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 Figure 4.

Molten metal may also be moved from one furnace to another or to a casting station by means of crucibles and

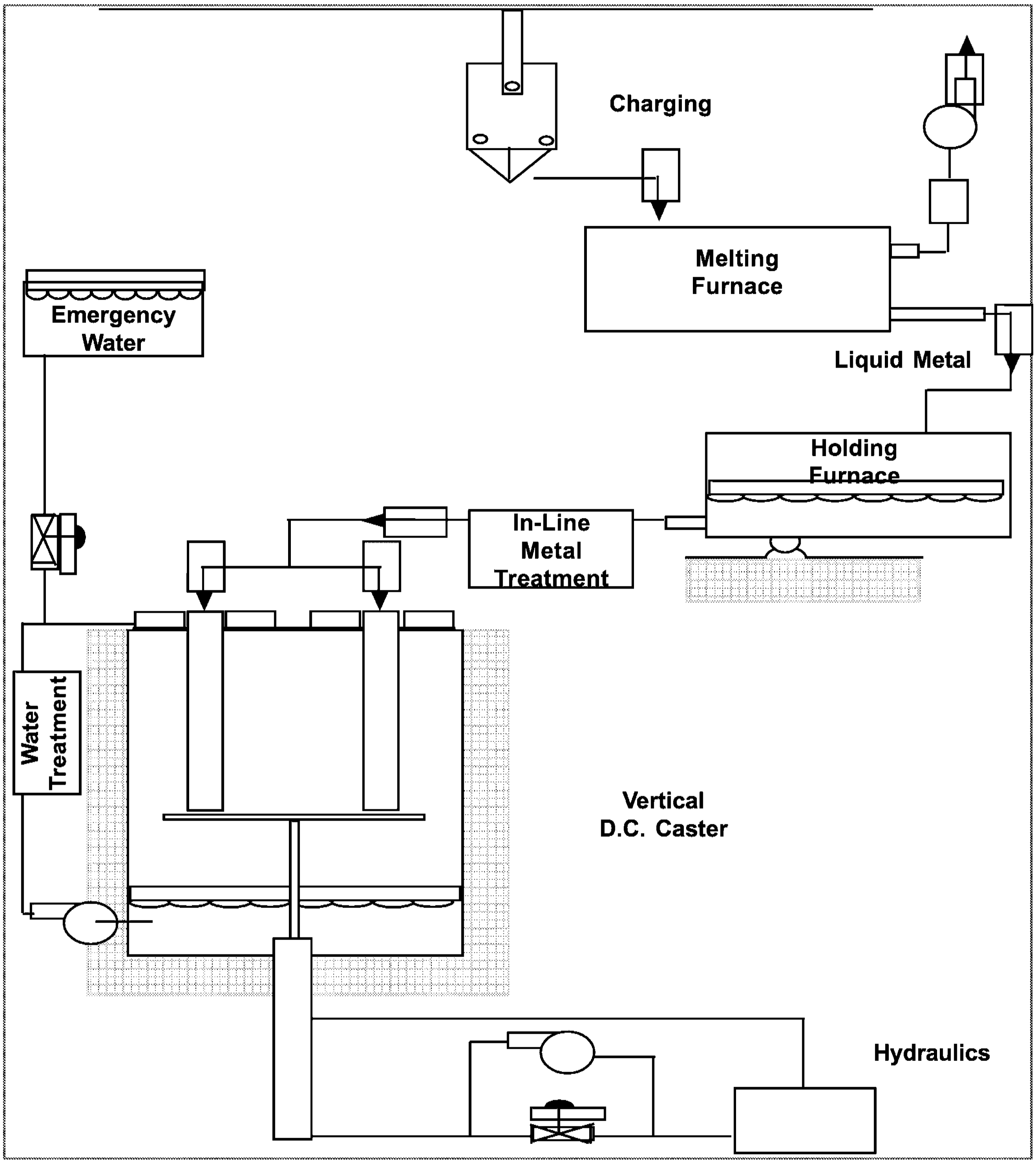

Figure 4: Typical Melting, Holding, Casting Process Flow Sheet

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 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 bottom block, starting head, stool cap, 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.

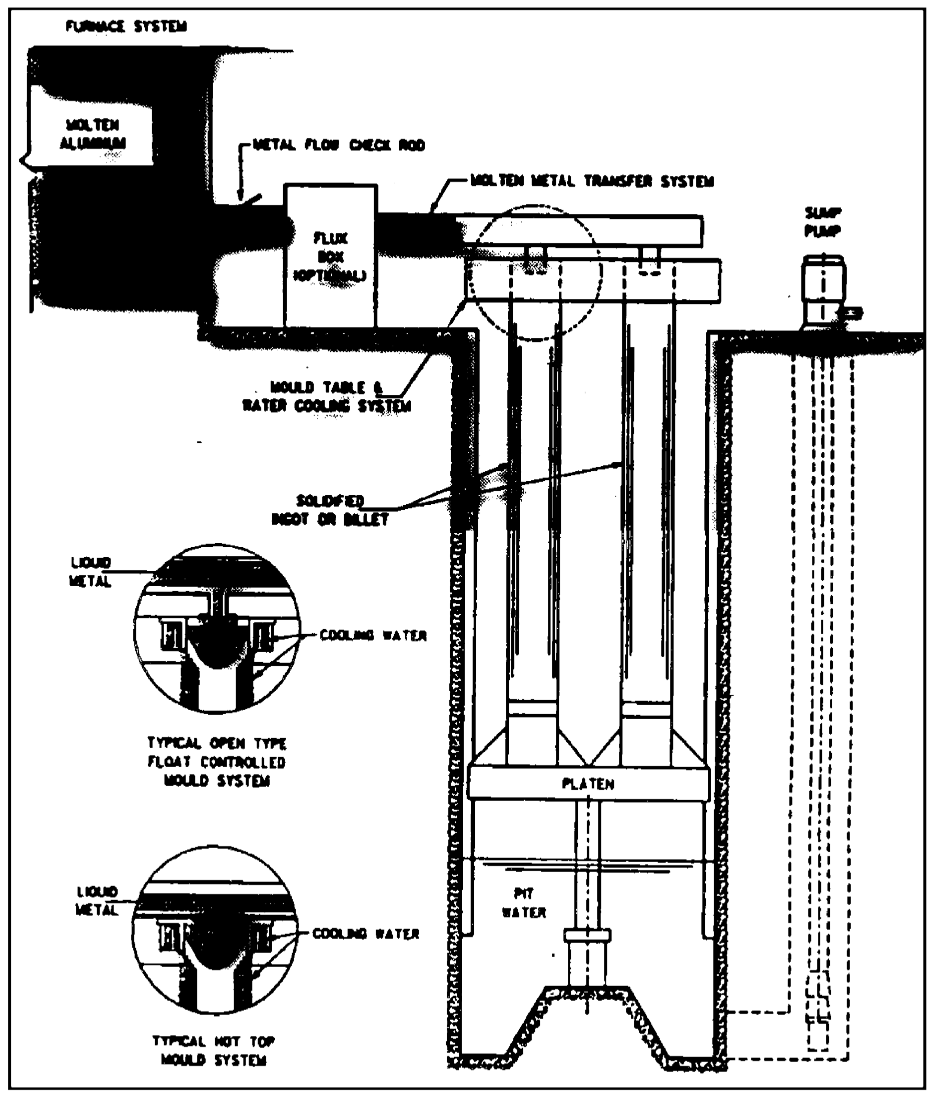

Figure 5: Schematic of Vertical DC Casting Station

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 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. Equipment used for vertical DC casting of aluminum is shown schematically in Figure 5.

The molds can be of many configurations, but are usually rectangular, circular, T, or square, to give the required product cross-sectional shape.

8.3.2: Hot Top Casting Process

Hot Top (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.

A typical Hot Top mold system is shown as an inset in Figure 5. More details are given in Section 23 and Figures 26 and 27.

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; 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.

More details of the EMC system are given in Section 24.

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. In some systems*, the metal solidifies around clinches (bolts fastened to the starting block); 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. Horizontal DC casting of aluminum is shown schematically in Figure 6.

