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NFPA 86D
Industrial Furnaces Using Vacuum as an Atmosphere
1990 Edition

NFPA

National Fire Protection Association 1 Batterymarch Park, PO Box 9101, Quincy, MA 02269-9101

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The Board of Directors reaffirms that the National Fire Protection Association recognizes that the toxicity of the products of combustion is an important factor in the loss of life from fire. NFPA has dealt with that subject in its technical committee documents for many years.

There is a concern that the growing use of synthetic materials may produce more or additional toxic products of combustion in a fire environment. The Board has, therefore, asked all NFPA technical committees to review the documents for which they are responsible to be sure that the documents respond to this current concern. To assist the committees in meeting this request, the Board has appointed an advisory committee to provide specific guidance to the technical committees on questions relating to assessing the hazards of the products of combustion.

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NFPA 86D

Standard for

Industrial Furnaces Using Vacuum as an Atmosphere

1990 Edition

This edition of NFPA 86D, *Standard for Industrial Furnaces Using Vacuum as an Atmosphere*, was prepared by the Technical Committee on Ovens and Furnaces and acted on by the National Fire Protection Association, Inc. at its Annual Meeting held May 21-24, 1990 in San Antonio, TX. It was issued by the Standards Council on July 20, 1990, with an effective date of August 17, 1990, and supersedes all previous editions.

The 1990 edition of this document has been approved by the American National Standards Institute.

Origin and Development of NFPA 86D

With the increased use of vacuum furnaces in industry, a Sectional Committee under the Committee on Ovens and Furnaces was organized in 1974 to prepare a standard covering Class D Furnaces. The first edition was adopted by the Association at the 1976 NFPA Fall Meeting. Editorial revisions were made in the 1978 edition. The 1985 edition included a complete rewrite of the foreword, the development of a new Chapter 12 for mandatory referenced publications, and a revision of Appendix F.

This latest 1990 edition has undergone a complete revision, incorporating a variety of technical and editorial changes. This includes a new Appendix A that consolidates appendix information in accordance with the NFPA *Manual of Style*.

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NOTE: Membership on a Committee shall not in and of itself constitute an endorsement of the Association or any document developed by the Committee on which the member serves.

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NOTICE: An asterisk (*) following the number or letter designating a paragraph indicates explanatory material on that paragraph in Appendix A.

Information on referenced publications can be found in Chapter 12 and Appendix H.

Foreword

Explosions and fires in fuel-fired and electric heat utilization equipment constitute a loss potential in life, property, and production. This standard is a compilation of guidelines, rules, and methods applicable to safe operation of this type of equipment.

There are other regulations and conditions that should be considered when designing and operating furnaces that are not covered in this standard, such as toxic vapors, noise levels, heat stress, and local, state, and federal regulations (EPA and OSHA).

Causes of practically all failures can be traced back to human failure. The most significant failures have been found to be:

(a) Inadequate training of operators

(b) Lack of proper maintenance

(c) Improper application of equipment.

Users and designers must utilize engineering skills to bring together that proper combination of controls and training necessary for the safe operation of the equipment. The Standards for Ovens and Furnaces are set forth under classification as follows:

Class A ovens or furnaces are heat utilization equipment operating at approximately atmospheric pressure wherein there is a potential explosion and/or fire hazard which may be occasioned by the presence of flammable volatiles or combustible material processed or heated in the oven. Such flammable volatiles and/or combustible material may, for instance, originate from paints, powder, or finishing processes, including dipped, coated, sprayed, impregnated materials or wood, paper and plastic pallets, spacers, or packaging materials. Polymerization or similar molecular rearrangements and resin curing are processes that may produce flammable residues and/or volatiles. Potentially flammable materials, such as quench oil, waterborne finishes, cooling oil, etc., in sufficient quantities to present a hazard, are ventilated according to Class A standards. Ovens may also utilize low-oxygen atmosphere to evaporate solvent.

Class B ovens or furnaces are heat utilization equipment operating at approximately atmospheric pressure wherein there are no flammable volatiles or combustible material being heated.

Class C furnaces are those in which there is a potential hazard due to a flammable or other special atmosphere being used for treatment of material in process. This type of furnace may use any type of heating system and includes the special atmosphere supply system. Also included in the Class C standard are Integral Quench and Molten Salt Bath furnaces.

Class D furnaces are vacuum furnaces which operate at temperatures above ambient to over 5000°F (2760°C) and at pressures normally below atmospheric using any type of heating system. These furnaces may include the use of special processing atmospheres.

Chapter 1 Introduction

1-1 Scope. This standard is for ovens and furnaces operating from ambient temperatures to over 5000°F (2760°C) and at pressures normally below atmospheric to 10^{-8} Torr (1.33×10^{-6} Pa).

1-1.1 This standard shall apply to new installations or alterations or extensions to existing equipment.

Exception: Section 1-9 and Chapter 11.

NOTE: Because this standard is based on the present state of the art, application to existing installations is not mandatory. Nevertheless, users are encouraged to adopt those features of this standard that are considered applicable and reasonable for existing installations.

1-1.2 Chapter 11, Maintenance of Vacuum Furnaces, and Section 1-9, Operator and Maintenance Personnel Training, shall apply to all operating furnaces.

1-2* Types of Furnaces. The requirements for vacuum furnaces determine the type of furnace walls, size of furnace, the special atmospheres required, or the reduction from normal atmosphere down to a special vacuum of 10^{-8} Torr (1.33×10^{-6} Pa).

Vacuum furnaces generally are described as either cold-wall furnaces, hot-wall furnaces, or furnaces used for casting or melting of metal at high temperatures up to 5000°F (2760°C). There may be other special types.

NOTE: Reference should be made to these various types of furnaces by taking special note of Table A-1-2, Vacuum Furnace Protection. This table describes the heating system requirement and notes the principal items supplied as a part of the furnace which includes the (A) Vacuum System, (B) Heating System, (C) Cooling System, (D) Process Atmosphere Cycle, (E) Material Handling, (F) Instrument Control, (G) Hazards of Heating Systems, and (H) Personnel Safety Hazards. Each item is included in the table for the 10 principal furnace types.

1-2.1* The cold-wall furnace types are further described as being a furnace that is heated by electrical induction, electrical resistance or electron beam, plasma arc, ion discharge, or fuel firing. Fuel fired burner controls and safeguards shall be provided as indicated in NFPA 86C, *Standard for Industrial Furnaces Using a Special Processing Atmosphere.*

1-2.2* The hot-wall furnace may be either a fuel fired or an electrically heated furnace. Fuel fired burner controls and safeguards shall be provided as indicated in NFPA 86C.

1-2.3* Special furnaces are available for casting and melting of steel, iron, copper, and other metals. These furnaces are heated using induction, electron beam, plasma arc, or electric arc systems.

1-3 Pressure Vessel Design. It is a general practice for the vacuum vessel to be considered a type of pressure vessel. Where applicable, it shall be designed in accordance with the latest published requirements of Section VIII of the ASME *Boiler and Pressure Vessel Code (see 2-6.13 and 2-6.14).*

1-4 Power Supply. Vacuum furnaces using induction, resistance, electron beam, plasma arc, or electric arc heating systems include an electric power supply with a high demand current. Consideration shall be given for the high voltage supply used for electron beam, plasma arc, or ion discharge furnace unit.

1-5 Cooling System. Cold-wall vacuum furnaces shall have a specifically designed cooling system to maintain the vacuum furnace vessel at proper temperatures. These cooling systems are critical as the furnace vessel walls must be maintained at safe temperatures when the furnace operates at maximum temperatures.

NOTE: The furnace cooling system may include, in addition to the vessel cooling system, one or more methods for cooling material in process. The systems may include gas quenching, oil quenching, or water quenching. Internal and/or external heat exchangers may be used and generally require supplementary cooling. Special atmospheres may be used for cooling.

1-6 Definitions. *(Reference American Vacuum Society).* For the purpose of this standard, the following definitions shall apply:

Absolute Pressure. A term used in engineering literature to indicate pressure above the absolute zero value corresponding to empty space or the absolute zero of temperature as distinguished from gage pressure.

NOTE: In vacuum technology, pressure always corresponds to absolute pressure not gage pressure, and therefore the term absolute pressure is not required.

Absorption. The binding of gas in the interior of a solid (or liquid).

Adsorbate. The gas removed from the gas phase by adsorption.

Adsorbent. The material which takes up the gas by adsorption.

Adsorption. Condensing of gas on the surface of a solid.

Air-Inlet Valve. A valve used for letting atmospheric air into a vacuum system (also called a vacuum breaker).

Approved. Acceptable to the "authority having jurisdiction."

NOTE: The National Fire Protection Association does not approve, inspect or certify any installations, procedures, equipment, or materials nor does it approve or evaluate testing laboratories. In determining the acceptability of installations or procedures, equipment or materials, the authority having jurisdiction may base acceptance on compliance with NFPA or other appropriate standards. In the absence of such standards, said authority may require evidence of proper installation, procedure or use. The authority having jurisdiction may also refer to the listings or labeling practices of an organization concerned with product evaluations which is in a position to determine compliance with appropriate standards for the current production of listed items.

Atmosphere, Special. Prepared gas or gas mixtures that are introduced into the work chamber of a heat-treating furnace to replace air, generally to protect or intentionally change the surface of the material undergoing heat treatment. Special Atmosphere, See Special Atmosphere, Carrier Gas; Special Atmosphere, Flammable; Special Atmosphere, Indeterminate; or Special Atmosphere, Inert (Purge Gas) Nonflammable.

Atmospheric Pressure. The pressure of the atmosphere at a specified place and time.

Authority Having Jurisdiction. The "authority having jurisdiction" is the organization, office or individual responsible for "approving" equipment, an installation or a procedure.

NOTE: The phrase "authority having jurisdiction" is used in NFPA documents in a broad manner since jurisdictions and "approval" agencies vary as do their responsibilities. Where public safety is primary, the "authority having jurisdiction" may be a federal, state, local or other regional department or individual such as a fire chief, fire marshal, chief of a fire prevention bureau, labor department, health department, building official, electrical inspector, or others having statutory authority. For insurance purposes, an insurance inspection department, rating bureau, or other insurance company representative may be the "authority having jurisdiction." In many circumstances the property owner or his designated agent assumes the role of the "authority having jurisdiction"; at government installations, the commanding officer or departmental official may be the "authority having jurisdiction."

Batch Process Furnace. A furnace into which the work is introduced all at one time.

Booster Pump. A vapor pump or a specially designed mechanical pump used between a vapor pump and a fore pump to increase the maximum gas throughput which can be handled.

Centrifugal Pump. A pump without a discharge valve that moves the gas from the axis to the circumference by the propelling action of a rapidly rotating member provided with ducts, blades, or vanes.

NOTE: The limiting or breaking forepressure of the booster at this maximum throughput must be appreciably greater than that of the vapor pump which it backs.

Cold Trap. A vessel designed to hold a coolant, or one cooled by coils in which a coolant circulates, inserted into a vacuum system so as to condense on its inner surface vapors present in the system.

Compound Mechanical Pump. A mechanical pump having 2 or more stages in series.

Condensation Rate. The number of molecules that condense on a surface per square centimeter per second.

Continuous Process Furnace. A furnace into which the work charge is more or less continuously introduced.

Diffusion Pump. A vapor pump having boiler pressures less than a few Torr and capable of pumping gas at intake pressures not normally exceeding about 20 milliTorr (2.7 Pa) and discharge pressures (forepressures) not normally exceeding about 500 milliTorr (66.7 Pa).

NOTE: The pumping action of each vapor jet occurs by the diffusion of gas molecules through the low density scattered vapor into the denser forward moving core of a freely expanding vapor jet.

Displacement. The geometric volume swept out per unit time by the working mechanism of mechanical pumps at normal frequency.

Duplex Mechanical Pump. A mechanical pump having 2 single stage units in parallel operated by the same drive.

Fore Pump. The pump that produces the necessary fore vacuum for a pump that is incapable of discharging gases at atmospheric pressure. (Sometimes called the backing pump.)

Free Air Displacement. The volume of air passed per unit time through a mechanical pump when the pressure on the intake and exhaust sides is equal to atmospheric pressure. (Also called free air capacity.)

Gas Ballast. The venting of the compression chamber of a mechanical pump to the atmosphere to prevent condensation of condensable vapors within the pump. (Also called vented exhaust.)

Gas Ballast Pump. A mechanical pump (usually of the rotary type) equipped with an inlet and valve through which a suitable quantity of atmospheric air or "dry" gas can be admitted into the compression chamber so as to prevent condensation of vapors within the chamber by maintaining the partial pressure of the vapors below the saturation value. (Sometimes called a vented-exhaust mechanical pump.)

Hazardous Material. Any material possessing a relatively high potential for harmful effects on persons, property, or process. A material having one or more of the following characteristics.

(a) Has a closed-cup flash point below 140°F (60°C) or is subject to spontaneous heating

(b) Has a threshold limit value below 500 parts per million in the case of a gas or vapor or below 500 mg/cu M for fumes, and below 25 mppcf in the case of a dust

(c) Has a single dose oral LD 50 below 500 mg/kg

(d) Is subject to polymerization with the release of large amounts of energy

(e) Is a strong oxidizing or reducing agent

(f) Causes first-degree burns to skin in short-time exposure, or is systemically toxic by skin contact

(g) In the course of normal operations, may produce dusts, gases, fumes, vapors, mists, or smokes that have one or more of the above characteristics.

High Vacuum. A pressure less than some upper limit, such as 1 mm Hg or 1 μ Hg.