8.3.5: Continuous Casting Processes

Vertical DC and some horizontal DC casting processes are classified as batch or semi-continuous 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

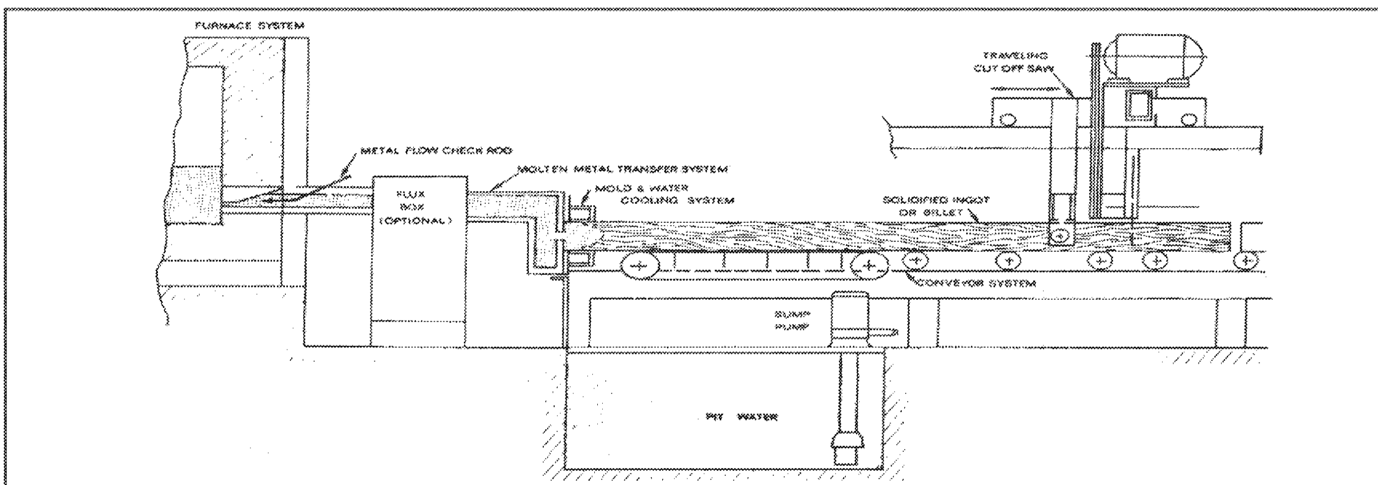

Figure 6: Schematic of Horizontal DC Casting Station

the case of sheet and rod. One such system for continuous strip casting is shown in Figure 7.

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 Figures 8 and 9.

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.

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.

Figure 7: One Type of Continuous Strip Casting Machine

* There are a number of proprietary horizontal casting systems with differing withdrawal mechanisms.

Figure 8: A Modern Pig Ingot Casting Machine with Skimming and Metal Filling Control

Figure 9: Modern Sow Casting Operation

Section 9
Considerations in Design of Equipment and Controls

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.

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, shut off 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.

Automatic sprinkler systems should not be installed where molten aluminum is processed.

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

The 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 shut off devices should be provided in easily accessible places and should be clearly marked.

Gas and oil lines should have provisions for remote shut off which should be clearly marked.

> ***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.***

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.

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 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 clean up 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.

In 1986, a catastrophic explosion occurred in a plant casting aluminum process ingot that was attributed to a lightning strike, by the company. 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, as shown in Figure 10. In one organization where gas-fired 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. 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.

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.

Figure 10: Preheating Sows In an Oven

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

Tap holes and related plugging or metal flow control equipment should be designed to minimize the possibilities of run-away 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 regress 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.

Water cooled 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 designed 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.

Figure 11: Billet Base plate with Starting Blocks

Platen assemblies (platen, base plate, and pedestal) should be designed and maintained such that water cannot accumulate. See Figure 11.

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.

The design of the table top and platen assembly should be such that it prevents cooling water (and molten metal from a bleed-out 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.

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 (1m) minimum at all times.

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.

With the High Level Water System, provisions 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 and Electromagnetic Casting (EMC) systems require 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:

1. Deposits, scratches or cracks which could promote weaknesses or tears in the ingot surface.

2. Plugged water holes or slots.

3. Damaged mold bores that are 'toed-in' and would cause an ingot to hang-up.

4. Inadequate lubrication.

The phenomenon of "bumping" is caused by a steam build-up 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.

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.

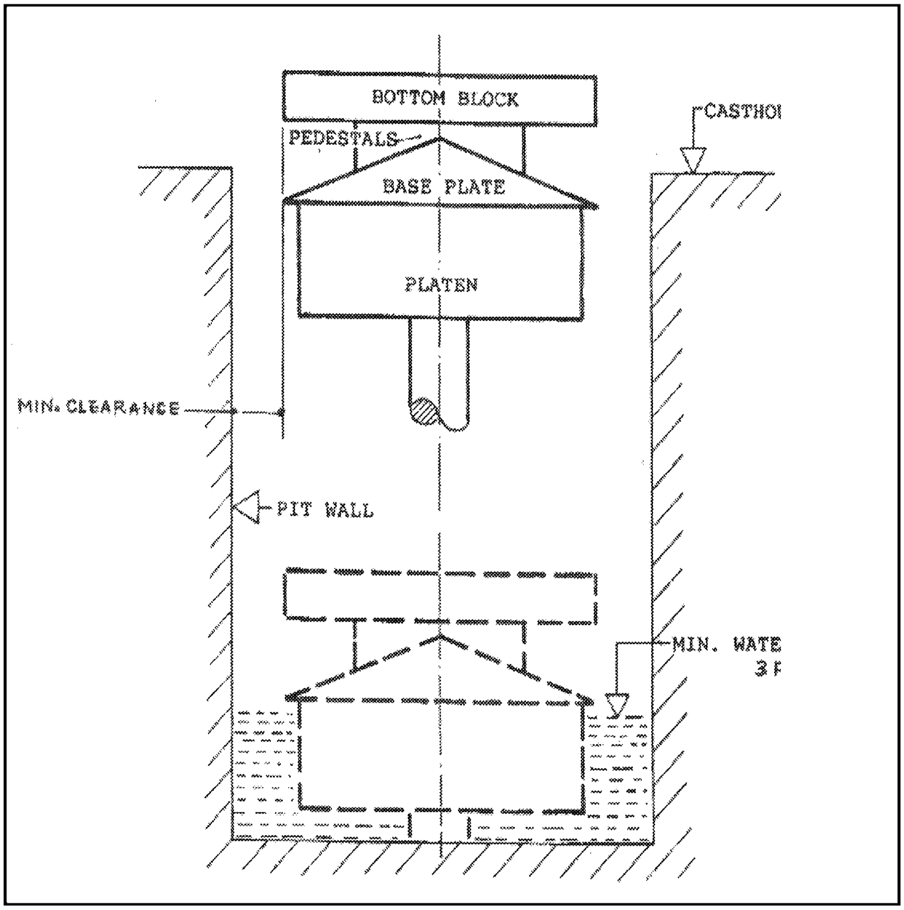

Figure 12: DC Casting with Low Water Level in Pit

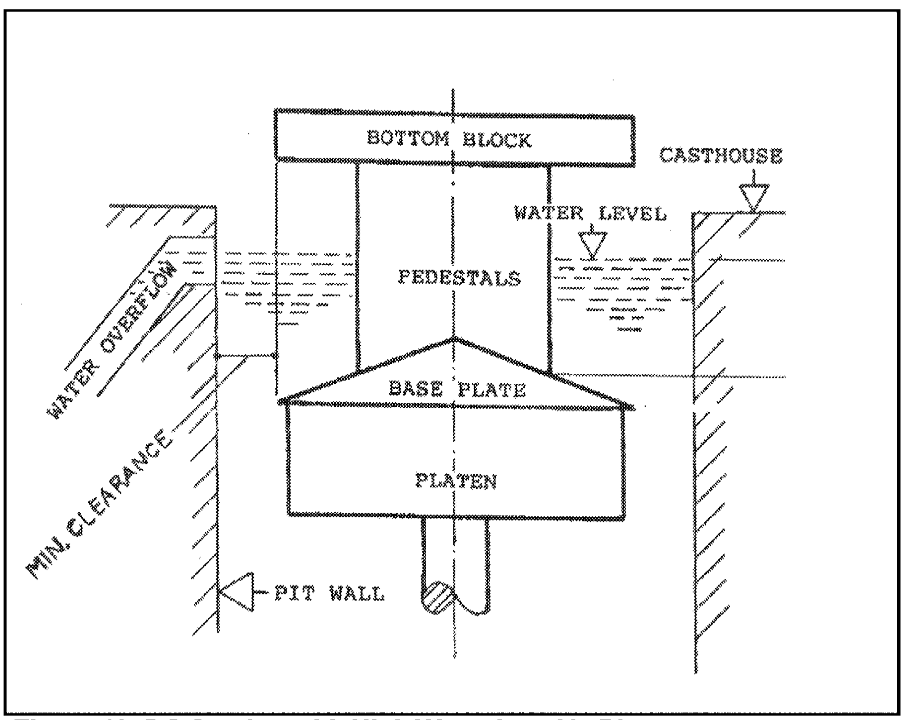

Figure 13: DC Casting with High Water Level in Pit

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

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 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, 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.

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 shut-down 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 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 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 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 diverts to the fail safe 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 lighted. 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 lead to unsuitable, hazardous work habits. Carelessness in handling molten metal can result in accidents.

> ***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. This applies to temporary lines as well as permanent lines.

> ***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***

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.

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.

10.3: Cleanup of Accumulated Fine Metallic Residues

Oxide and metal dust fines should not be allowed to accumulate over 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 practice are a must to prevent fires and explosions.