Holding Pump. A fore pump used to hold a vapor pump at efficient operating conditions while a roughing pump reduces the system pressure to a point at which the valve between the vapor pump and the system can be opened without stopping the flow of vapor from the nozzles.

Implosion. The rapid inward collapsing of the walls of a vacuum system or device as the result of failure of the walls to sustain the atmospheric pressure. Usually followed by an outward scattering of the pieces with possible danger to nearby equipment and personnel.

Inleakage Rate. The combined leak rate (in pressure-volume units per unit time) from all existing leaks in a specified evacuated vessel, sometimes expressed in terms of the rate of rise of pressure in the isolated vessel.

Inlet Pressure. The "total static pressure" measured in a standard testing chamber by a vacuum gage located near the inlet port.

Labeled. Equipment or materials to which has been attached a label, symbol or other identifying mark of an organization acceptable to the "authority having jurisdiction" and concerned with product evaluation, that maintains periodic inspection of production of labeled equipment or materials and by whose labeling the manufacturer indicates compliance with appropriate standards or performance in a specified manner.

Leak. A hole or porosity in the wall of an enclosure capable of passing gas from one side of the wall to the other under action of a pressure or concentration differential existing across the wall.

Leak Detector. A device for detecting and locating leaks and indicating the magnitude thereof.

Leak Rate. The quantity of gas in pressure-volume units at room temperature flowing into the system or through the pump from an external source in unit time.

NOTE: Recommended unit is Torr liter per second at 20°C (68°F). (Also expressed in micron-liter per second or micron cubic feet per minute or cc-atmos/sec at 25°C (77°F).)

LEL (Lower Explosive Limit). See Range, Explosive.

Limit, Excess Temperature. A device designed to cut off the source of heat if the operating temperature exceeds a predetermined temperature set point.

Limit Switch. See Switch, Limit.

Limits of Flammability. See Range, Explosive.

Listed. Equipment or materials included in a list published by an organization acceptable to the "authority having jurisdiction" and concerned with product evaluation, that maintains periodic inspection of production of listed equipment or materials and whose listing states either that the equipment or material meets appropriate standards or has been tested and found suitable for use in a specified manner.

NOTE: The means for identifying listed equipment may vary for each organization concerned with product evaluation, some of which do not recognize equipment as listed unless it is also labeled. The "authority having jurisdiction" should utilize the system employed by the listing organization to identify a listed product.

Low Vacuum. The condition in a gas-filled space at pressures less than 760 Torr (101 kPa) and greater than some lower limit.

Manometer. An instrument for measuring pressure of gases and vapors whether above or below atmospheric pressure.

McLeod Gage. A liquid level vacuum gage in which a known volume of the gas, at the pressure to be measured, is compressed by the movement of a liquid column to a much smaller known volume, at which the resulting higher pressure is measured.

NOTE: Particular designs are named after the inventors of various trade names.

Mean Free Path (of any particle). The average distance that a particle travels between successive collisions with the other particles of an ensemble.

Mechanical Pump. A pump that moves the gas by the cyclic motion of a system of mechanical parts such as piston, eccentric rotors, vanes, valves, etc.

Micron of Mercury. A unit of pressure equal to 1/1000th of one millimeter of mercury pressure. Abbreviated as m of Hg or m Hg.

Millimeter of Mercury. A unit of pressure corresponding to a column of mercury exactly 1 millimeter high at 0°C under standard acceleration of gravity of 980.665 cm/sec^2.

MilliTorr. A unit of pressure equal to 10^{-3} Torr (1.3×10^{-1} Pa).

Oil Separator. An oil reservoir with baffles to reduce the loss of oil by droplets in the exhaust.

Operators. The individuals responsible for the startup, operation, shutdown, and emergency handling of the specific installation or furnace and the associated equipment.

Outgassing. The spontaneous evolution of gas from a material in a vacuum.

Partial Pressure. The pressure of a designated component of a gaseous mixture.

Programmable Controller. A digitally operating electronic system designed for use in an industrial environment, that uses a programmable memory for the internal storage of user oriented instructions for implementing specific functions such as logic, sequencing, timing, counting, and arithmetic to control, through digital or analog inputs and outputs, various types of machines or processes.

Pump-Down Factor. The product of the time to pump down to a given pressure and the displacement (for a service factor of one) divided by the volume of the system (F = t D/V).

Pump Fluid. The operating fluid used in vapor pumps or in liquid-sealed mechanical pumps. (Sometimes called working medium, working fluid, or pump oil.)

Pump, Vacuum. Mechanical pump used to purge to a vacuum generally in the range of 100 microns (0.1 mmHg).

Purge. The replacement of a flammable or high-oxygen bearing atmosphere with an inert gas to a nonflammable state, i.e., 50 percent of the lower explosive limit (LEL) or //Ll 1 percent oxygen.

Purge Air. Positive removal and/or dilution of flammable vapors with air to a point below 25 percent of the lower explosive limit.

Purge, Inert Atmosphere. The replacement of a flammable or high-oxygen bearing atmosphere with an inert gas to a nonflammable state.

Range, Explosive (Limits of Flammability). The range of concentration of a flammable gas in air within which flame is propagated. The lowest flammable concentration is the lower explosive limit (LEL). The highest flammable concentration is the upper explosive limit (UEL). See NFPA 325M, *Fire Hazard Properties of Flammable Liquids, Gases, and Volatile Solids*.

Rate of Rise. The time rate of pressure increase at a given time in a vacuum system that is suddenly isolated from the pump by a valve.

NOTE: The volume and temperature of the system are held constant during the rate-of-rise measurement.

Reciprocating Pump. A pump that moves the gas by means of a system or reciprocating pistons and valves.

Roots Blower Pump. A rotary blower pump having a pair of two-lobe, inter-engaging impellers of special design.

Rotary Blower Pump. A pump without a discharge valve that moves the gas by the propelling action of one or more rapidly rotating members provided with lobes, blades, or vanes. (Sometimes called a mechanical booster pump when used in series with a mechanical fore pump.)

NOTE: Rotary blowers are sometimes classified as either axial flow or cross flow types depending on the direction of flow of gas.

Rotary Piston Pump. A liquid-sealed mechanical pump employing a rotor, stator, and sliding vanes.

Roughing Line. A line running from a mechanical pump to a vacuum chamber through which preliminary pumping is conducted in the rough vacuum range.

Roughing Pump. The pump used to reduce the system pressure to the point at which a vapor pump (or other pump requiring a fore vacuum) can take hold and operate efficiently.

NOTE: The roughing pump may then also be used as the fore pump for the vapor pump, or the roughing pump may be shut off and a smaller pump used as fore pump when the gas load is relatively small.

Roughing Time. The time required to pump a given system from atmospheric pressure to the take-hold pressure for the vapor pump (or other high-vacuum pump) or to a pressure at which valves to the vapor pump can be opened without stopping the flow of vapor from the nozzles.

Safety Interlock. A device required to ensure safe start up, safe operation, and/or cause safe equipment shutdown.

Shall. Indicates a mandatory requirement.

Should. Indicates a recommendation or that which is advised but not required.

Special Atmosphere, Carrier Gas. Any gas or liquid component of the special atmosphere that represents a sufficient portion of the special atmosphere gas volume in the furnace such that, if the flow of this component gas or liquid ceases, the total flow of the special atmosphere in the furnace would not be sufficient to maintain a positive pressure in that furnace.

Special Atmosphere, Flammable. Gases that are known to be flammable and predictably ignitible when mixed with air.

Special Atmosphere, Indeterminate. Atmospheres that contain components that, in their pure state, are flammable but in the mixtures used (diluted with nonflammable gases) are not reliably and predictably flammable.

Special Atmosphere, Inert (Purge Gas). Nonflammable gases that contain less than 1 percent oxygen.

Special Atmosphere, Nonflammable. Gases that are known to be nonflammable at any temperature.

Susceptor. Energy-absorbing device generally used to transfer heat.

Switch, Limit. A switching device that actuates when an operating limit has been reached.

Time of Evacuation. The time required to pump a given system from atmospheric pressure to a specified pressure. (Also known as pump-down time or time of exhaust.)

Torr. An international standard term to replace the English term millimeter of mercury and its abbreviation mm of Hg.

Ultimate Pressure. The limiting pressure approached in the vacuum system after sufficient pumping time to establish that further reductions in pressure will be negligible. (Sometimes called the ultimate vacuum.)

NOTE: The terms blank-off pressure or base pressure are also sometimes used in referring to a pump under test.

Vacuum. A given space filled with gas at pressures below atmospheric pressure.

Vacuum Gage. A manometer for pressures below 760 Torr (101 kPa).

NOTE: Terms such as vacuum gage, Pirani gage, ionization gage, etc., should be used only when referring to the complete gage and not merely to the gage tube.

Vacuum Impregnation. A process for filling voids or interstices with a fluid by first subjecting the article to a vacuum, then flooding with the desired fluid, and breaking the vacuum.

Vacuum Manifold. An enclosure with several ports so that a number of vacuum devices may be attached to it at one time for evacuation and processing.

Vacuum System. A chamber or chambers having walls capable of withstanding atmospheric pressure and having an opening through which the gas can be removed through a pipe or manifold to a pumping system.

NOTE: The pumping system may or may not be considered as part of the vacuum system. A complete vacuum system contains all necessary pumps, gages, valves, and other components necessary to carry out some particular process; such a system is referred to in England as a vacuum plant.

Vacuum Thermal Insulation. The use of evacuated space for reduction of conductive and convective heat transfer.

Vapor. A gas whose temperature is below its critical temperature, so that it can be condensed to the liquid or solid state by increase of pressure alone.

Vapor Pressure. The sum of the partial pressures of all the vapors in a system or the partial pressure of a specified vapor.

Vapor Pump. Any pump employing a vapor jet as the pumping means. (Applies to diffusion pumps and ejector pumps.)

1-7* Approvals, Plans, and Specifications.

(a) Before new equipment is installed or existing equipment remodeled, complete plans and specifications shall be submitted for approval to the authority having jurisdiction. Plans shall be drawn to an indicated scale and show all essential details as to location, construction, heating equipment, fuel piping, heat input, and safety control wiring diagrams. The plans shall include a list of equipment giving manufacturer and type number.

(b) Any deviation from this standard shall require special permission from the authority having jurisdiction.

(c) Wiring diagrams and sequence of operations for all controls, including "ladder type" schematic diagrams, shall be provided. See Figures A-1-7(a), (b), and (c).

(d) For application of programmable controllers, also see Section 5-5.

1-8 Electrical. All wiring in and around furnaces shall be in accordance with NFPA 70, *National Electrical Code*.®

NOTE 1: The *National Electrical Code* is indicated as a reference source for safe practices and wiring methods. Where it is considered that variation of the recommended wiring methods as currently specified in the *National Electrical Code* is necessary, such variations are required to meet with the approval of the authority having jurisdiction.

NOTE 2: NFPA 497A, *Recommended Practice for Classification of Class I Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas* is referenced, specifically 2-6.4, regarding certain equipment with open flames and hot surfaces.

1-9 Operator and Maintenance Personnel Training.

1-9.1 The selection of alert and competent personnel shall be required. It is recognized that their knowledge and training is vital to safe furnace operation and maintenance.

1-9.1.1 All personnel shall be thoroughly instructed and trained under supervision of experienced person(s) and shall be required to demonstrate understanding of the equipment and of its operation to ensure knowledge of and practice of safe operating procedures.

1-9.2 Regular personnel shall receive retraining to maintain a high level of proficiency and effectiveness.

1-9.3 Personnel shall have access to operating instructions at all times.

1-9.4 Operator training shall include, where applicable:

(a) Vacuum technology

(b) Combustion of fuel-air mixtures

(c) Explosion hazards

(d) Sources of ignition including auto-ignition (for instance, by incandescent surfaces)

(e) Functions of control and safety devices

(f) Handling of special atmospheres

(g) Confined space entry procedures

(h) Handling and processing of hazardous materials.

1-9.5 Operating instructions shall be provided by the equipment manufacturer. These shall include:

(a) Schematic piping and wiring diagrams

(b) Start up procedures

(c) Shutdown procedures

(d) Emergency procedures including those occasioned by loss of special atmospheres, electric power, or other essential utilities

(e) Maintenance procedures.

Chapter 2 Location and Construction

2-1 Location of Vacuum Furnaces and Related Equipment.

2-1.1 General.

2-1.1.1 Vacuum furnaces and related equipment shall be located with consideration to the possibility of fire resulting from overheating, ignition of quench oil, ignition of pump oil, etc., or from escaping of processing atmosphere where applicable, with the resulting possibility of building equipment damage and injury to personnel.

2-1.1.2 Consideration shall be given to the location of furnaces to provide protection against damage by heat, vibration, and mechanical hazards.

2-2 Grade Location.

NOTE: Vacuum furnaces designed for use with special flammable atmospheres should be located at or above grade to make maximum use of natural ventilation and to minimize restrictions to adequate explosion relief and sufficient air supply for personnel who may be working in confined quarters.

2-2.1 When basements or other confining areas must be used, consideration shall be given to ventilation and the ability to safely provide the required explosion relief and sufficient air supply for all personnel who may be working in confined quarters.

2-2.2 In the event that furnaces are below grade level, consideration shall be given to ventilation and the prevention of stagnant areas that may be depleted of oxygen and cause asphyxiation.

NOTE: Vacuum furnaces designed for use with inert gas backfilling or quenching should be located above grade level to make use of natural ventilation and to ensure an adequate supply of air to personnel.

2-3 Structural Members of Buildings. Although vacuum furnaces do not present a particular adverse temperature effect on building structures, consideration shall be given to structural loading.