IV. Personal Protection

Section 11
Personal Protective Clothing and Equipment

11.1: Personal Protective Equipment

New and improved protective clothing has been developed since the *Guidelines* were first issued. However, some workers in operations involving molten aluminum are still not using proper equipment or wearing protective clothing, which has resulted in injuries and fatalities.

The wearing of approved safety glasses, foot gear, protective clothing, etc., does not prevent accidents, but it can prevent injury or reduce the extent of injury in the event of an accident. Fully protected casthouse personnel are depicted in Figures 14 and 15.

Melting and casting of molten aluminum are operations that necessarily involve heat sources, and there is an ever-present possibility that a worker may be splashed by molten aluminum. Since it is impossible to remove all sources of ignition from the workplace, it is essential that reasonable practices that can significantly reduce the risk of serious burns to workers be followed.

11.2: Recommendations to Casthouse Personnel

a. Know and follow your company requirements (safety rules) in regard to head protection, eye and face protection, foot and hand protection, and protective clothing.

Figure 14: Casthouse Worker in Protective Coat, Face Shield, and Gloves (Spats and Safety Shoes not pictured)

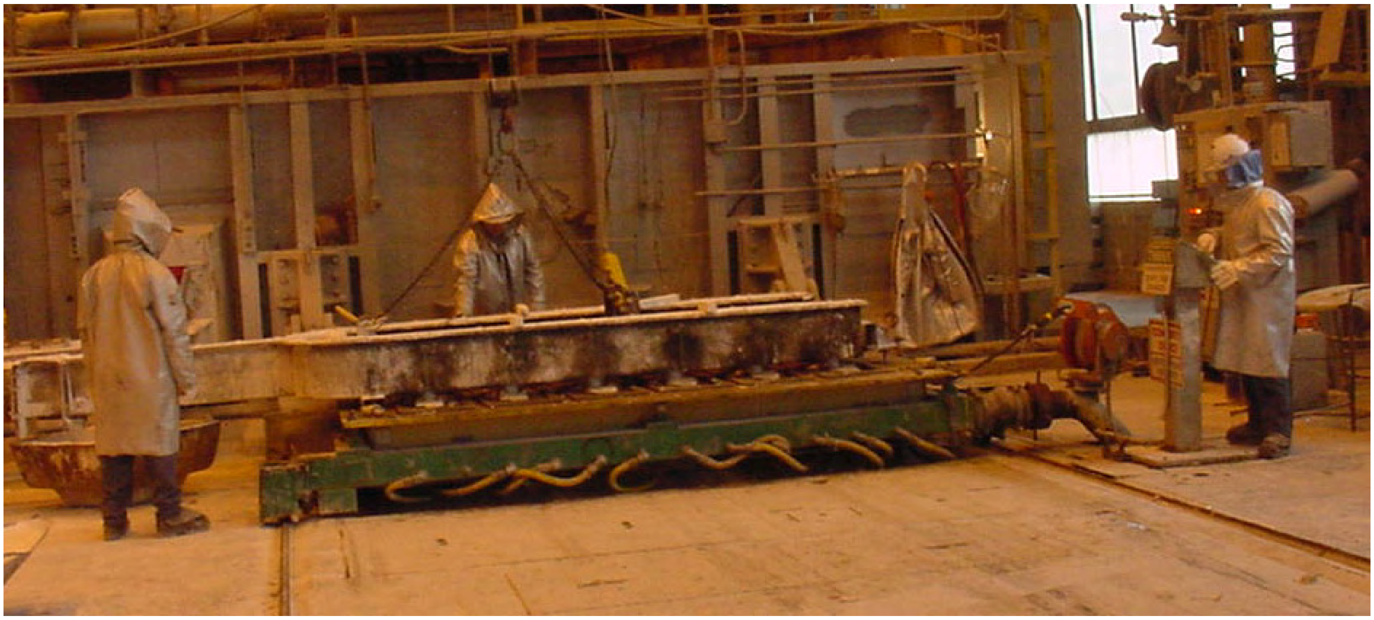

Figure 15: Starting a Drop of DC Ingot

b. Casthouse personnel: Wear all items of protective equipment for the start of the cast as required by company safety rules. This is the period in casting operations when most accidents occur and when you need the most protection. Primary protective clothing should not be removed until the cast is considered to be in "steady state."

c. 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.

d. See subsection 11.6 for factors involving selection of personal protective equipment (PPE), and steps to develop a PPE program to protect casthouse personnel against job hazards.

11.2.1: Head Protection

For hazards of impact and penetration from falling or flying objects and electrical shock, suitable head covering should be worn. The safety hats must meet the specifications of American National Standard 289.1, Requirement for Protective Headwear for Industrial Workers.

All personnel working around molten aluminum should wear a head covering. Industrial safety 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.

11.2.2: Eye and Face Protection

Due to the possibility of splash, personnel working with molten aluminum must wear eye and face protection. Industrial safety glasses with side shields should be considered minimum protection against molten metal splash.

During periods of greatest exposure, such as charging, opening or closing a tap hole, starting or terminating a cast, or skimming molten metal during casting of sows and foundry ingot, it is recommended that workers wear a face shield in addition to the safety glasses. See Figure 16.

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

11.2.3: Footwear

Proper protective footwear should be worn. Laceless safety toe boots or pourer's (molders) boots are recommended for molten substance exposure. These shoes can be removed easily and rapidly in an emergency because they have no fasteners.

Laced safety toe boots worn around molten substances should be covered with spats to prevent them from capturing the molten metal. As a precaution, laces, if permitted, should be of materials that will burn through quickly.

Where there is a potential for molten metal to enter the top of the shoes, or where lower extremities are exposed to molten metal splash, leggings with spats should be worn. See Figure 17.

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

11.2.4: 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. Cotton hot mill gloves are recommended as a minimum. Under most circumstances, gloves that minimize the opening at the wrist where molten metal might enter should be selected.

Figure 16: Use of Face Shield Saved One Worker's Eyesight

Figure 17: Close-up of Spats

11.2.5: 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 most exposures. "Ordinary" work clothing may not protect employees from molten aluminum.

Burns have been one of the leading causes of work injuries in molten aluminum operations. The most serious injuries, of course, are the disabling burns that involve a major portion of a worker's body. Such serious burns are generally caused by the use of inadequate or improper protective clothing and equipment. Protective clothing for workers is divided into two categories:

Secondary protective clothing is protective clothing designed for continuous wear for work activities in designated locations in which intermittent exposure to molten substance splash, radiant heat and flame sources is possible. 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.

Secondary clothing may be made from specially treated cotton (non-phosphorus treatment such as FR-8), specially treated wool (such as Zirpro-treated), inherently flame retardant fabrics (such as PR-97), or a special type of non-melting, synthetic fabric (such as Vinex FR-9B). There are other fabrics and materials that resist molten aluminum but they have not been found suitable for the manufacture of secondary clothing. Research and development by fabric manufacturers and aluminum producers is continuing.

Some workers, with limited exposure, wear outer garments (pants and shirts) made of 100% cotton or wool. Workers should be encouraged to wear natural fiber undergarments (longjohns) and socks since they will provide additional protection against burns. Most synthetic materials or synthetic blends offer little or no protection against molten metal and should not be used.

Primary protective clothing is "protective clothing designed to be worn for work activities during which significant exposure to molten substance splash, radiant heat and flame is likely to occur. Such work activities include charging, tapping, and casting, during which work is carried out in close proximity to molten substances and hot surfaces and contact with either is likely."

It consists of jackets, capes, aprons, chaps, leggings, spats and sleeves designed and fabricated from materials capable of withstanding a major assault from the substance it is protecting against. It is worn by workers actually working with the metal. Primary protective clothing is worn over secondary protective clothing, thereby providing a layering effect and greater protection to the worker. This clothing may be made from aluminized fabrics (also reflects radiant heat), specially treated wool (such as Zirpro-treated), blend (such as PR-97), leather or a specialized synthetic fabric (such as FR-9B).

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. Each facility should determine the area in which workers are considered exposed. One 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 exposure, primary protective clothing and equipment are recommended. Where possible, exposure should be reduced or eliminated by adequately designed shields that protect against frontal, side and overhead exposures.

In selecting personal protective equipment to protect workers, employers should be aware that there is no universal protective device. Face shields, gloves, hats, jackets, pants, etc., that provide adequate protection against one substance or exposure may not provide that same degree of protection against another substance or exposure. For example, molten aluminum sticks to some fabrics but not to others and some types of aluminized fabrics ignite when splashed with molten aluminum but others do not. Simple molten metal splash tests can be conducted in the casthouse to determine the effect of the molten metal on the protective devices being considered. Testing of many different devices will allow selection of the most effective ones.

A cautionary note on personal protective equipment: 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 serious illness 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 cool-out rooms.

11.2.6: 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 955-96, *Standard Test Method for Evaluating Heat Transfer through Materials for Protective Clothing Upon Contact with Molten Substances.*

Beginning in 1992 the Association has held workshops on personal protective equipment (PPE) worn in casthouses and in potrooms regionally and on a regular basis. The Association 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. A final report is available from The Association.