2-4 Location in Regard to Stock, Processes, and Personnel.

2-4.1 Stock and Processes.

NOTE: Class D furnaces should be well separated from unrelated stock, power equipment, process equipment, and separated from fire protection facilities in order to minimize interruption of production and to provide protection in the event of accidents.

2-4.2 Personnel. Vacuum furnaces shall not obstruct personnel travel to exitways, particularly when large doors are in the open position.

2-4.3 Finishing Operations. Class D furnaces shall be safely located and protected from exposure to flammable liquid dip tanks, spray booths, flow coaters, or storage and mixing rooms or areas. This shall not apply to integral quench systems.

NOTE: The hazard is particularly severe when vapors from dipping operations may flow by gravity to heating units at or near floor level.

2-5 Floors and Clearances.

2-5.1 Class D vacuum furnaces shall be located for ready accessibility, with adequate space above, and on all sides, to permit inspection and maintenance. The space above, below, and around the equipment shall be properly ventilated to keep temperatures at combustible floors, ceilings, and walls below 160°F (71°C).

2-5.2 Class D vacuum furnaces shall be located on or above noncombustible floors. If such a location is not possible, then one of the following procedures shall be employed:

2-5.2.1 Remove combustible floor members and replace with a monolithic concrete slab that extends a minimum of 3 ft (1 m) beyond the outer extremities of the furnace.

2-5.2.2 Air channels shall be provided between the floor and the equipment (perpendicular to the axis of the equipment and/or noncombustible insulation). This shall be adequate to prevent surface temperatures of floor members from exceeding 160°F (71°C).

2-5.3 Where electrical wiring will be present in the channels of certain types of floors, the wiring shall be installed in accordance with Article 356 (cellular metal floor raceways) of NFPA 70, *National Electrical Code*.

2-5.4 Floors beneath mechanical pumps and related equipment shall be vibration free and be provided with a noncombustible, nonporous surface to prevent floors from becoming oil soaked.

2-5.5 Where furnace ducts or stacks penetrate combustible walls, floors, or roofs, clearances and insulation shall be provided to prevent surface temperatures of combustible members from exceeding 160°F (71°C).

2-6 Construction of Furnaces.

2-6.1 Class D vacuum furnaces and related equipment shall be built in a substantial manner with due regard to the fire hazard inherent in equipment operating at elevated temperatures, the hazard to operators from high temperatures and mechanical equipment, and the need of ensuring reliable, safe operation over the expected maximum life of the equipment.

2-6.2 Furnace internals and all material therein exposed simultaneously to elevated temperature and air (oxygen), including the basic vessel and internal support structures, shall be constructed of noncombustible and nonvolatile material.

2-6.3 Furnace structural supports and material handling equipment shall be designed with adequate factors of safety at the maximum operating temperatures, with consideration given to the strains imposed by expansion and contraction and any other mechanical/electrical design and safety standards.

2-6.4 Adequate facilities for access shall be provided to permit proper inspection and maintenance. Ladders, walkways, and so forth shall be designed in accordance with applicable standards.

2-6.5 Heating devices and heating elements of all types shall be substantially constructed or located to resist mechanical damage from falling work, trucking, or other mechanical hazards inherent in industrial use.

2-6.6 Radiation shields, refractory material, and materials of insulation shall be retained or supported so they will not fall out of place under designed use and with proper maintenance.

2-6.7 Water-cooled components, such as vacuum vessels, shall be designed with minimum wall thicknesses in accordance with corrosion tables and vessel standards (see ASME *Pressure Vessel Code*, Section VIII. Also see paragraphs 2-6.13 and 2-6.14 of this document.).

NOTE: Where subject to corrosion, metal parts should be adequately protected.

2-6.8 Items of instrumentation and control equipment that can be centrally grouped together shall be so brought to a singular location and mounted for ease of observation, adjustment, and maintenance and for protection against unavoidable hazards including physical and temperature damage and exposure to other ambient hazards. Design of electrical components and the interconnection thereof shall be in conformance with current NEMA standards and with NFPA 70, *National Electrical Code*.

2-6.9 External parts of furnaces which operate at temperatures in excess of 160°F (71°C) shall be guarded by location, guard rails, shields, or insulation to prevent accidental contact with personnel. All parts of equipment operating at elevated temperatures shall be installed in accordance with Section 2-5, Floors and Clearances.

2-6.10 Pressure relief ports or gas burn-off ports of the furnace shall be so located or guarded so as to prevent injury to personnel from discharge of hot gas.

2-6.11 If sight ports are provided, they shall be properly protected from radiant heat and physical damage.

2-6.12 Water-cooling system devices such as relief valves, open sight drains, and waterflow switches shall be designed and installed for ready observation by the operator. (*Also see 2-12.*)

2-6.13 The vacuum chamber shall be designed in general accord with the ASME *Boiler and Pressure Vessel Code*, Division 1, Section VIII and shall not have a rate-of-rise (leak-up rate) greater than 5 × 10-3 Torr (66.7 × 10^{-2} Pa) per hour. (*Also see paragraph 1-3 and 2-6.14.*)

2-6.14 Where the vacuum chamber will operate at a positive internal pressure of greater than 15 psig, the vacuum chamber shall be designed and constructed in accordance with the ASME *Boiler Code* (Division 1 - Section VIII).

2-7 Furnace Exhaust Systems. Furnace exhaust systems shall be in accordance with requirements of Chapter 4.

NOTE: The need for a furnace exhaust system for removal of products of combustion, heat, toxic gases, and other objectionable gases will depend on the heating processes, type of combustion, hazard to personnel, and all applicable air pollution control regulations.

2-8 Auxiliary Equipment, Access, and Mounting.

2-8.1 Mounting for auxiliary equipment, such as control instruments, pumps, and safety devices, shall provide protection against damage by heat, vibration, and mechanical hazards.

2-8.2 Auxiliary equipment, such as conveyors, racks, shelves, baskets, and hangers shall be of noncombustible material.

2-9 Pumping Systems.

2-9.1 Pumping systems shall consist of pumps, valves, related protective equipment, and measuring and control instrumentation that produce and control the level of vacuum in a vacuum furnace. (*See Appendix B for general pump information.*)

NOTE 1: Vacuum pumps may be the ejector, mechanical, or diffusion type.

NOTE 2: Where automatic pump control modes are provided, a manual control mode should also be provided as an override.

2-9.2 Mechanical pumps utilizing hydrocarbon oils shall not be used for pumping gases with oxygen contents greater than 25 percent by volume.

2-9.3 Diffusion pumps and other pumps employing a heating source shall include thermostats or other automatic temperature controlling devices.

NOTE: It is recommended that diffusion pumps be charged with a vacuum grade of silicon-based fluid to reduce the risk of explosion on inadvertent exposure to air when heated. Diffusion pump fluids with equivalent or superior fire resistance may be considered.

2-9.4 A fluid level gage shall be installed on diffusion pumps with a pump fluid capacity over one quart (0.95 L).

2-9.5 When petroleum or other combustible fluids are used, the system shall be designed to minimize the possibility of fluid release that may result in a fire or explosion.

2-9.6 Sufficient cooling shall be provided for diffusion pumps so as to prevent excess vapors from backstreaming into furnace chambers and to mechanical pumps to prevent overheating of the pump fluids.

2-9.7 Protection from fly wheels, belts, and other moving parts shall conform to the requirements of applicable standards.

2-9.8 Electrical wiring, switches, and complementary electrical equipment shall conform to the requirements of NFPA 70, *National Electrical Code.*

2-10 Vacuum Gages and Controls.

2-10.1 Vacuum gages and vacuum controls shall be selected for a particular system with consideration to vacuum level, sensitivity, and expected contamination.

NOTE: Vacuum gages may contain controlling devices to operate equipment sequentially.

2-10.2 Suitable vacuum gages shall be installed so levels of vacuum may be ascertained in the furnace chamber and between vacuum pumps of multipump systems.

2-10.3 Vacuum gage controls that operate in conjunction with sequential controls shall be interlocked to prevent damage to furnace components or work load.

2-10.4 Hot wire filament gages shall not be used at pressures above 1 × 10^{-1} Torr (13.3 Pa) in the presence of explosive vapors or combustible atmospheres.

2-11 Vacuum Piping Systems.

2-11.1 Vacuum pipe lines, valves, and manifolds shall be designed to withstand differential pressures, sufficient conductance for the application, and a maximum leak rate as required by the process but no greater than the leak rate specified by the manufacturer for the furnace.

NOTE: Pipes and manifolds should be as short and as large in cross section as practical, consistent with good maintenance and economic consideration.

2-11.2 Pipes, valves, and manifolds shall be mounted so as to provide protection against damage by heat, vibration, and mechanical hazard.

2-11.3 Isolation vacuum valves shall be installed between the mechanical fore pumps and the remaining system including the furnace chamber. These valves, if powered, shall automatically close when there is a loss of power to the fore pump or the control switch for the fore pump is in the "off" position.

2-11.4 Where applicable, a bypass shall be provided between the furnace and roughing and/or fore pump so that the chamber can be rough pumped while the diffusion pump remains isolated.

2-11.5 Inlet gas quenching valves shall be designed to operate at applicable pressures on the gas side and on the vacuum side.

2-11.6 A pressure relief valve shall be provided on the furnace, where pressurized backfilling is employed. It shall be located on the chamber side of all vacuum valves and shall be set for a safe positive pressure limit consistent with the furnace chamber design criteria (*see Section 5-3, Vacuum Furnace Systems*).

2-11.7 A warning label shall be permanently affixed to diffusion pumps covering safe methods of servicing pumps stating the following: Do not open oil drain or fill plugs for service until pump heater is at room temperature. Otherwise, ignition of pump oil can occur with rapid expansion of gas causing damage to pump and furnace hot zone.

2-12 Water-Cooling Systems.

2-12.1 A water-cooling system of a vacuum furnace shall include the apparatus, equipment, and method used to cool vacuum chamber walls, electrical terminals, seals, work load, and, where applicable, the interior of the furnace. Integral liquid quench systems are covered under Chapter 6.

2-12.2 Closed cooling systems shall be provided with a pressure relief valve to prevent rupture of lines, coils, and chamber due to accidental overheating of the cooling water. (*See 5-3.3.*)

2-12.3 Interlocks shall be provided to prevent heating system operation without proper flow of the exit cooling water.

2-12.4 Consideration shall be given to provide flow indicators or temperature gages on exit cooling lines.

2-12.5 If cooling water is discharged into an open drain, provisions shall be made for visual inspection of waterflow at outlets.

2-12.6 If heat from the electric power terminals can damage seals during processing cycles, provision shall be made to cool the terminals.

2-12.7 When water is used as a cooling medium, the control valve shall stay open in the event of a power failure or coil failure so that cooling water is guaranteed for the unit.

2-13 Gas Quenching Systems. (*Also see 5-3.4.*)

NOTE: After the thermal cycle has been completed, the work load is either transferred to a gas quenching vestibule or is gas quenched in the heating zone. Gas quenching is performed by introducing a cooling gas (usually nitrogen, hydrogen, argon, or helium) until the pressure reaches a predetermined level (usually from 2 psig to 12 psig above atmospheric) and recirculating the cooling gas through a heat exchanger and over the work by means of a fan or blower. The heat exchanger and fans or blower are either internal (within the furnace vacuum chamber) or external (outside the furnace vacuum chamber).

2-13.1 Internal Heat Exchanger. Internal heat exchangers installed in the furnace chamber for the purpose of extracting heat from a recirculating cooling gas shall be protected from excessive pressure and heat damage and also mechanical damage while loading or unloading the furnace.

2-13.1.1 Heat exchangers, components, and connections shall be free from water and air leaks.

2-13.1.2 Heat exchangers shall be mounted to prevent vibration or thermal damage that could cause a rupture during processing cycles.

2-13.1.3 Heat exchanger components shall have sufficient strength to resist permanent deformation while exposed to the simultaneous maximum pressure of the coolant source and the maximum vacuum and/or pressure attained in the furnace.

2-13.2 External Heat Exchangers. External heat exchangers used for the purpose of extracting heat from a recirculating cooling gas shall be enclosed in a vacuumtight chamber that has a leak rate not exceeding the leak rate specified by the manufacturer for the furnace chamber.

2-13.2.1 Heat exchangers, components, and connections shall be free from water and air leaks.

2-13.2.2 Heat exchangers shall be mounted to prevent vibration or thermal damage that could cause a rupture during processing cycles.

2-13.2.3 Heat exchanger components shall have sufficient strength to resist permanent deformation while exposed to the simultaneous maximum pressure of the coolant source and the maximum vacuum and/or pressure attained in the furnace.

2-13.2.4 If external heat exchangers are used, they shall be installed on the inlet of recirculating fans and blowers.

2-13.3 Fans and Blowers.

2-13.3.1 Internal Fans and Blowers. Internal fans and blowers used to circulate cooling gas within the furnace chamber and through a heat exchanger shall be constructed to resist damage by the hot gases generated at the highest temperature and heaviest mass work load warranted by the manufacturer of the furnace.

2-13.3.1.1 All fans and blowers shall be so interlocked as to be inoperable when exposed to the operator.

2-13.3.1.2 Direct electrically driven fans and blowers shall have a pressure switch control that prevents operation below approximately 7 psi (48 kPa) absolute to prevent motor failure.

2-13.3.1.3 Where motor windings are exposed to argon gas or other ionizing gases, the voltage on the motor shall be limited to 260 volts maximum.