11.2.7: Respiratory Protection

Normally, respiratory protection is not necessary in cast houses 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 than 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 a full facepiece, 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 adequate records kept of the results.

11.3: Safety Belts

The use of safety belts by personnel during overhead or elevated repair or maintenance in the melting and casting area is covered in American National Standard A10.14, *Construction and Use of Individual Safety Belts, Harnesses, Lanyards and Droplines.*

11.4: Visitors

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 for loan to visitors.

11.5: Selection of Personal Protective Equipment (PPE)

The selection of Personal Protective Equipment will involve:

a. An analysis of the type of hazard and the degree of exposure and

b. Consideration of any mandatory standards or guidelines issued by:

   (1) regulatory agencies (Federal or State OSHA, MSHA, etc.);*

   (2) consideration for employee comfort and health;

   (3) 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, toxicity of any treatment, 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.

11.6: Establishing a Personal Protective Equipment 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.

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*MSHA — Mine Safety and Health Administration
ANSI — American National Standards Institute
ASTM — American Society for Testing and Materials
NFPA — National Fire Protection Association
ACGIH — American Conference of Governmental Industrial Hygienists
OSHA — Occupational and Safety Health Administration

V. Melting, Melt Treatment, & 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 the molten metal, inspect the materials and shipment containers, including trucks and railroad cars, for signs of contamination. Suspect all foreign substances 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,* Second Edition (2002).

Particularly hazardous contaminants are:

a. Residual fertilizers, dry fire extinguisher powder, chemicals such as nitrates and sulfates and all "oxidizing materials.**" 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, 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 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 Aluminum Association operates a Scrap Rejection Notification Program to provide information to participants on scrap loads that have been rejected for safety or health considerations. Contact the Association for details on this program.

The use of an incoming inspection check list by trained and experienced receiving personnel is recommended.

12.2: Storage of Materials to be Melted

After incoming inspection, materials should be stored under conditions which prevent contamination, including accumulation of condensed 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.

Ensure that inside storage structures are kept in good repair to prevent water contamination of charge materials by rain, snow, leaks, etc.

* Aluminum ingot, sow, RSI, all forms of scrap, alloying elements and master alloys, grain refining alloys, and salt fluxes

** Materials which readily release oxygen in contact with molten aluminum, such as nitrates, chlorates, perchlorates, permanganates, chromates, and phosphates

Section 13
Premelting Precautions and Check List

13.1: Premelting 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 aluminum. Do everything possible to guard against this situation.

13.1.1: Scrap and Remelt Scrap Ingot (RSI)

Inspect all scrap prior to charging for foreign materials and moisture. Suspect all material. Ensure that company procedures for inspection, drying and/or storage were followed. Purchased bulk metal and scrap including heavy plate are of greater concern since the user does not have control over contamination and visual inspection is difficult. Look for ice, snow or heavy deposits of grease and oil. Remove all pieces of ferrous scrap, other metals and non-metal contaminants. Do not charge scrap or ingot that are suspected of foreign material contamination or moisture. Crimped tubing, extrusions, containers, etc. can be a hazard if they contain moisture. Ideally, tubing and other suspect scrap should be shredded prior to charging.

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 liquid metal.

13.1.2: Primary Sow, Ingot & T-Ingot

Ensure that there is no moisture or foreign material in shrinkage cavities and cracks in ingots. Inspect to ensure that the material is dry. Primary sows should be dried prior to use because of the potential presence of water or ice in the shrinkage cavities. Primary T-ingot may have cracks and surface moisture when atmospheric conditions are such that produce condensation of moisture or "sweating" on the metal surface. Inspect the primary sow, ingot or T-ingot for cracks or inclusions that have been closed by hammering or by other means. Primary sow, ingot and T-ingot should be preheated and dry before charging into molten metal.

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.*

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 aluminum without first being dried according to company procedures and subsequently kept above room temperature.

Figure 18: Storage of Alloying Materials

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, lead and bismuth are all capable of a thermite reaction with molten aluminum.

Magnesium ingots should be relatively free from oxide and corrosion products which may contain moisture. All magnesium ingot should be dried as specified in the suppliers' material safety data sheets (MSDS).

Figure 19: Magnesium Storage

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.

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 and skimming 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 preheating is important.

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 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 from furnace tools before repair by welding, otherwise a thermite reaction can take place.

Welders should wear complete face and body protection.

13.1.5: 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.

Routinely audit your 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.

13.1.6: Salt Fluxes

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.

13.2: Premelting Check List

a. Scrap & RSI

(1) Remove all foreign material. Be suspicious of all material.
(2) Ensure that scrap material was dried and/or stored according to company procedure.
(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 extrusions for moisture.
(6) Inspect RSI sow for salt contamination and moisture. Check to see that RSI sow has been dried.
(7) Multiple poured RSI should be remelted on a dry hearth.
(8) Remove all trash, cans and bottles and crimped tubing.

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) Multiple poured primary sows should be remelted on 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 scrap 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.

d. Furnace Tools

(1) Keep tools clean and dry.
(2) Never coat tools with lime.
(3) Dry tools after coating if a refractory wash is applied.
(4) Always preheat tools prior to use, especially when used for the first time.
(5) Avoid the build up 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 are preferred for non-bulk shipments.

f. Furnace Temperature Control

(1) Do not overheat metal in the furnace because of increased explosion potential and the risk of lining failure.
(2) Routinely audit temperature control devices.
(3) Always keep your 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 to the Furnace

The capability to dry scrap or other charge materials 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, the material should be charged into a dry hearth (molten metal depth less than 2 inches (50 mm) or heel solidified) or where the residual molten metal has been frozen by charging dry scrap. Even material that has been dried some time before melting can be hazardous if the material is not stored in a warm area. Certain atmospheric conditions may cause condensation of moisture or "sweating" on metal surfaces.

Severely oxidized or corroded sow, RSI or ingot should not be charged into molten metal but should be remelted on a dry hearth.

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. Obviously 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.

If drying of charge material is to be accomplished by setting the material on the ledge of an operating furnace (not recommended), extreme care should be taken to prevent it from being charged too soon or prematurely falling into the molten aluminum bath. This is particularly important in the case of sows. **This situation has been identified as one of the primary causes of molten metal explosions.**

Routine audits of ingot drying equipment performance and actual practices utilized are recommended.

Section 15
Handling and Processing of Sow and T-Ingot

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).

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 Figure 20. 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 insure that the sows are not wet or contain moisture in internal cavities.

T-ingots 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 the water-based saw lubricant. T-ingots usually range in weight between 700 and 2000 pounds (315 and 910 kg).

15.1: Storage and Shipment of Sows and T-Ingot

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

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

Sows that are produced in a plant and stored indoors but 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.

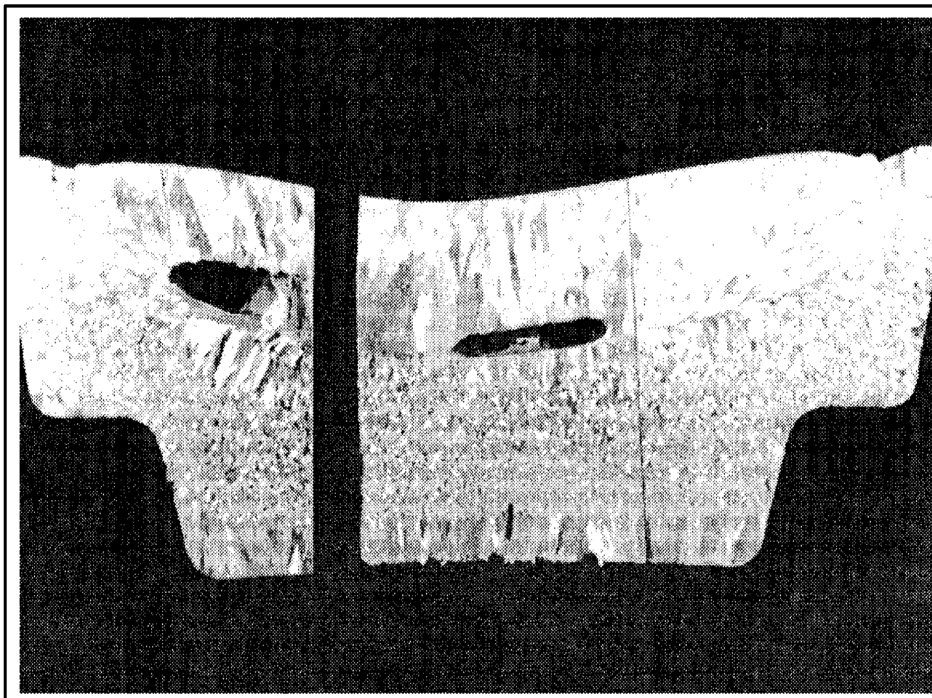

Figure 20: Internal Shrinkage Cavities in Sow Revealed by Sawing

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

Ultrasonic testing may reveal voids but grain structure and porosity make this technique unreliable. Water in sow cavities is frequently not detected by ultrasonic inspection. Cracks in T-ingot 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 a essential that all RSI be carefully inspected for surface moisture prior to charging. The preferred practice would be 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 and T-Ingot

If water is present on or in an internal cavity or crack of a sow or T-ingot submerged in molten aluminum, an explosion of some magnitude will most probably occur. Therefore, water must be removed by drying the sow or T-ingot for a period of time and at a temperature which will completely evaporate the water before the sow or T-ingot is charged into molten aluminum. Since there are many sizes and shapes of sows, it is impossible to specify a time and temperature that will guarantee complete dryness for all sizes and shapes of sows. However, furnace drying for four hours with an internal metal temperature of 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 at a metal temperature of 300°F (150°C).

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

15.4: Modification of Sow Molds

Studies have been conducted on the solidification of aluminum in a sow mold with the objective of developing a mold design which will minimize shrinkage cavities. Although improvement has been made in minimizing shrinkage cavities, no one is currently producing sows that never have a shrinkage cavity. Therefore, it should be assumed that all sows have shrinkage cavities.

15.5: Charging Sows and T-Ingot

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

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

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

c. Sows produced in your plant that are properly stored (temperature maintained above dew point).

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

a. Sows and T-ingot produced at another plant that have not been furnace dried,

b. Sows and T-ingot stored outdoors that have not been furnace dried,

c. Sow and T-ingot 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 sows or T-ingot in a dry hearth or on top of a bed of scrap until the sows or T-ingot show significant signs of melting.

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.

Care must be exercised to ensure melting and holding furnaces are not overcharged. Overcharged furnaces can overflow the door sill and onto the casthouse floor.

Means should be provided to alert personnel that charging and melting are taking place.

16.1: Charging Sequence

Take care in adding the charge to a furnace with a molten heel and, particularly, to a top charging furnace. With this type of furnace, the charge tends to submerge more quickly below the molten metal than with a side- or end-charging furnace increasing the risk of an explosion from moisture or contamination.

Plan the charging sequence to avoid full submersion of sow, 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.

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.

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 melt-down. Magnesium also should be added after melt down. When hand charging alloying materials, personnel should be aware of the possible surface moisture on the alloying material and guard against splashing.

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 that 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.

16.3: Protective Shields on Mobile Charging Equipment

Mobile charging equipment used to charge melting furnaces should be equipped with a shield that can protect the operator from splashing metal. In addition, openings around floor controls, etc., should be sealed. The shield should be constructed to minimize the possibility of any metal splash reaching the operator. One such shield design consists of three layers. Two layers are each one half inch thick heat resistant glass, and the other one quarter inch thick Plexiglas facing the operator.

Another shield design consists of three layers of glass, with the outside and middle layers of Herculite and the layer facing the operator made of Lexan. All three layers are one half inch thick. The shields should be held in a strong frame.

Figure 21 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. Figure 22 shows a fork truck shield following a furnace explosion.

16.4: 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. 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 build up of salt products of reaction, such a magnesium chloride.