2-13.3.2 External Fans and Blowers. External fans and blowers shall be enclosed in a vacuumtight chamber or casing that has a leak rate not exceeding the leak rate specified for the furnace.

2-13.3.2.1 Fans and blowers that are automatically sequenced in the processing cycle shall have a manual override control.

2-13.4 Quenching Gas.

2-13.4.1 The recirculating gas shall be one that is not harmful to the elements, furnace heat shields or insulation, or work when introduced at the quenching temperature.

2-13.4.2 Recirculating Cooling Gas Lines. Consideration shall be given to the inclusion of isolating valves between an external heat exchanger system and the furnace chamber.

NOTE: Automatically controlled isolation valves sequenced in the processing cycle should have a manual override control.

2-13.4.2.1 All lines shall be vacuumtight with a maximum leak rate as specified for the furnace chamber.

2-14 Heating Elements and Insulation.

2-14.1 Material for heating elements shall have a vapor pressure lower than the lowest pressure at the manufacturer's specified maximum temperature.

2-14.2 Internal electrical insulation material shall remain nonconductive through the full range of vacuum and temperature limits specified by the manufacturer.

2-15 Heat Baffles and Reflectors.

2-15.1 Baffles, reflectors, and hangers shall be designed to minimize warpage due to expansion and contraction.

2-15.2 Baffles, reflectors, and hangers shall be of heat resistant material that will minimize sag, rupture, or cracking under normal operating limits specified by the manufacturer.

2-15.3 Baffles and reflectors shall be accessible and removable for the purpose of cleaning and repairing.

2-16 Hydraulic Systems.

2-16.1 Furnace hydraulic systems shall utilize fire resistant fluids.

Exception: Other hydraulic fluids can be used if furnace casing temperatures are below the auto-ignition temperature of the fluid, and no other sources of ignition are present.

NOTE: Drawings for fluid power diagrams should follow ANSI Standards Y14.17 and Y32.10.

Chapter 3 Heating System for Resistance Heated Vacuum Furnaces

3-1 General.

3-1.1 For the purpose of this chapter, the term "furnace heating system" shall include an electrical power supply, generally 240/480 volt, 3 phase, 60 Hz, the heating elements, and the furnace insulation and/or heat shields.

NOTE: The source of heat is a result of electrical heating (I^2R) of the internal heating elements. The transfer of heat into and throughout such a furnace is principally by radiation.

3-1.2 Electrical installation shall be in accordance with NFPA 70, *National Electrical Code*, and as described hereafter. (*See 1-8.*)

3-1.3 All components, such as the vacuum chamber and control cabinet, shall be grounded.

3-2 Power Supply.

3-2.1* It shall be the purpose of the power supply to transform the relatively high voltage power line to low voltage, high current power suitable for energizing the heating elements. Consideration shall be given to furnishing the power supply with a means of proportional control.

NOTE: Generally this is accomplished with either a saturable core reactor transformer, an adjustable auto transformer, a solid state silicon-controlled rectifier unit, or an electronic ignition system or equivalent. The most common variable power supply is the saturable core reactor transformer. An example of a schematic is indicated in Figure A-3-2.1. (The design of the power supply is specific for each individual furnace and size.)

3-2.2 The power supply shall contain a stepdown transformer, a control device such as a saturable core reactor transformer, primary fuses or circuit breakers for electrical protection, an electrical disconnect switch for service, and a power controller to accept a control signal from the furnace temperature controller.

NOTE: The power supply output voltage should be limited to a maximum of 80 volts to prevent electrical breakdown or internal furnace arcing. As the atmospheric pressure is reduced in the hot zone area and the heating elements, the arcing voltage changes. Arcing voltage change is a function of electrical spacing and pressure. This function is not linear but has a minimum value for most gases utilized as cooling or partial pressure media in vacuum furnaces. If the voltage stress and mean free path relationship reaches a critical value, corona discharge and arcing commences as a result of field emission of electrons.

3-2.3 Assuming a 3 phase power line, every attempt shall be made to provide balanced line currents across all 3 phases as a result of heating element load.

3-3 Heating Elements.

3-3.1 The design may take several forms such as rods, bars, sheet, or cloth but shall be limited to materials that will not vaporize under minimum vacuum and maximum temperature.

NOTE: Suitable materials are generally graphite, molybdenum, tantalum, tungsten, and others.

3-3.2 The heating element placement and geometry shall be carefully considered to achieve proper heating rate, to maintain operating temperature, and to meet temperature uniformity specifications. The heating elements are electrically energized and shall be supported in such a way as not to come in contact with work pieces or fixtures and as not to come in contact with furnace heat shield or insulation retainer materials.

NOTE: In the event of contact, electrical short circuits can result in major damage to the heating elements, work, or furnace parts.

3-3.3* Heating element support hangers and insulators shall be of compatible materials to provide electrical insulation and nonreacting materials at specified vacuum levels and temperatures.

NOTE: Since material surfaces are generally oxide-free in vacuum, reaction occurs easily in the solid state. Some eutectic temperatures are indicated in Table A-3-3.3.

3-3.4 Heating element connections shall be designed to minimize arcing and disassembly problems.

3-3.5 Heating element power terminal and vessel feedthrough design shall be considered for vacuum integrity and heating effects. Vacuum mating surfaces shall be free from dirt and scratches and equivalent to O-ring designs.

3-3.6 Power terminal connection points to power supply cables shall be covered or housed to prevent high current electrical hazard to personnel.

3-4 Furnace Thermal Insulation and Heat Shields.

NOTE: The heat energy produced by the heating elements transfers into the work principally via radiation and through the insulation or heat shields into the cooled walls of the vacuum vessel. The cooling medium is continually circulated through the walls of the vessel, maintaining a cold wall. Generally water is used as the cooling medium.

3-4.1 Insulation shall not break down at specified vacuum levels and temperatures.

NOTE: Examples of proper insulation may be graphite wool, alumina/silica fibers, and other material.

3-4.2 Multiple layers of metal heat shields shall be suitable assuming that these materials are in accord with the temperature and vacuum specification.

NOTE: Molybdenum, tantalum, tungsten, palladium, and 304/316 stainless steel are examples.

3-4.3 Careful attention shall be given to retain either the insulation or heat shields to prevent contact with the heating elements.

3-4.4* Since most furnace designs utilize forced gas quenching, care shall be taken to prevent insulation from breaking up and becoming "airborne," thereby blocking heat exchangers and causing vacuum valve seals to leak.

Chapter 4 Equipment Ventilation

4-1 Pump Vents. Mechanical vacuum pumps with capacity larger than 15 cu ft per minute ($7 \times 10^{-3} m^3/s$) shall be vented to a safe location in accordance with all applicable codes and air pollution control regulations.

4-2 Oil Drip Legs. An oil drip leg in accord with the vacuum pump manufacturer's recommendation shall be designed into the vent piping system.

4-3 Vent Piping. Vent piping shall be free from gas or oil leaks and shall be of noncombustible pipe construction.

4-4 Oil Mist Separators. Consideration shall be given to provide an oil mist separator when the discharge vapor concentration is excessive.

4-5 Exhausts. Exhaust from a furnace and related equipment into a room shall be diluted to make the exhaust nonhazardous to personnel. Mechanical ventilation (if necessary) shall consist of an air intake system bringing air in from the outside and an exhaust system exhausting an equal amount of air to the outside. (*See 7-3.2 and Hazardous Material definition.*)

4-5.1 Consideration shall be given to ascertain that the supply air is uniformly distributed within the area and that the exhaust duct is arranged to eliminate all pockets and dead air areas at either floor or ceiling levels, depending on the type of contaminant being evolved.

4-6 Procedures. When any reactive gases or other combustible gases are exhausted, precautionary procedures for pumping, purging, or operating shall be in accordance with the manufacturer's recommendations.

4-7 Personnel Entry. Personnel shall never enter a chamber in which atmospheres other than air have been used without first purging the chamber with air to remove residual gas. A warning label alerting personnel to this hazard is recommended. (*See ANSI Z117, "Working in Confined Spaces" and Appendix E.*)

NOTE 1: Purging may be accomplished by evacuating the chamber to one Torr or less and refilling with air. When purging the chamber directly with air changes, sufficient cycles should be run to dilute any residual gases below threshold limits. Additional consideration should be given to providing personnel with special safety equipment before entering the chamber and additional personnel should be in attendance outside of the chamber.

NOTE 2: Gas atmosphere densities can be greater or less than air, and thus consideration should be given to air inlet and outlet locations for direct purging.

Chapter 5 Safety and Control Equipment for Class D Vacuum Furnaces

5-1 General Requirements.

5-1.1 For safety of personnel and protection of property against explosion, implosion, or fire, careful consideration shall be given to all hazards peculiar to each individual installation connected with the utilization of a resistance-heated, electric, Class D vacuum furnace. All auxiliary apparatus utilized in the operation of the furnace shall be safeguarded to avoid these hazards.

5-1.2 Safety devices shall be used that will provide protection against:

(a) Excess temperature;

(b) Rupture or collapse due to excessive pressures;

(c) Explosion and fire due to misuse of atmospheres and/or internal quenching media;

(d) Out-of-sequence operation of the vacuum pumping system and other auxiliary equipment and accidental introduction of air.

5-1.3 Safety devices shall be properly specified and installed where prescribed in this standard. Safety devices shall not be shorted out or bypassed in the system.

5-1.4 All safety control equipment, as well as the furnace itself, shall be inspected and maintained in accordance with a maintenance checklist. (*See typical checklist in A-11-2.*)

5-1.5 Where special maintenance and inspection procedures are required due to the nature of the equipment, plant management and the authority having jurisdiction shall prescribe the time interval at which the equipment and the controls shall be tested for service reliability, based on the recommendations of the equipment manufacturer.

NOTE: Partial protection caused by the failure of any one safety device could be more dangerous than no protection at all.

5-2 Electric Heating Systems.

5-2.1 Safety control application for the heating system in such furnaces shall provide for protection from excess temperature, for protection of the heating element, radiant shields, and/or insulation, and for the safety of the operator of such a furnace. Safety control instruments shall be of the fail-safe type.

NOTE: For a description of electric heating systems in vacuum resistance furnaces, refer to Chapter 3.

5-2.2 Electric heating equipment in a vacuum furnace shall not be operable until sufficient cooling water or fluid is provided to prevent overheating of the vessel, power terminals, and other cooled systems.

5-2.3 Electric heating equipment in a vacuum furnace shall not be operable until a sufficient vacuum level has been attained inside the furnace chamber to provide protection for the furnace elements, radiant shields, and/or insulation.

5-2.4 Electric heating equipment in vacuum furnaces shall be equipped with a main disconnect device, capable of deenergizing the entire heating system under load in accordance with NFPA 70, *National Electrical Code* and current NEMA standards. (*See 3-2.1 and 3-2.2.*)

5-2.5 All controls, using thermal protection or trip mechanisms, shall be so located or protected as to preclude faulty operation due to abnormal temperatures or other furnace hazards.

5-2.6 Material handling or positioning controls shall be arranged for proper sequence of operation with other furnace special atmosphere and safety controls and also to ensure emergency action as may be needed in the event of malfunction of the material handling system.

Exception: It is permissible to install provision for operating conveyors manually or by means of a constant pressure pushbutton for the purpose of removing material from the furnace in event of malfunction in the automatic system.

5-2.7 Where a furnace is subject to damage, an excess furnace temperature limit control shall be provided for annunciation and interruption of power supply to the furnace heating system.

5-2.7.1 Manual reset shall be provided to prevent automatic restoration of power.

5-2.7.2 These controls shall be in addition to any normal operating temperature control devices.

5-2.8 Branch circuits and branch circuit protection for all electrical circuits in the furnace heating system shall be provided in accordance with NFPA 70, *National Electrical Code*. (*See 1-8.*)

5-3 Vacuum Furnace Systems.

5-3.1 Pressure controls shall be installed on all Class D vacuum furnaces to prevent excessively high pressures beyond the inherent design of the vacuum vessel. These controls are designed to prevent damage due to excessive pressures, damage due to oxidation of internal equipment materials, and harm to the safety of the furnace operator.

5-3.2* An indicating or recording vacuum gage shall be employed to read pressures in the vessel chamber, in the foreline of the vacuum system, and at critical areas of the vacuum system. Wherever vacuum levels are below 1×10^{-3} Torr (1.3×10^{-1} Pa), an ionization-type gage or equivalent shall be employed.

NOTE: The calibration of all vacuum gages should follow the standards specified by the American Vacuum Society. For a description of the various types of vacuum gages, see A-5-3.2.

5-3.3 Wherever a closed loop cooling water system (not an open sight drain system) is utilized, temperature or flow sensing devices shall be located at exit water lines to sense and indicate the temperature or flow of the cooling water.

5-3.3.1 Consideration shall be given to having these devices connected to alarms and to deenergize the furnace system, whenever a set temperature is exceeded. In any case these sensing devices shall be connected to indicating instruments that can be read by the furnace operator.

5-3.4 The vacuum chamber (and the cooling or quench vestibule, if separate) shall be equipped with a pressure relief valve that protects the chamber, attachments, and doors from excessive gas pressure during the pressurizing or cooling cycles.

5-3.5 In order to relieve excess pressure on the vacuum chamber cooling water jacket, a pressure relief device shall be installed. (*See Section 2-13.*)

5-3.6 Automatic valves shall be provided to close the holding pump, foreline, roughing, and main vacuum valves in the event of a power supply or other valve actuating medium failure, in order to prevent pump oil or air from passing through the system or causing damage to the furnace and/or load.