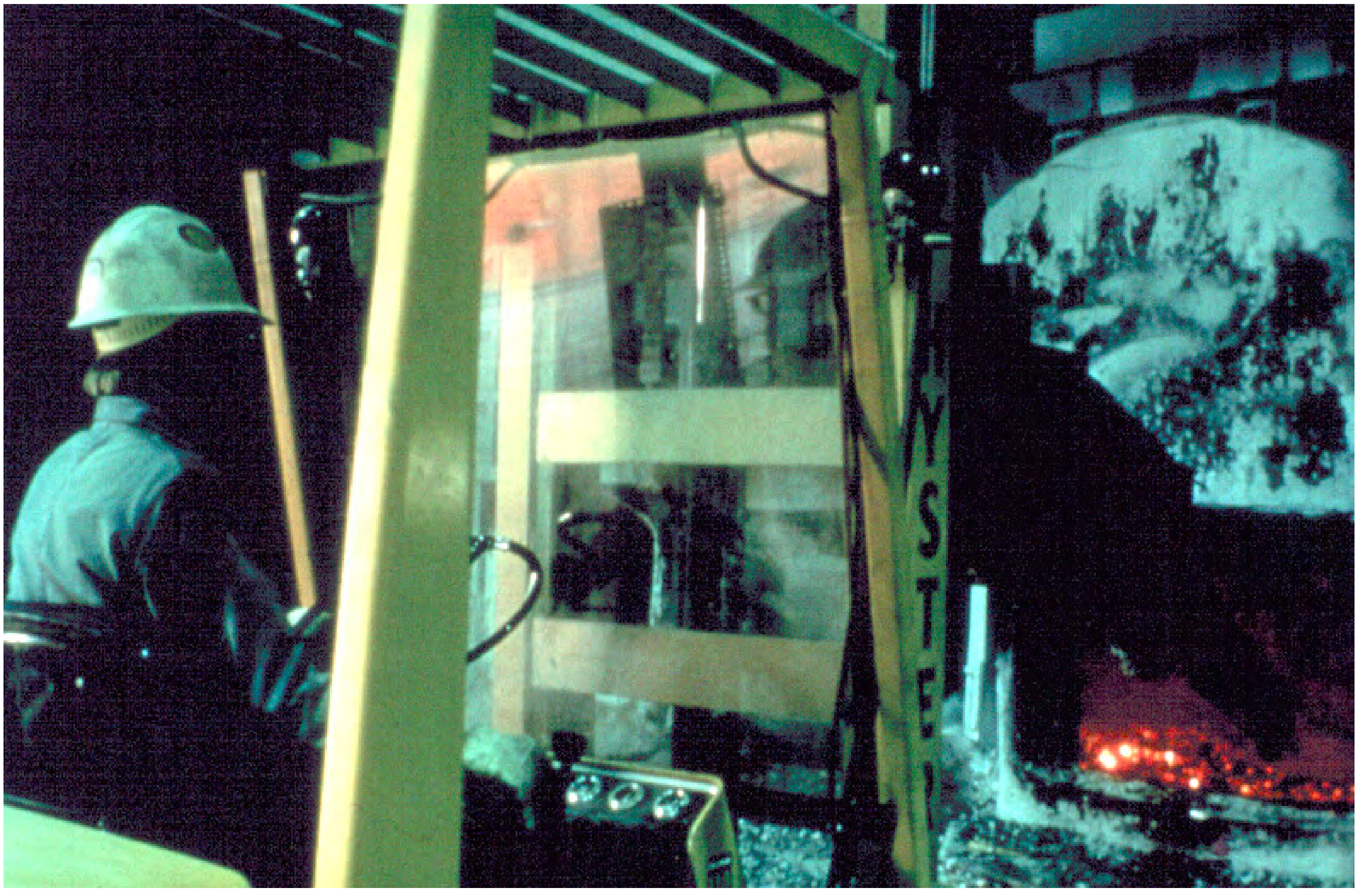

Figure 21: Charging Scrap into a Remelt Furnace Using a Shielded Fork

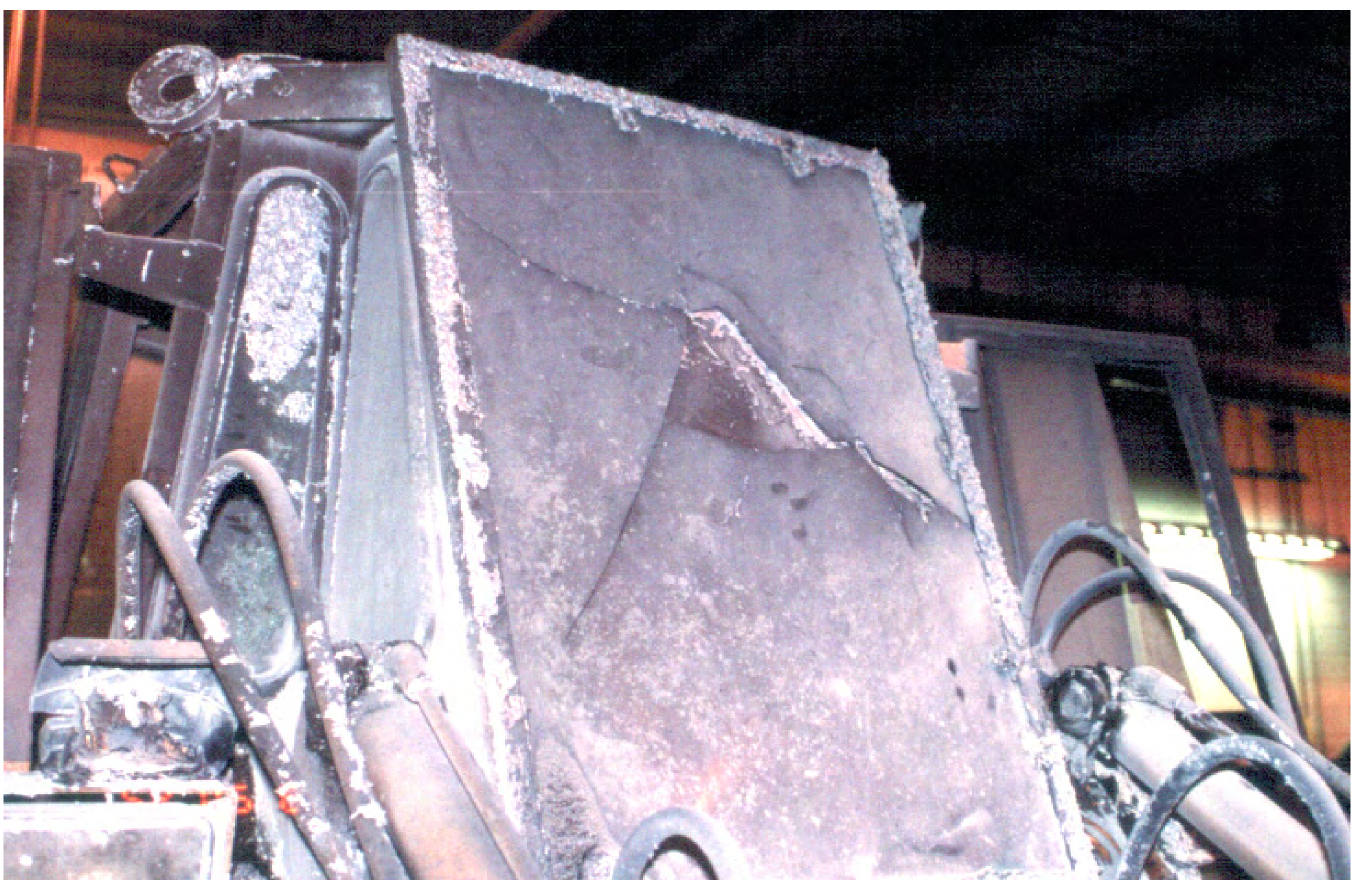

Figure 22: Fork Truck Shield Following Furnace Explosion

16.5: 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.

Figure 23 shows casthouse personnel skimming dross from a remelt furnace. Skim and drosses should be kept dry at all times to prevent ignition if wetted. The truck used for dumping should have a protective shield. An enclosed truck should be used for transporting dross.

Proprietary dross cooling equipment and processes are not covered in these *Guidelines.*

As an alternative, the skim may be spread over a clean, dry floor, surfaced with brick or specially designed refractory concrete but not on a Portland-based concrete floor.

16.6: Use of Compressed Air

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

Figure 23: Skimming Dross from Furnace by Mechanical Skimmer

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 "run-outs" from such systems. Ensure that the surrounding area does not contain water and other hazards in the event of leaks 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 manufacturers. 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 take 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 use. Rotating nozzles at higher than recommended speeds may 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.

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 free standing 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, 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 non-cured 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 cut off 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 non flaming 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 build-ups to prevent splashes if pieces fall or break off.

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

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

m. Use a lid when practical in transporting metal. This will 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, etc., to ensure right of way for molten material.

c. Carry the load a minimum practical distance from the floor.

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. Give 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.

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.

Section 19
Melt Transfer During Casting of Process Ingot

Many of the same guidelines in Section 18.1 apply to transfer of molten aluminum during casting.

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 non-cured 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 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. If the release agent contains water the pans must be heated prior to use.

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.

19.1: Clean-up of Metal Spills

See Section 26 for hazards to avoid in clean-up of metal spills.

VI. Casting Operations

Section 20
Precasting Precautions

Operators with experience in direct chill (DC) casting 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. The fact that the greatest number of personnel are around the casting machine at that time increases the hazard to personnel.

Know and follow the steps in your Casting Standard Practices Manual for starting the cast, including checkout of equipment in advance. Also, know what to do when you have a bleed-out, lose an ingot, or have an ingot hang up in the mold. Memorize your emergency shut down procedures.

Your local Standard Practices Manual has been developed specifically for the equipment in your plant. The following general guidelines are in no way to be considered a Practices Manual. They are intended to be used in training and safety programs to help you perform your 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.

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 insure 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 the painted areas for burned off paint. Remove aluminum debris from pit walls and base plate. Repaint areas where the paint has burned off. Remove debris from the casting pit if it is impossible to guarantee that at least three feet (1 m) of water is present in the pit at all times.

c. Keep aisles and passageways from the casting pit open and free of clutter. Ensure that there are at least two open exits from the pit area.

d. Keep employees not directly involved in casting out of the casting area.

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

f. Ensure that the metal to be cast is at the proper temperature and that the transfer equipment and flow control and other devices, if used, are dry and heated. Either too cold or too hot metal can create serious hazards during casting. Observe the temperature range specified in your standard practice.

g. Inspect spouts, control rods, headers, transition plates, etc. for cracks and chipped areas. Replace defective components.

h. Check the condition of molds. Look for cracks, gouges and excessive surface roughness. Then check the water and oil pattern on molds to insure 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.

i. Inspect the condition of troughs. Repair damaged areas and dry them thoroughly before exposing them to molten aluminum.

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. Tools with hollow handles must be vented. Ensure plug-off

Figure 24: Maintaining Metal Distribution System on a Hot Top Table

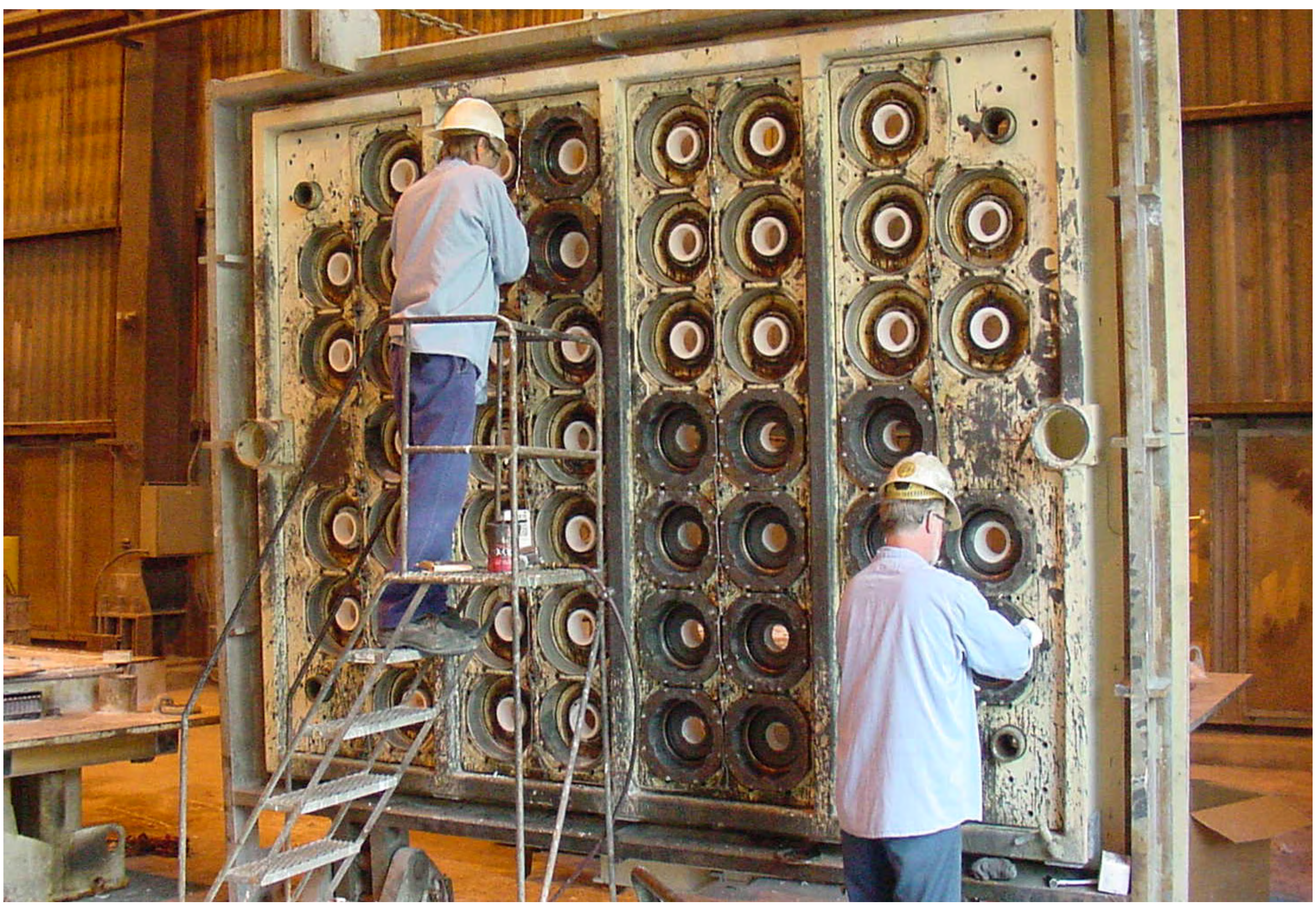

Figure 25: Maintaining Molds on a Hot Top Table

devices are clean, warm and in close proximity to the casting pit.

l. Check starting blocks for cracks, oxidation and/or rust. Replace all cracked blocks immediately. Clean oxidized or rusty blocks. Ensure all starting blocks are dry before starting the next drop. Oiling the block 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. It is recommended that low viscosity oils such as kerosene not be used.

m. Check the functioning of the emergency water supply at regular intervals, at least annually, to insure proper functioning.

n. 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.

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

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

q. Make sure operators are wearing appropriate protective clothing and safety equipment for the start of the cast.

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 Figure 5.

22.1.1: Before Starting the Cast

a. Review and follow Precasting Check List (Sec. 20).

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

c. 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.

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

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

f. Inspect the manual or automatic metal flow control devices for being properly positioned and in working order.

22.1.2: During the Cast

a. Maintain constant surveillance over casting operation, metal flow, gauges, controls, indicators, ingots being cast, etc. Follow the plant practices for any necessary adjustments or alarms.

b. 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 permit safe operation.

c. 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 would be to stop the platen, 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 under the molten head of the ingot.

Never hammer on a mold when an ingot is hung-up. 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 and allow the water to flow down the ingots until they are 100% solid. For large ingot this may require 10 to 15 minutes. Then 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.

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 shrinkage void area has solidified completely.

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

22.2: DC Casting - Horizontal

This method of casting is depicted in Figure 6.

A number of proprietary horizontal DC casting system have their own specific design and arrangement of components, take-away mechanism, etc. Each has a specific mode of operation which cannot be covered in these *Guidelines*. As with all equipment, for safe operation you must understand and follow the steps outlined in your Standard Practices Manual.

a. Follow an established check out 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 take away 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 take away mechanism, conveyor or sled.

f. Inspect starting blocks to make sure anchor bolts or other pull out 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 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 water cooling 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

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 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 Figure 26.

Hot Top technology is most often applied to mold tables with large numbers of round molds for high quantity 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.

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.

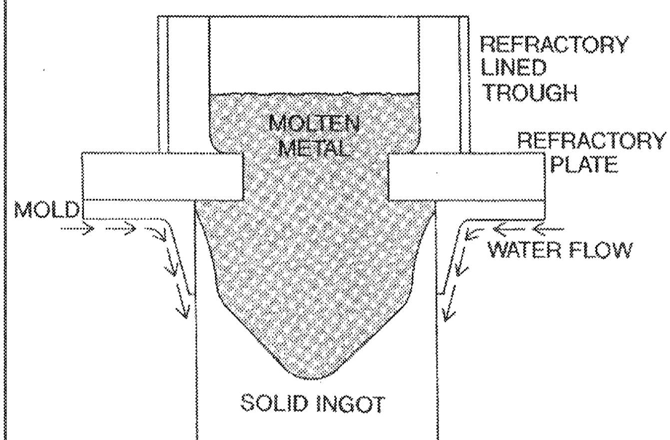

Figure 26: Schematic of Hot Top DC Casting System

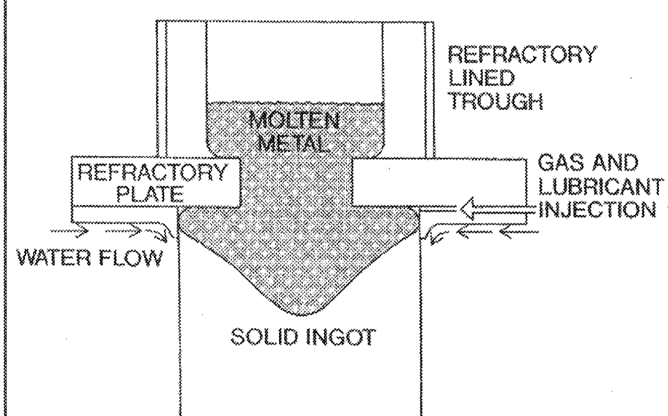

Figure 27: Schematic of Hot Top Mold with Air Injection System

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. an air injection system which surrounds the solidifying metal with an insulating layer of gas to further reduce mold wall cooling. See Figure 27.

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

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 get it repaired 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 careful inspection should be made of all starting blocks to insure that they have been oiled and no water is present.

e. Check your 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 and molten aluminum can trap water that has penetrated into the mold and cause an explosion.

23.1.2: During the Cast

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

b. Remain alert for bleed-outs during the entire cast. A Hot Top 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.

c. 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 molds. It is a good practice to specify in the standard practice the maximum number of molds 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.

d. 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 drop.

e. Never walk on top of a casting table filled with molten aluminum during the cast for any reason! If the problem cannot be fixed or the ingot plugged off without walking on top of the table, abort the drop.

23.1.3: When Cast is Completed

a. 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 of 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.

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.

Section 24
Electromagnetic Casting (EMC)

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 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. Conditions of process and safety put on the design and operation of the facility specific to EMC are supplied by the vendor/designer of the EMC system employed.

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 ferromagnetic 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 process computer (PLC).

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 Figure 28.

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 the facility is freed for the drop.

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 (**emergency 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 symbiosis with the automation program, arranges the equipment required for the casting operation and tests the facility's principal control devices or sensors.

The checklist having been completed, the start of the automatic casting operation is authorized. 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 start up 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

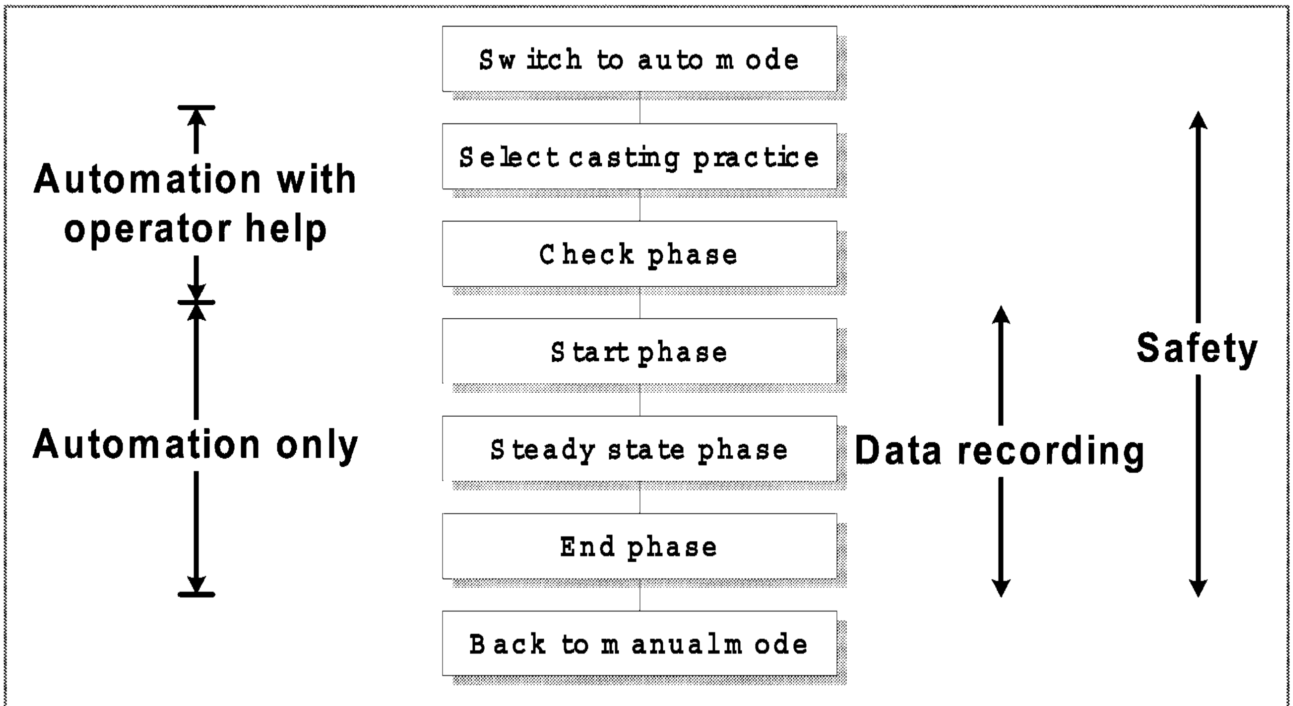

Figure 28: Typical Automated EM/DC Casting Sequence

in the 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 is a planned action intentionally introduced by the casting machine operator before the slabs have reached the set length.

24.3.2: Quick Stop

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 if one of the critical parameters is outside the acceptable tolerances.

24.3.3: Emergency Stop

The emergency stop is actuated by the casting machine operator if he/she senses serious occurrences for personnel and/or machine. In principle, it is initiated when:

a. the supply of cooling water is interrupted;
b. metal spills over in the mold or trough;
c. the process computer fails.

Contrary to the quick stop, the emergency stop reacts always via hardware, i.e., purely mechanically.