5-3.7 Consideration shall be given to the installation of a visible device that indicates the on-off condition at each vacuum pump whether it is operated manually or automatically. In an automatic pumping system the use of an alarm to indicate the interruption of an operation shall also be given consideration.

5-3.8 Wherever liquid nitrogen is employed as a coolant in cold traps, consideration shall be given to the installation of a liquid level sensor and controller with an alarm to indicate low levels of nitrogen.

5-3.9 A label or sign shall be posted at each diffusion pump where it can easily be seen by maintenance personnel with a warning that the oil filter plug is not to be loosened or removed unless the diffusion pump oil is at room temperature.

5-4 Internal Quench Vacuum Furnaces.

5-4.1 Wherever a vacuum furnace has an internal liquid quench chamber, in addition to the above safety controls, the following controls shall be provided:

5-4.1.1 Automatic temperature controls shall be installed in pressure-type water-cooling and oil-cooling systems to ensure the desired jacket temperature.

5-4.1.2 Wherever an external door adjacent to the quench chamber is employed, the operation of such door shall be interlocked so that it cannot be opened unless the elevator is in its full loading or quenching position.

Exception: A manual override may be used in emergencies.

5-4.1.3 Controls for the admittance and maintenance of special atmosphere within the quench chamber shall conform to the controls described in Section 7-2.

5-4.1.4 The quench reservoir shall be equipped with a reliable quench medium level indicator. If of the sight glass type, the level indicator shall be of heavy-duty construction and protected from mechanical damage.

5-4.1.5 Where the furnace arrangement dictates, a limit switch shall be interlocked into the load transfer system to prevent transfer of the load in the heat chamber to the quench rack unless the quench rack is in proper position.

5-4.1.6 The quench tank shall be equipped with a low liquid level device arranged to sound an alarm, prevent start of quenching, and shut off heating medium in case of a low liquid level condition.

5-4.1.7 Excess temperature limit control shall be provided and suitably interlocked to automatically shut off the quench heating medium and shall require operator attention in case of excessive quench medium temperature. Excess temperature limit shall be interlocked to prevent start of quenching in case of excessive quench medium temperature. Audible and/or visual alarms shall be provided.

5-4.1.8 Where agitation of the quench medium is required to prevent overheating, then the agitation shall be interlocked to prevent quenching until the agitator has been started.

5-4.1.9 Where a combustible liquid quench medium is used with water jackets or internal water-cooled heat exchanger, a means of water detection shall be considered for the quench tank to sound an audible alarm and interlocked to prevent quenching in the event that water content of the quench medium exceeds 0.35 percent by volume.

5-5 Programmable Controllers.

5-5.1 A programmable controller is a general purpose industrial processor capable of applications for safety and control purposes; therefore, the following requirements shall apply:

(a) In the event of a power failure, the programmable controller (hardware and software) shall not prevent the system from reverting to a safe condition. A safe condition shall be maintained upon the restoration of power.

(b) The control system shall have a separate manual emergency switch, independent of the programmable controller, that will cause the system to revert to a safe condition.

(c) The software for the programmable controller shall reside in some form of nonvolatile storage (memory that retains information on loss of system power).

(d) Where the programmable controller is applied to a safety function, it shall have the capability of detecting failures and unprogrammed logic changes of its safety-dependent inputs and outputs and, upon detection of same, shall annunciate and cause the system to revert to a safe condition.

(e) Where the programmable controller is applied to a safety function, its internal status shall be monitored. In the event of a programmable controller failure, the system shall annunciate and revert to a safe condition.

(f) Application software that contains safety logic shall be separated from all other programming. Application software that interacts with safety logic or detection logic for input/output devices shall also be separated from all other programming. Application software that contains safety logic or detection logic shall not be modified in any manner that does not comply with this standard. The authority having jurisdiction shall be notified, in writing for permanent documentation, of any changes.

(g) System operation shall be verified for compliance with this standard whenever the programmable controller is replaced, repaired, or updated.

(h) The supplier of the application software for the programmable controller shall provide the end user and the authority having jurisdiction with documentation needed to verify that all related safety devices and safety logic are functional before the programmable controller is placed in operation.

(i) The system access shall be limited by incorporating measures to prevent remote or local instructions to the programmable controller that could result in hazards to personnel or equipment.

Chapter 6 Integral Liquid Quench Vacuum Furnaces

6-1 General.

NOTE: Integral liquid quench systems may be constructed within the furnace vacuum chamber or may be in quench vestibules separated from the heating portion of the chamber with a door or vacuumtight valve. Semicontinuous furnaces employ valves on each end of the hot vacuum zone. These furnaces may be divided into 3 separate chambers: a loading vestibule, hot vacuum chamber, and cooling vestibule. With this arrangement, cooling or pressurizing the hot vacuum chamber is not required for loading and unloading. Cooling vestibules are often equipped with elevators so that loads may be either vacuum, gas, or oil quenched.

6-2 Requirements.

6-2.1 The vacuum chamber and/or quench vestibule shall be equipped with a pressure relief valve that protects from excessive pressure during the backfilling portion of the cycle.

NOTE 1: The integral quench tank, using a combustible liquid, may be subject to the introduction or accumulation of water from a number of sources which, when exposed to the heat released from quenching of work, flashes to steam. The resulting increase in volume causes over-pressurization of the quench vestible.

NOTE 2: Cooling medium for the vacuum vessel and furnace cover should be controlled by restricting the flow or by recirculation to maintain vessel walls above ambient dewpoint temperatures.

6-2.2 Where quench vestibules are used with semicontinuous furnaces, the quench vestibule shall be vacuumtight and shall be constructed of noncombustible materials with due regard to the fire and explosion hazards. Attention to mechanical functions and corrosive conditions is vital to ensuring reliable, safe operations.

NOTE: The quench vestibule's design and size are dependent upon end use. If the quench vestibule doubles as atmosphere gas cooling chamber, forced cooling is normally required, provided by water, jackets, plate coils, or tubing tracing.

6-2.3 If an intermediate door between furnace and quench vestibule is employed, it shall be closed during the quenching operation to serve as a baffle.

6-2.4 Manual facilities shall be provided to permit opening of the outer quench vestibule door. Opening of this door under emergency conditions shall be an operating personnel decision.

6-3 Construction of Quenching Tanks.

NOTE: These requirements are intended to cover any design using water as a cooling medium, whereby means of leakage or condensation, the quench medium is exposed to an accumulation of water.

6-3.1 The quench tank shall be designed and constructed to contain the quench medium capacity at the expected operating temperature and with maximum work load volume.

6-3.1.1 The quench tank shall be tested for leaks prior to use.

6-3.1.2 The quench tank shall be designed and operated with a maximum quench medium level, when elevator and work load are submerged, of not less than 6 in. (15.2 cm) below door or any opening into the furnace.

6-3.1.3 The quench tank shall have sufficient capacity to quench a maximum gross load with a maximum temperature rise that will not exceed 50°F (10°C) below the flash point and cooling capabilities to recover quench medium temperature between minimum design quench cycles.

6-3.2 Where hot rolled steel plate is used, oil or other compatible coolant shall be used in place of water.

NOTE 1: Although hot rolled steel plate has been used for many years with water cooling, its use is not recommended as corrosion is continuous and its extent is difficult to determine.

NOTE 2: Jacketed stainless steel plate may be used, with water as a coolant, to eliminate the hazards of corrosion of hot rolled steel. However, unless all of the stainless steel is of the stabilized type, such as columbium or titanium or the low carbon L-series type, corrosion can take place faster than in hot rolled steel due to carbide precipitation in the steel at the welds. If used, a careful study should be made as to compatibility of materials and welding techniques employed.

Steel plate coils, attached by thermo contact cement to the external surfaces of the quench chamber, fabricated of hot rolled steel plate, have produced acceptable heat transfer, and careful attention given to the design of the junction of the upper and lower chambers minimizes the possibility of water leak into the quench reservoir.

Steel plate coils can be used with either water- or oil-type coolants, although the eventual plugging of the passages with rust and mineral deposits can be anticipated when water is used as a coolant. The use of stainless steel plate coils, while a more expensive construction method, will considerably reduce the possibility of plugging the water passages.

Serpentine coil formed from a noncorrosive tubing material brazed or welded to the exterior surfaces of a cooling chamber, fabricated of hot rolled steel plate, has produced acceptable heat transfer. When careful attention is given to the design of the junction of the upper and lower quench vestibule, the possibility of a water leak into the quench tank is minimized.

NOTE 3: This paragraph does not apply to the vacuum furnace chamber.

6-3.3 If a water-cooled exchanger is employed, the quench oil circulating pump shall be installed on the inlet side of the heat exchanger, and the quench medium pressure shall always exceed that of the cooling water.

6-4 Elevators.

6-4.1 The elevator's function shall be to immerse the work charge into the quench medium with minimum splash. At termination of the timed quench cycle, the elevator shall be raised to drain position at hearth level.

6-4.2 The elevating mechanism shall be substantially supported by structural members to handle the maximum rated loads.

6-4.3 Elevator guides or ways shall be provided to ensure uniform stabilized movement of the elevator in the confined areas of the quench tank.

6-4.4 Tray guides or stops shall be provided to ensure that the tray is properly positioned on the elevator.

6-5 Cooling Systems.

NOTE: Quench medium tanks generally utilize a cooling system to maintain the general quench medium at an operating temperature to reduce the quantity of quench media required. Three basic cooling systems are in general use, consisting of:

(a) Internal cooler, where heat transfer medium is circulated through heat exchanger within quench tanks.

(b) External cooler, where quench medium is withdrawn from quench tank, circulated through a water-cooled heat exchanger, and returned.

(c) External cooler, where quench medium is withdrawn from quench tank, circulated through an air-cooled heat exchanger, and returned.

6-5.1 Consideration shall be given to the use of noncorrosive materials for the construction of internal tank cooled heat exchangers.

6-5.2 The heat exchanger shall be subjected to a minimum pressure test of 150 percent of maximum designed working pressure after installation in quench tank.

NOTE: The heat exchanger should be subjected to similar test prior to being placed in service and at periodic intervals thereafter, to ascertain that it is free of leaks.

6-5.3 The heat exchanger shall be located within the quench tank in such a manner as not to be subject to mechanical damage by the elevator or load to be quenched.

6-5.4 The cooling medium flow shall be controlled by an automatic temperature controller.

6-5.5 If it is possible to completely close off the internal heat exchanger, a pressure relief shall be provided, terminating in a safe location.

NOTE: Tubes of the heat exchanger that are exposed to contact with water should be constructed of noncorrosive materials.

6-5.6 The heat exchanger, after fabrication, shall be subjected to a minimum pressure test of 150 percent of the maximum design working pressure.

NOTE: The heat exchanger should be subjected to similar test prior to being placed in service and at periodic intervals thereafter, to ascertain that it is free of leaks.

6-5.7 The pressure of the quench medium through the heat exchanger shall be greater than the water pressure applied.

6-5.8 External air-cooled heat exchangers installed out-of-doors shall be structurally reinforced to withstand anticipated wind forces without damage at elevation at which it is mounted.

6-5.8.1 External air-cooled heat exchangers installed out-of-doors or which utilize supplemental water cooling shall be constructed of materials suitably protected against corrosion.

6-5.9 External water-cooled heat exchangers shall incorporate the following protective features:

(a) The oil pressure through the heat exchanger shall be maintained greater than the water pressure.

(b) If it is possible to completely close off the external heat exchanger, a pressure relief shall be provided, terminating in a safe location.

6-5.10 External Air-Cooled System.

6-5.10.1 An external heat exchanger installed out-of-doors shall be provided with lightning protection if located in an exposed, rooftop location.

6-5.10.2 If the air-cooled heat exchanger is installed in a rooftop location, it shall be installed in a curbed or diked area, drained to a safe location outside of the building.

6-6 Electric Immersion Heaters.

6-6.1 Electric heaters shall be of a sheath-type construction.

6-6.2 Heaters shall be installed so that the hot sheath is fully submerged in the quench medium at all times.

6-6.3 The quench medium of electrically heated quench tanks shall be supervised by:

(a) A temperature controller arranged to maintain quench medium at proper temperature and interlocked to shut off the immersion heating when excess temperature is detected.

(b) A quench medium level control interlocked to shut off the immersion heating when low level is detected.

6-6.4 The electrical heating control system shall be interlocked with the quench medium agitation or recirculation system to prevent localized overheating of the quench medium.

Chapter 7 Vacuum Furnaces Used With Special Atmospheres, Flammable

7-1 General.

7-1.1* Flammable gases may be used in conjunction with vacuum furnaces for thermal processes such as carburizing, nitriding, brazing, sintering, and chemical vapor deposition. Flammable gaseous hydrocarbons, disassociated ammonia, and hydrogen are frequently employed either at pressures below atmosphere or slightly above atmosphere. These furnaces usually are first operated at a vacuum level before the introduction of the process gas.

7-1.2 This section shall apply to any vacuum chamber or furnace in which a flammable gas is used at a pressure of $1/2$ of its lower explosive limit in air or above.

NOTE: The lower explosive limit for hydrogen is 4 percent in air. This represents a pressure of 30 Torr. For safety a lower limit of $1/2$ of this, 15 Torr, has been used. Other gases have other lower explosive limits. See Appendix G.

7-2 Safety Controls and Equipment

7-2.1 When flammable atmospheres are used, the vacuum systems and the systems used to introduce flammable and inert gas shall be interlocked in such a way that these systems operate automatically without intervention of an operator.

7-2.2 In addition to the flammable gas, a supply of inert purge gas shall be available. The inert gas storage supply shall at all times contain sufficient gas to completely purge the system. The supply shall be a minimum of 5 times the total vacuum system volume, and shall be maintained at a pressure sufficient to introduce it rapidly into the furnace chamber. Any use of inert gas in processing shall not deplete this purge gas supply below the amount specified above.

7-2.3 The purge gas supply shall be connected to the vacuum chamber through a normally open valve. A pressure sensor shall monitor the purge gas line pressure and shall stop the supply of flammable gas if the pressure becomes too low to permit adequate purging. Any purge gas shutoff valve shall be interlocked to prevent introduction of flammable atmospheres if the valve is shut.

7-2.4 The flammable gas supply shall be connected to the vacuum chamber through a normally closed valve. A pressure sensor shall monitor the flammable gas line pressure and shall shut off the supply of gas when its pressure drops below a value adequate to maintain flow to the vacuum chamber. A manual shutoff valve shall be provided in any flammable atmosphere supply pipe.

7-2.5 The gas supply system shall be interlocked with the vacuum system to prevent the introduction of any flammable atmosphere until the furnace has been evacuated to a level of 1×10^{-1} Torr (13.3 pa) or less.

NOTE: It is recommended that flammable gas not be introduced directly into a furnace chamber until the temperature is above 1400°F (760°C) and, after initial evacuation, the chamber is purged with inert gas and the flammable gas then introduced.

7-2.5.1 In the case of a multiple chamber or continuous type of vacuum furnace, each chamber shall be regarded as a separate system. Interlocks shall be provided that will prevent the valves from opening between adjacent interconnecting chambers once a flammable atmosphere has been introduced into any one of them.

NOTE: If a residual amount of air is retained in an external chamber, the inadvertent opening of a valve to an external system in the presence of a flammable atmosphere could create an explosive mixture.

7-2.6 The vacuum pumping system shall be interlocked with the supply gas system so that mechanical pumps shall continue to operate while flammable gas is in the vacuum chamber, whether or not the flammable gas is to flow through the pumps, or the vacuum pumping lines shall be backfilled with an inert atmosphere during this interval.

NOTE: Air may backstream through mechanical pumps that are not operating.

7-2.7 Mechanical pump gas ballast valves, which are normally furnished with mechanical vacuum pumps, shall be plugged or piped to a source of inert gas. Vacuum air release valves on roughing or foreline shall be piped to a source of inert gas.

7-2.8 Since hydrocarbon oils are used in mechanical vacuum pumps, the discharge reservoir and piping shall be maintained below any ignition temperature for the oil.

7-2.9 No manual air release valve shall be permitted in a vacuum furnace that is used with flammable atmospheres at a pressure of $1/2$ of its lower explosive limit in air or above.

7-2.10 Each vacuum chamber that is used with flammable atmospheres at a pressure of $1/2$ of its lower explosive limit in air or above shall be equipped with a self-closing explosion venting device. See NFPA 68, *Guide for Venting of Deflagrations*.

7-2.11 Special attention shall be given to door clamping for chambers used with flammable gases. Consideration shall be given to pneumatic clamps interlocked to ensure that doors are tightly and positively closed.

NOTE: Even though a chamber can be pumped to 1×10^{-1} Torr, upon backfilling the door can open if not clamped.

7-2.12 Sight glasses shall be removed or valved off during operation with flammable gases. This does not pertain to sight glasses used solely for pyrometers.

NOTE: Cracking of a sight glass, which is not unusual, can admit air to the chamber, or allow flammable gas to escape.

7-3 Flammable Gases.

7-3.1 During processing, flammable gases are normally exhausted from vacuum furnaces by pumping them through the vacuum pumps, or by venting in continuous flow to atmosphere, with or without ignition and burning.

7-3.2 If the flammable gas is exhausted through a vacuum pump, the system shall be designed to prevent air backflow through the pump if it stops. Vent lines for the pump shall run to the exterior of any closed area and in an area where atmosphere circulation prevents concentration at ignition levels. Alternately, the pump discharge may be diluted with air in volume sufficient to prevent concentration at ignition levels, or the discharge may be passed through a burner.

7-3.3 If the flammable gas is vented to atmosphere directly without passing through the vacuum pumps, the vent line shall be provided with a positive means of preventing air from entering the furnace chamber.

7-3.4 If the flammable gas is vented to atmosphere through a burner, the vent line shall be provided with a positive means of preventing air from entering the furnace chamber. The existence of the burner ignition source shall be independently monitored, with interlocks to shut off the flammable gas supply and initiate inert gas purge if the flame is not sensed.

7-3.5 In all applications where flammable gas is used, a pressure switch shall be interlocked to close the flammable gas supply at a preset pressure above atmosphere and below that which activates the explosion venting device.

7-3.6 In all applications where flammable gas is used at pressures above atmosphere, a pressure switch shall be interlocked to close the flammable gas supply and initiate purge if the chamber pressure should fall close to atmospheric pressure.

7-3.7 Where flammable gas is exhausted through a vent, the vent valve shall not open until a pressure above atmosphere is attained in the chamber.

7-4 Removal of Flammable Gas.

7-4.1 Purging with inert gas.

7-4.1.1 The valve for admitting the inert gas to the furnace shall be opened and then the valves supplying the flammable gas to the furnace shall be closed or the valves operated simultaneously.

7-4.1.2 When an analysis of the vent gas from the furnace indicates that less than 50 percent of the lower explosive limit of the process gas is being exhausted on 2 consecutive readings, the purge shall be considered complete.

7-4.2 Purging with Vacuum.

7-4.2.1 As an alternate procedure to inert gas purging for the removal of the flammable gas atmosphere, the furnace shall be pumped down to a minimum vacuum level of 1×10^{-1} Torr (13.3 Pa) prior to air release or inert gas backfill. Since the exhaust of the vacuum pump is flammable it shall be treated as described in 7-3.2.

7-5 Emergency Shutdown Procedure.

7-5.1 In the event of an electrical power failure and/or flammable gas failure, the emergency purge gas standby system shall be immediately actuated to purge the furnace. The purge gas flow shall continue until at least 5 times the volume of the furnace has been provided.

NOTE: In case of electric power failure, the following can be expected to stop:

(a) Heating system
(b) Flammable atmosphere gas system
(c) Vacuum pumping system.

7-5.2 All flammable atmosphere gas valves to the furnace shall be closed.

7-5.3 When an analysis of the exhausted gas from the furnace indicates that less than 50 percent of the lower explosive limit of the process gas is being exhausted on 2 consecutive readings, the purge shall be considered completed.

Chapter 8 Bulk Atmosphere Gas Storage Systems

8-1 Construction.

8-1.1 All storage tanks and cylinders shall comply with local, state, and federal codes relating to pressures and type of gas. NFPA standards shall also be followed.

8-1.2 Vessels, controls, and piping shall be constructed to maintain their integrity under maximum design pressures and temperatures.

8-2 Location. Locations for tanks and cylinders containing flammable or toxic gases shall be selected with adequate consideration given to exposure to buildings, processes, storage facilities, and personnel. Tables of distances specified in the various NFPA standards shall be followed.

8-3 Storage Systems. Storage systems shall comply with the following NFPA standards:

(a) Liquefied petroleum gas systems shall be in accordance with NFPA 58, *Standard for the Storage and Handling of Liquefied Petroleum Gases.*

(b) Gas piping shall be in accordance with NFPA 54, *National Fuel Gas Code.*

(c) Hydrogen storage systems shall be in accordance with NFPA 50A, *Standard for Gaseous Hydrogen Systems at Consumer Sites.*

(d) Oxygen storage systems shall be in accordance with NFPA 50, *Standard for Bulk Oxygen Systems at Consumer Sites.*

(e) Processing atmosphere gas storage systems not covered by an NFPA standard (e.g., anhydrous ammonia) shall be installed in accordance with recommendations from the supplier and all applicable local, state, and federal codes.

NOTE: Special reference is made to ANSI Standard ANSI K61.1-1989, *Storage and Handling of Anhydrous Ammonia.*

Chapter 9 Vacuum Induction Furnaces

9-1 General.

9-1.1 For the purpose of this chapter vacuum induction furnaces shall be those furnaces which use both induction heating as the heating source and a vacuum atmosphere as noted in Section 1-1 of this standard.

NOTE: Induction heating is the heating of a nominally conductive material by its own I^2R power when the material is placed in a varying electromagnetic field. Heating may be by direct coupling, indirectly by a secondary cylinder or susceptor, or by a combination of both of these methods. (*See Figure 9-1.1.*)

9-1.1.1 The different types of induction furnaces considered in this chapter shall be those furnaces used for: melting, casting, sintering, hot pressing, outgassing, degassing, metal purification, general heat treating, brazing, and chemical vapor deposition.

9-1.2 All standards for induction heating equipment specified in NFPA 70, *National Electrical Code*, shall also apply to this chapter.

9-2 Location.

9-2.1 Vacuum induction furnaces and their ancillary equipment shall be so located as to minimize the possibility of fire.

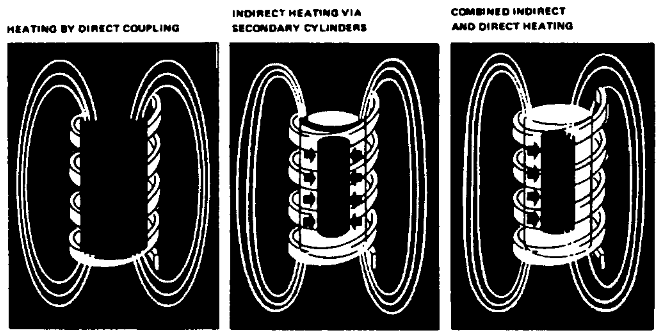

Figure 9-1.1 The Three Induction Heating Methods.

NOTE: Fire may result from spillage of molten metal, overheating, ignition of pump oil, stray electrical currents, and escaping of flammable process gases.

9-2.2 Consideration shall be given to the location of vacuum induction furnaces to prevent injury to all personnel.

9-2.3 All paragraphs 2-1 through 2-5.5 in this standard shall also apply to vacuum induction furnaces.

9-3 Construction.

9-3.1 The basic vessel or vacuum chamber of an inductive vacuum furnace shall be designed in general with the ASME *Boiler and Pressure Vessel Code*, Section 8, Division 1. The vacuum tightness (leak rate) shall be specified in relation to the required operating vacuum level.

9-3.2 Water-cooled components shall be designed with wall thicknesses in accordance with corrosion tables and vessel standards (*see ASME Pressure Vessel Code, Section 8*).

NOTE: The bottom one-third of a water-cooled vessel of a vacuum melting induction furnace should be trace cooled instead of jacketed to provide minimum water storage in the event of a melting crucible breakthrough.

9-3.3 Induction heating coils of all types shall be constructed and located to resist mechanical damage from falling or molten metal, trucking, or other mechanical hazards inherent in industrial use.

9-3.4 Susceptors, refractory materials, power cables, and insulation materials shall be retained or supported so that they will not fall out of place.

9-3.5 The furnace chamber design shall take into account the heating effect of the induction field and shall be of suitable size and of suitable materials to minimize the heating effect on its walls.

9-3.6 When water is used as a cooling medium the main water control valve shall remain open in the event of a power failure so that cooling water continues to flow to the furnace.

NOTE 1: The bottom of the furnace chamber should be equipped with a separate cooling circuit that can be valved off in the event of a molten metal burnthrough of the chamber.

NOTE 2: Cooling water quality should be considered to minimize plugging of the induction coil or coils and to minimize corrosion or attack of all water-cooled components.

9-3.7 Wherever a coil or coils having multiple sections or multiple water pads are used, such coils or pads shall have separately valved water circuits in order to ensure continuity of cooling in the event of a water leak.

9-3.8 Water-cooled induction leads shall be of sufficient length and proper design to minimize any work-hardening as a result of movement.

9-3.9 Wherever an elevator is used the elevating mechanism shall be substantially supported by structural members to handle the maximum loads. Elevator guides or ways shall be provided to ensure uniform stabilized movement. The elevator mechanism shall be shielded from spillage of molten metal.

9-3.10 All paragraphs in Section 2-6 of this standard dealing with the construction of vacuum furnaces and vacuum systems shall also apply to this chapter.

9-4 Heating Systems.

9-4.1 For the purpose of this chapter, the term "heating system" shall include an electrical power supply, induction coil, and related hardware.

9-4.2 All components, such as the vacuum chamber, power supply, and control cabinet, shall be grounded.

Exception: Induction coils shall not be grounded (see 9-5.7).

9-4.3 It shall be the purpose of the power supply to transform the power line to suitable voltage and current (and where necessary convert from 60 Hz to another frequency) to energize the induction coil. Consideration shall be given to furnishing the power supply with a means of proportioning control.

NOTE 1: Generally this is accomplished with either a motor generator, an electronic oscillator, or silicon-controlled solid-state converter units. In most cases a DC control signal is provided for proportioning control. The design of the power supply is specific for each individual furnace and size.

NOTE 2: The power supply may include a transformer (or a motor generator), capacitors with control switches as required, a control device such as a saturable core reactor, primary fuses or circuit breakers for electrical protection, and electrical disconnect switch for service. A power controller may be used when required to accept a signal from the furnace temperature controller.

NOTE 3: The power supply output voltage should be limited to a maximum of 80 volts, for noninsulated induction coils, to prevent electrical breakdown or internal furnace arcing. As the atmospheric pressure is reduced in the vacuum chamber, arcing voltage changes. This voltage change is a function of electrical spacing and pressure. This function is not linear but has a minimum value for most gases used as cooling or partial pressure media in vacuum furnaces. If the voltage stress and mean free path relationship reaches a critical value, corona discharge and arcing commence as a result of field emission of electrons. For insulated induction coils the operating voltage may be higher in accord with the dielectric of the insulating media chosen by the designer.