Quick stop and emergency stop are based on the following philosophy:

a. Molten Metal: In both cases, the supply of molten metal has to be interrupted and the molten metal evacuated in the direction of the furnace or into the trough draining container.
b. Platen: In both cases, the lowering of the platen is stopped.
c. Cooling Water: The supply of cooling water is not interrupted.

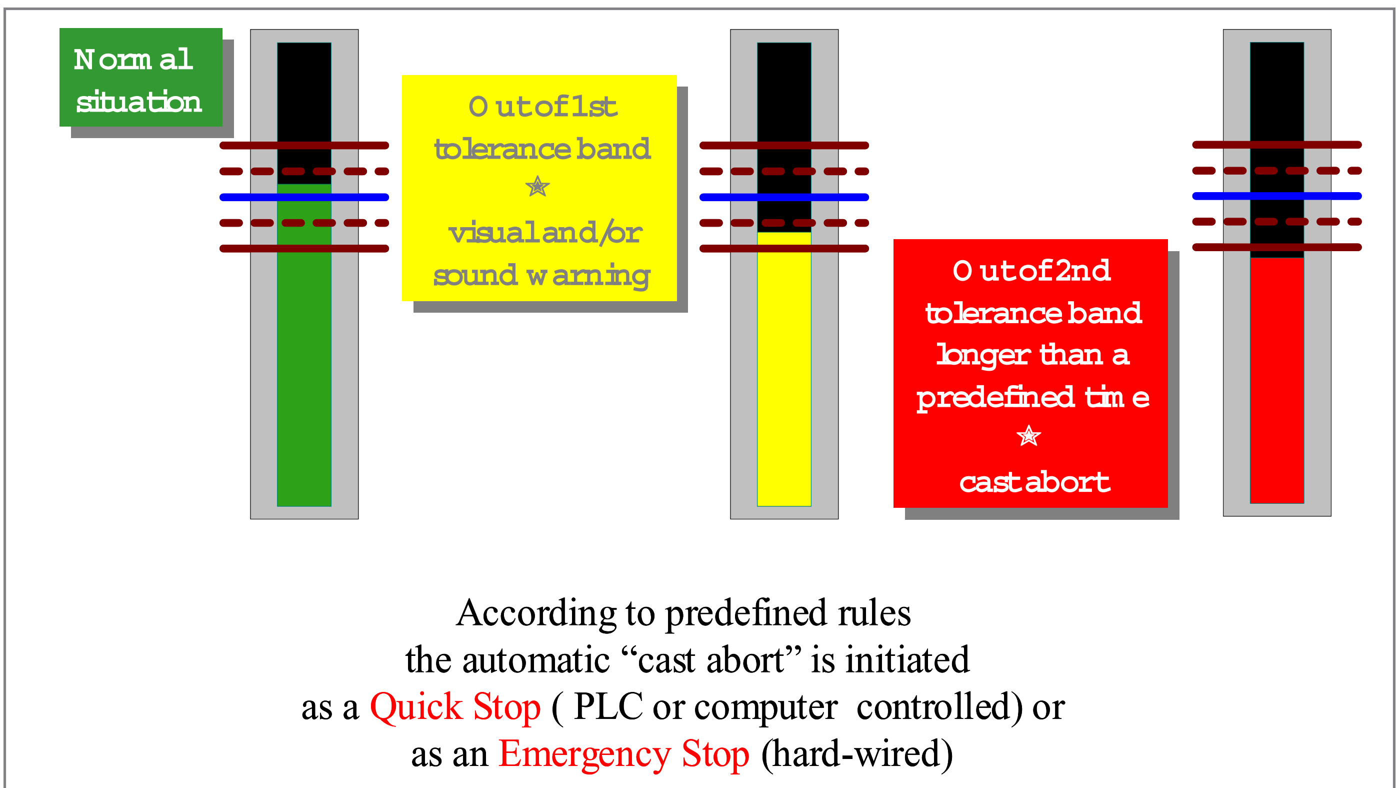

Figure 29: Automated Safety Stops in EM/DC Casting

Section 25
Other Casting Systems

25.1: 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.

25.2: Casting Sow & 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 water base release agent is used, dry the coating with applied heat before pouring molten aluminum in the mold.

f. Keep tools, skimmers, etc. coated with a protective wash, but be sure they are 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 should be worn during the transfer, mold filling and skimming operations.

Section 26
Clean-up of Metal Spills

Since major spills of molten metal occur infrequently, there is a risk that workers may forget proper procedures for clean up. 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 clean up should wear proper clothing and protective equipment. If a torch is used or heat applied, standby fire extinguishers should be on hand.

26.1: Spills from Furnaces and Transfer Equipment

When molten aluminum spills on concrete, some small but potentially hazardous eruptions 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 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 and 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 careful safety review should be performed before oxygen lancing, which should be used as a last resort.

26.2: 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 if possible. 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 27
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 the potential explosions from molten metal bleed-outs or spills when molten metal comes in contact with coated steel and concrete.

The surfaces of metal casting equipment* and the walls and bottom of the casting pits before being used should be coated with an organic coating approved by your company. Once the equipment and pits are in use, the condition of this coating should 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 pits 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 around 1994. The Association coordinated a program at the Alcoa Technical Center to test coatings as possible replacements for Tarset Standard. This effort began in mid-1995 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.

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 most surface. This is important in the case of DC casting pit walls which are difficult to dry completely.

Recommendations on specific proprietary protective coatings are not made in these *Guidelines*. Information on application and performance should be obtained from the manufacturers.

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 and steel components of casting equipment* and support structures should be protected and maintained with a suitable organic coating.

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.

* 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.

VIII. Explosions Involving Molten Aluminum

Section 28
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 quickly turns to steam and, in so doing, expands more than a thousand 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.

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 31) the Aluminum Association has defined them as Force 1, Force 2, and Force 3 explosions, which are characterized as follows:

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.

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. 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.

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 Figures 1 and 2 for a DC casting incident and a furnace charging incident, respectively. 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 30), 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. Fertilizers such as ammonium nitrate, heavily oxidized metals and other oxidizing agents when charged into molten metal in a furnace or when contacted by molten metal have given rise to these events. Other sources of contamination in scrap, such as live ammunition and closed containers, have been suspected of causing catastrophic explosions.

Section 29
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 used 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 30
Research on Molten Aluminum Water Explosions

30.1: 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.

30.2: References

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

30.3: 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 bleed-out 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 3¼ 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.

30.4: 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 were 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 white-out 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 by products 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.

30.4: IITRI Studies

Between 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 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.

30.5: 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 pound (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 bleed out.

30.6: 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 shock wave of controlled strength; the intensity required to make the drop of aluminum explode was then 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.

30.7: 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. 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 the coating becomes protective was recently completed. Once again, Oak Ridge National Laboratory participated through an extended CRADA with the Aluminum Association.

Section 31
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 Figure 30. 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, contact The Association's Health & Safety Department.

ALUMINUM ASSOCIATION
MOLTEN METAL INCIDENT REPORT

Date of Incident ______________________ (month/year) Type of Plant ______________________ (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 Capcity ______________ lbs. % Full ______________ Alloy ______________

Metal Temperature ______________ °F Approximate Amount of Metal Involved ______________ lbs.

Materials Charged ______________________

Outside Storage? Yes ☐ No ☐ Preheat? Yes ☐ No ☐ Preheat Time and temp.: ________Hrs. ________°F

Transfer Type ______________________ (Crucible, Trough, Sand & P.M., etc.)

Alloy ______________ Temperature __________°F Approximate Amount of Metal Involved ______________ lbs.

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

Alloy ______________ Temperature __________°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: ______________________

Use back of form if more space is needed.

***Explosion characterization**

Force 1	Property Damage	- None
	Light	- Minimal
	Sound	- Short Cracking
	Vibration	- Short Sharp
	Metal Dispersion	- <15′ Radius
Force 2	Property Damage	- Minor
	Light	- Fash
	Sound	- Loud Report
	Vibration	- Brief Rolling
	Metal Dispersion	- <15–30′ Radius
Force 3	Property Damage	- Considerable
	Light	- Intense
	Sound	- Painful
	Vibration	- Massive Structural
	Metal Dispersion	- >50′ Radius

Please return to:

Chuck Johnson
Manager, Environment, Health & Safety
The Aluminum Association
900 – 19th Street, NW
Washington, DC 20006

Figure 30: Molten Metal Incident Reporting Form

IX. References & Audiovisuals on Molten Aluminum - Water Explosions

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Audiovisual Training Aids on Preventing Molten Aluminum Water Explosion

1. Alcoa, "Molten Aluminum Water Explosions" (16mm sound motion picture film).

2. Aluminum Association, "Containers That Kill" (7.5 minute videotape).

3. Aluminum Association, "Guidelines for Handling Molten Aluminum" (80 slide carousel with audio cassette). **The Association will release a VHS training video based on the Guidelines and this slide show in the fall of 2002.**

4. Aluminum Association, "Molten Metal Explosions - Two Case Histories" (9 minute videotape).

5. Aluminum Association, "Preventing Explosions in Aluminum Melting Operations" (17 minute videotape).

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