NOTE 4: Assuming a 3 phase power line, consideration should be given to provide balanced line currents across all 3 phases as a result of the induction coil load.

9-4.4 The geometry of the coil and placement with respect to the susceptor or load shall be carefully considered to provide proper heating rate, maintaining operating temperature, and meeting temperature uniformity specifications.

NOTE: The design of the induction coil is generally circular and wound from copper tubing allowing water cooling of the coil.

9-4.5 The electrically energized induction coil shall be supported in such a way as not to come in contact with the susceptor or work pieces or fixtures and to avoid contact with other internal furnace components.

NOTE: In the event of contact, electrical short circuits can result in major damage to the induction coil, charge, or furnace parts.

9-4.6 The electrical insulation of the induction coil supports or coil separators shall be of suitable material to withstand exposure to specified temperature, vacuum levels, and operating voltage and frequency.

9-4.6.1 In the case of an insulated or individually wrapped coil this requirement shall also apply to the tape or insulation.

9-4.7 The design of the induction coil shall be carefully considered for proper impedance matching between the power supply, the coil, and the susceptor or work load.

9-4.8 The induction coil power terminal and vessel feedthrough design shall be considered for vacuum integrity and induction heating effects.

NOTE: Generally the feedthrough flange should be of nonelectrically conductive material, and the power feedthrough leads should be grouped in close proximity.

9-4.9 Power terminal connection points to power supply cables shall be covered or housed to prevent electrical hazard to personnel.

NOTE: In many applications the induction coil is thermally insulated from the susceptor or work load to prevent high temperature radiation or heat damage.

9-4.10 The choice and sizing of the thermal insulation shall be determined by operating temperature, vacuum level, and other operating criteria, such as compatibility with the process.

9-5 Safety Controls.

9-5.1 All electrical safety controls and protective devices required for induction systems in NFPA 70, *National Electrical Code*, shall apply. All vacuum safety controls and devices required in Chapter 8 shall also apply.

9-5.2 An interlock shall be provided to disconnect power to the furnace whenever opening the control cabinet door exposes persons to contact with hazardous voltages.

9-5.3 An open sight drain in the water cooling shall be provided to give an immediate visible indication of water-flow in the cooling line of the induction coil when an open system is used.

NOTE: Whenever a closed loop system is used, see 5-3.3.

9-5.4 Cooling water flow shall be monitored at the discharge of each induction coil circuit to shut down the power in the event of inadequate cooling water flow.

9-5.5 Temperature sensors at the outlet of the cooling system shall be furnished with contact switches to shut down the heating power in the event that the cooling water temperature is beyond the recommended temperature of operation as specified by the design of the equipment.

NOTE: Consideration should also be given to the installation of separate indicator lights for the control circuit to indicate malfunctions. Light circuits should be reset by separate pushbutton switches when the malfunction has been corrected.

9-5.6 A molten metal leak detector shall be installed on all vacuum melting induction furnaces where the capacity for melting is more than 500 lbs (227 kg) of metal. Such detector shall sound an alarm whenever it senses molten metal in the refractory surrounding the crucible, indicating a leaking crucible.

9-5.7 A ground-fault detection device shall be provided and installed on the induction coil itself to sound an alarm and shut off power in the event of a ground-fault.

9-5.8 Wherever an elevator is used in a vacuum induction melting furnace the external door operation shall be so interlocked that it cannot be opened unless the elevator is in the proper position.

9-5.8.1 Also when such an elevator is used the crucible shall be so interlocked as to be unable to be in the pour position unless the elevator is in the proper position.

Chapter 10 Fire Protection for Furnace Areas

10-1 General. Furnaces can present fire hazards to the surrounding area in which they will be installed. Consideration shall be given to providing fixed fire extinguishing systems to protect against such hazards as overheating, spillage of molten salts or metals, quench tanks, ignition of hydraulic oil, escape of fuel, etc. It is the responsibility of the user to consult with the authority having jurisdiction concerning the necessary requirements for such protection.

CAUTION: Personnel shall be cautioned that hydrogen flames are practically invisible and may only be detected by heat waves.

NOTE 1: Hydrogen fires are not normally extinguished until the supply of hydrogen has been shut off because of the danger of reignition or explosion. In the event of fire, large quantities of water have been sprayed on adjacent equipment to cool the equipment and prevent involvement in the fire. Combination fog and solid stream nozzles have been preferred to permit widest adaptability in fire control. Small hydrogen fires have been extinguished by dry chemical extinguishers or with carbon dioxide, nitrogen and steam. Reignition may occur if a metal surface adjacent to the flame is not cooled with water or other means.

NOTE 2: The various conditions under which gaseous hydrogen will be stored at consumer sites, including unattended installations, necessitates coordination between the supplier, consumer, and authority having jurisdiction for adequate and reliable fire protection of the system.

10-2 Sprinkler and Spray Systems.

10-2.1 Automatic Sprinkler Systems. Automatic sprinkler installations shall conform to NFPA 13, *Standard for the Installation of Sprinkler Systems*, for hazardous locations.

10-2.2 Water Spray Systems. Water spray systems shall be fixed systems, automatic in operation and conforming to NFPA 15, *Standard for Water Spray Fixed Systems for Fire Protection*.

10-3 Portable Protection Equipment.

10-3.1 Extinguishers. Approved portable extinguishing equipment shall be provided near the furnace and related equipment. Such installations shall be in accordance with NFPA 10, *Standard for Portable Fire Extinguishers*.

10-3.2 Small Hose Streams. When small hose streams are required, they shall be in accordance with NFPA 14, *Standard for the Installation of Standpipe and Hose Systems*.

Chapter 11 Maintenance of Vacuum Furnaces

11-1 Responsibility. A regular maintenance program shall be established to ensure that the equipment is in proper working order. The equipment manufacturer shall impress upon the user the need for adequate operational checks and maintenance and shall issue complete and clear maintenance instructions. The final responsibility of establishing a maintenance program that ensures that the equipment is in proper working order shall rest with the user.

11-2* Check Lists. The user's operational and maintenance program shall include all listed procedures that are applicable to the user's furnace. An operational and maintenance check list shall be maintained and is essential to safe operation of the equipment.

Chapter 12 Referenced Publications

12-1 The following documents or portions thereof are referenced within this standard and shall be considered part of the requirements of this document. The edition indicated for each reference is the current edition as of the date of the NFPA issuance of this document.

12-1.1 NFPA Publications. National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101.

NFPA 10-1990, *Standard for Portable Fire Extinguishers*

NFPA 13-1989, *Standard for the Installation of Sprinkler Systems*

NFPA 14-1990, *Standard for the Installation of Standpipe and Hose Systems*

NFPA 15-1990, *Standard for Water Spray Fixed Systems for Fire Protection*

NFPA 50-1990, *Standard for Bulk Oxygen Systems at Consumer Sites*

NFPA 50A-1989, *Standard for Gaseous Hydrogen Systems at Consumer Sites*

NFPA 54-1988, *National Fuel Gas Code*

NFPA 58-1989, *Standard for the Storage and Handling of Liquefied Petroleum Gases*

NFPA 70-1990, *National Electrical Code*

NFPA 86C-1987, *Standard for Industrial Furnaces Using a Special Processing Atmosphere*

12-1.2 ASME Publications. American Society of Mechanical Engineers, 345 East 47th St., New York, NY 10017

ASME *Boiler and Pressure Vessel Code*, Section VIII, Division 1, 1989 Edition

12-1.3 US Government Publication. US Government Printing Office, Washington, DC 20401

OSHA 29 CFR 1910

Subpart E – Means of Egress

Subpart H – Hazardous Materials

Subpart L – Fire Protection

Subpart S – Electrical

Subpart Z – Toxic & Hazardous Substances

12-1.4 Other Publications.

National Electrical Manufacturers Association, 2101 L St., NW, Washington, DC 20037

Appendix A

This Appendix is not a part of the requirements of this NFPA document, but is included for information purposes only.

Table A-1-2 Vacuum Furnace Protection

OPERATING AND SUBJECT SAFETY DEVICES	COLD WALL			HOT WALL		CASTING AND MELTING			
	Induction	Resistance	Electron Beam	Gas-Fired	Electric	Induction	Electron Beam	Electric Arc	Plasma Arc
A-Vacuum System	yes	yes	yes	yes	yes	yes	yes	yes	yes
Vacuum Chamber	yes	yes	yes	yes	yes	yes	yes	yes	yes
Roughing Pump	yes	yes	yes	yes	yes	yes	yes	yes	yes
Diffusion Pump	op	op	yes	op	op	op	yes	op	no
Holding Pump	op	op	op	op	op	op	op	op	no
Retort	no	no	no	yes	yes	no	no	no	no
Multi-chamber	op	op	op	op	op	op	op	op	op
Internal Fan [Temp. uniformity]	no	op	no	op	op	no	no	no	no
B-Heating System	yes	yes	yes	yes	yes	yes	yes	yes	yes
High Voltage	no	no	yes	no	no	no	yes	yes	yes
High Current	yes	yes	no	no	yes	yes	yes	yes	yes
C-Cooling System									
Work Cooling	yes	yes	yes	op	op	op	op	no	yes
Gas Quench	op	op	op	op	op	op	op	no	no
Oil Quench	op	op	no	no	no	no	no	no	no
Water Quench	op	op	no	no	no	no	op	no	no
Fans-Blower	op	op	op	op	op	op	op	no	op
Port-Bungs	op	op	op	op	op	no	no	no	op
External-Internal Heat Exchanger	op	op	op	op	op	op	op	op	op
Equipment Water Cooling	yes	yes	yes	yes	yes	yes	yes	yes	yes
D-Process Atmosphere Cycle									
Hydrogen	op	op	no	op	op	no	no	no	op
Nitrogen	op	op	no	op	op	no	no	no	op
Methane	op	op	no	op	op	no	no	no	op
Argon	op	op	no	op	op	no	no	no	yes
Helium	op	op	no	op	op	no	no	no	op
E-Material Handling									
Internal	yes	yes	yes	yes	yes	yes	yes	yes	yes
External	yes	yes	yes	yes	yes	yes	yes	yes	yes
F-Instrument Controls									
Temperature	yes	yes	yes	yes	yes	yes	yes	yes	yes
Vacuum	yes	yes	yes	yes	yes	yes	yes	yes	yes
Pessure	yes	yes	yes	yes	yes	yes	yes	yes	yes
Flow	yes	yes	yes	yes	yes	yes	yes	yes	yes
Electrical	yes	yes	yes	yes	yes	yes	yes	yes	yes
G-Hazards of Heating System				[Refer to NFPA 86 & 86C]					
Gas-Fired	no	no	no	yes	no	no	no	no	no
Electric Heated	yes	yes	yes	no	yes	yes	yes	yes	yes
Cooling Water to be Circulating	yes	yes	yes	yes	yes	yes	yes	yes	yes
Over Heating	yes	yes	yes	yes	yes	yes	yes	yes	yes
Steam Build-up	yes	yes	yes	yes	yes	yes	yes	yes	yes
Diffusion Pump Element	yes	yes	yes	yes	yes	op	yes	op	no
Pump Element Over Heating	yes	yes	yes	yes	yes	op	yes	op	no
Accumulation of Air	yes	yes	yes	yes	yes	yes	yes	yes	yes
Hydrogen Accumulation	op	op	op	op	op	no	no	no	no
Other Combustibles	no	no	no	no	no	no	no	no	no
Water in Oil Explosion	no	yes	no	no	yes	no	no	no	no
Radiation	no	no	yes	no	no	no	yes	yes	yes
Water Sentinel	yes	yes	yes	yes	yes	yes	yes	yes	yes
Electrical Short Safety Shut-down	yes	yes	yes	—	yes	yes	yes	yes	yes
H-Person Safety Hazards	yes	yes	yes	yes	yes	yes	yes	yes	yes

yes — means equipment is provided or condition is present

op — optional and there may be a choice

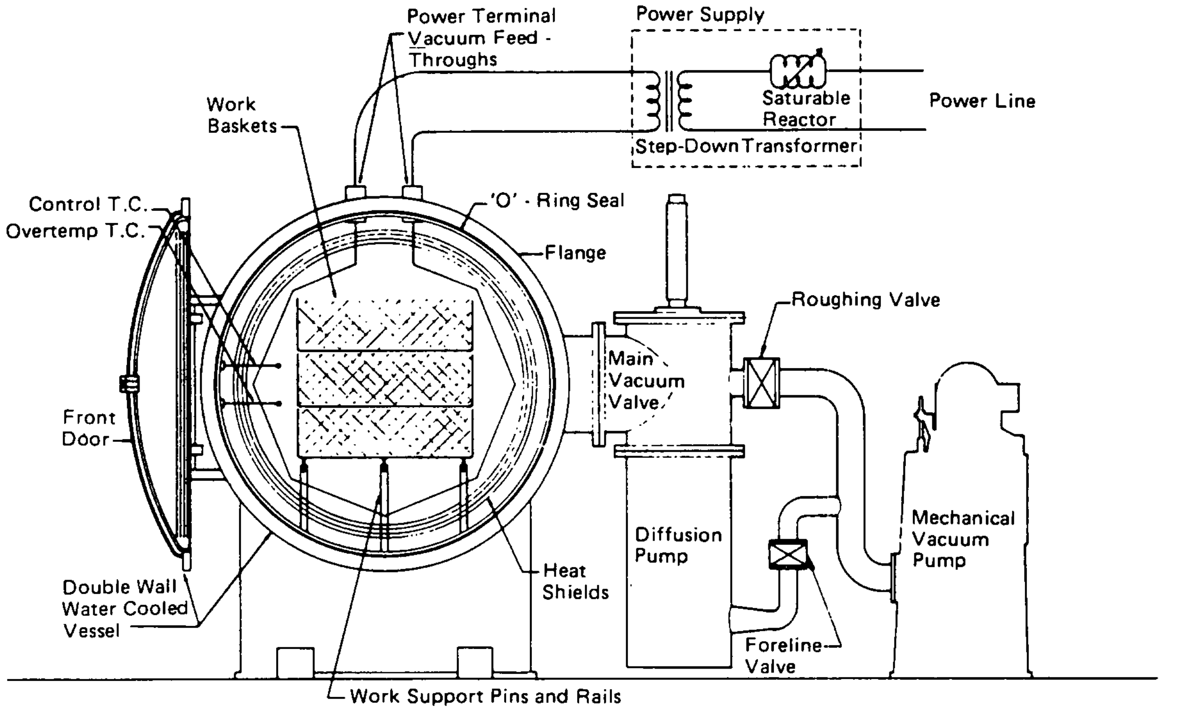

Figure A-1-2.1(a) Example of Cold-Wall, Horizontal, Front Loading Vacuum Furnace.

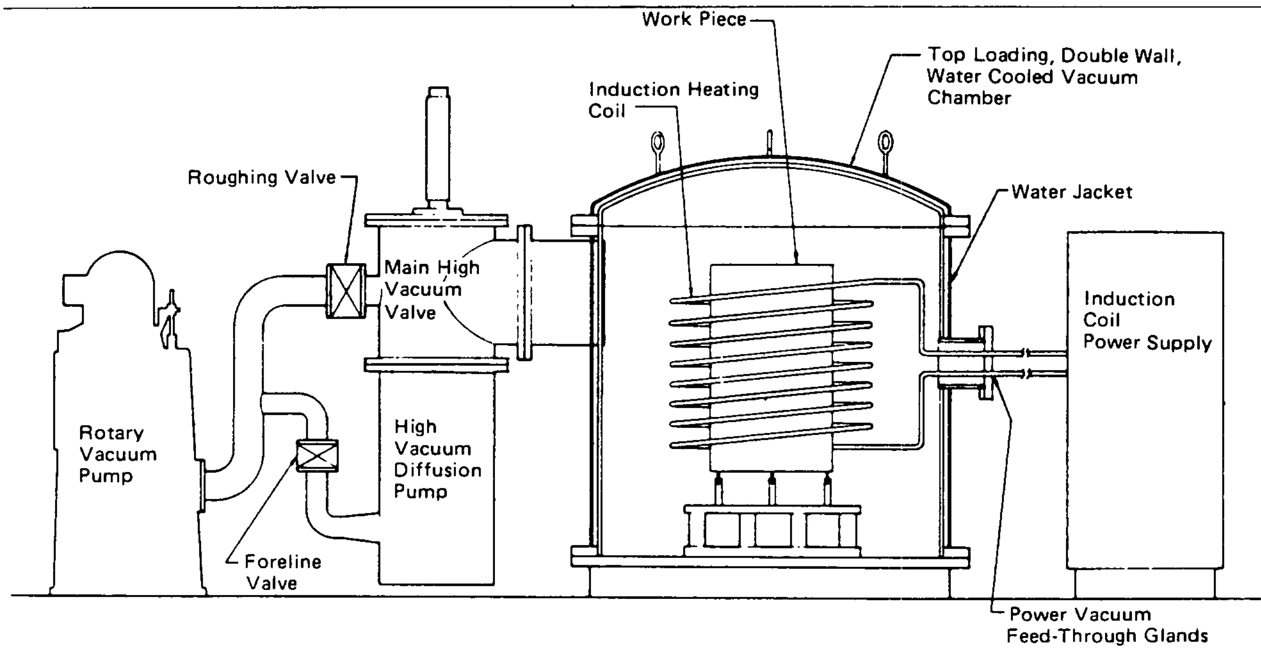

Figure A-1-2.1(b) Example of Cold-Wall, Induction Heated Vacuum Furnace.

A-1-2.3 Melting and Casting Furnaces.

A. Plasma Melting.

(1) Plasma melting is a process by which metal solids, powders, chips, and fines may be consolidated into ingot or slab form. Melting is accomplished by an ionized gas which transfers heat from the plasma torch to the material. The gas may be oxidizing, reducing, or inert depending on the process requirements. The temperature of the plasma gas is in excess of 20,000°C (36,032°F). Material consolidation may be in the form of an ingot, usually extracted from the bottom of the melt chamber, or a slab that is removed horizontally from the melt chamber.

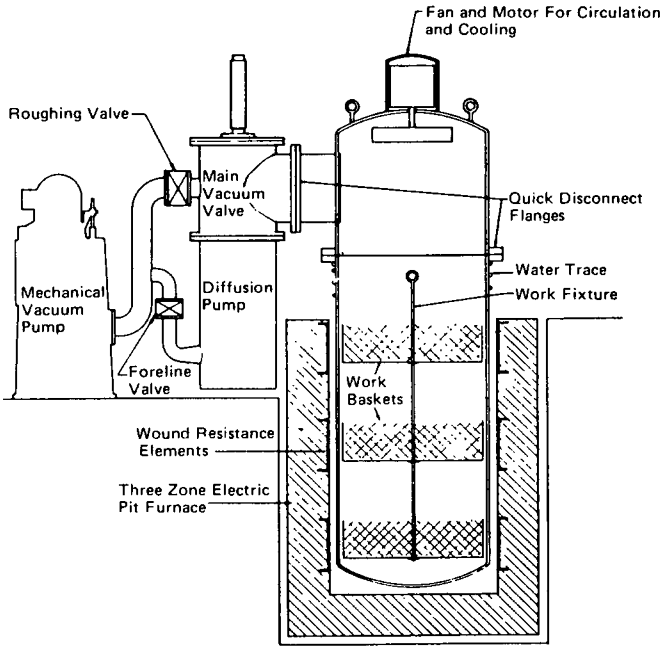

Figure A-1-2.2 Example of Hot-Wall, Single Pumped Retort Vacuum Furnace.

(2) The melt chamber operating pressure may be varied from 10^{-2} atmospheres to 2 atmospheres, making the process suitable for a wide variety of metals and alloys. Cleaning and refinement of the material may be accomplished by the use of hearth melting, stirring action by torch manipulation, inductive stirring coils, and vacuum/pressure cycling of the melt chamber.

(3) The melt chamber, torches, copper hearths, consolidation containment system, and power supplies are water cooled. Each water cooled circuit is monitored for low flow and/or high temperature with alarms for all circuits and power disruption for critical circuits.

(4) Solid state power supplies are utilized to provide power to the torches that range in size from 50 Kw for a small research unit to multiple torches of 1000Kw each for large production melters. The torches provide x, y, and z movements with x and y movements being programmable or computer controlled.

B. Electron Beam (EB) Melter.

(1) Of all commercial melting techniques, electron-beam melting is capable of producing the highest refinement of end product. The beam of the electron gun can be focused to produce heat so intense as to vaporize even metals with the highest melting points. When combined with a vacuum atmosphere in the order of 10^{-4} Torr, most impurities can be separated from the product being melted. EB melting is especially suited for refining refractory metals and highly reactive metals, but it also finds applications in melting alloy steels.

(2) Commercial EB melters are availabe in a variety of sizes and configurations. Figure A-1-2.3(b) illustrates a vertical feed system that allows the molten metal to drop from

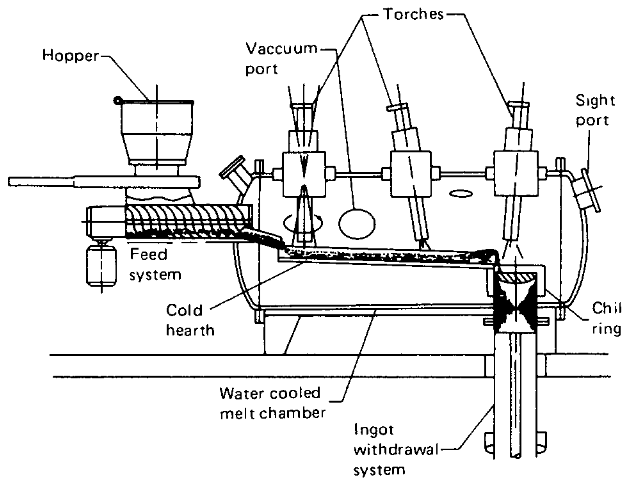

Figure A-1-2.3(a) Example of Three Torch Production Plasma Melter.

the feed stock into a water-cooled copper retention hearth where the molten metal is further refined by the oscillating beams of the two guns. The retention time of the metal in the hearth is controlled by adjusting the melt rate of the feed stock. The metal flows over a weir at the end of the hearth and falls into a water-cooled chill ring, where it solidifies into a billet as it is withdrawn downward from the chamber. Vaporized impurities condense on the cold inner walls of the vacuum chamber or on special collector plates that are easily removed for cleaning. Because of the intense heat required for the melting and refining process, the vacuum chamber is usually of double-wall construction so that large quantities of cooling water can circulate through the passages of the chamber.

(3) The following are some safety considerations applicable to this type of equipment. Water cooling circuits should be constructed to be reliable so as to prevent steam pockets from forming in confined areas which could result in an explosion. Beam gun controls should be designed so as not to allow the beam to become fixed on one spot which could cause a burn through into a water circuit. All sight ports should be covered with dark glass for eye protection when viewing the melt process. Over pressure relief systems should be incorporated where there is potential for adverse conditions. Installations might well consider emergency alternative cooling water sources for added protection of equipment and personnel. Since accelerating voltages may run as high as 100 KV, special protection should be provided to protect personnel against X-ray exposure in addition to the high voltage hazards.

C. Vacuum Arc Melting and Vacuum Arc Skull Casting.

(1) Vacuum arc melting is a high-volume production method for alloying and refinment of metals. Alloys can be produced by sandwiching and welding strips of different metals together to produce an electrode which, after melting, will result in the proper alloy.

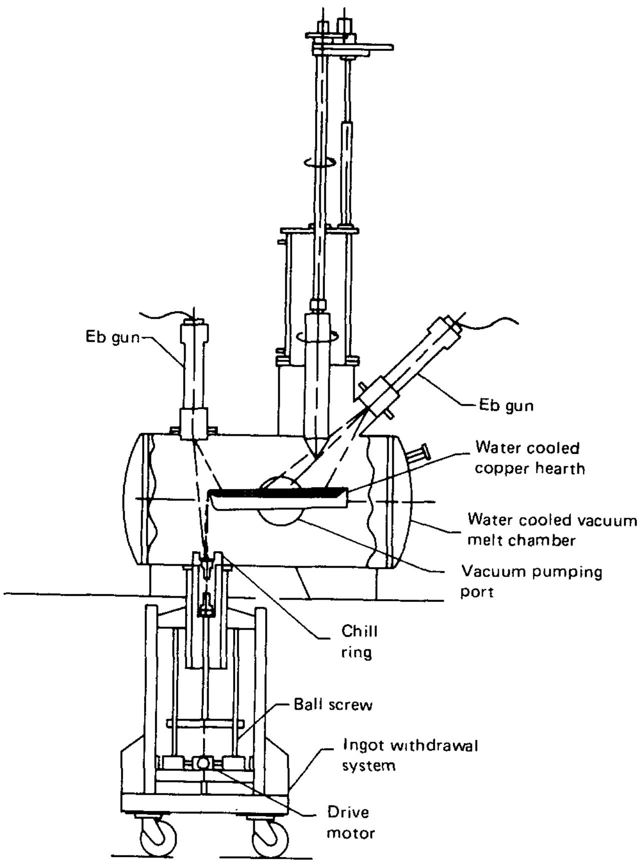

Figure A-1-2.3(b) Example of Electron Beam (EB) Melter.

Second and third melts are sometimes necessary to refine the alloy. Most arc melters are of the consumable electrode type; however, nonconsumable electrode melters are commercially available. Figure A-1-2.3(c) illustrates the principal components of one type of consumable electrode arc melter.

(2) In operation, dc voltage potential is established between the stinger rod, which has the electrode attached to it, and the water-cooled copper melt cup. The stinger rod is driven down until an arc is established between the electrode and a metal disk placed in the bottom of the melt cup. Once the arc has stabilized and melting begins, the voltage may be reduced, thus shortening the arc length and lessening the possibility of arcing to the water-cooled sidewall of the cup.

(3) Automatic control systems are available for controlling the arc length and melt rates. A mechanical booster pumping system provides vacuum operating levels in the range of 10^{-2} Torr. Water cooling circuits are provided for the stinger rod, head, melt cup, solid state power supply, cables and connections, and vacuum pumping system.

(4) The vacuum arc skull caster is a variation of the vacuum arc melter with the essential difference being instead of melting the electrode into a copper cup and letting the molten metal solidify, the electrode is melted into a cold wall copper crucible. The crucible is then tilted, pouring the molten metal into a casting mold, leaving in the crucible a solidified metal lining or "skull".

(5) Burn throughs into water jackets which allow water to come in contact with hot metal are not uncommon in arc melting. Equipment damage can be minimized by providing over pressure relief ports, reliable cooling water sources, well designed and monitored cooling circuits, and well trained operators. Blast protection walls are frequently installed for personnel protection.

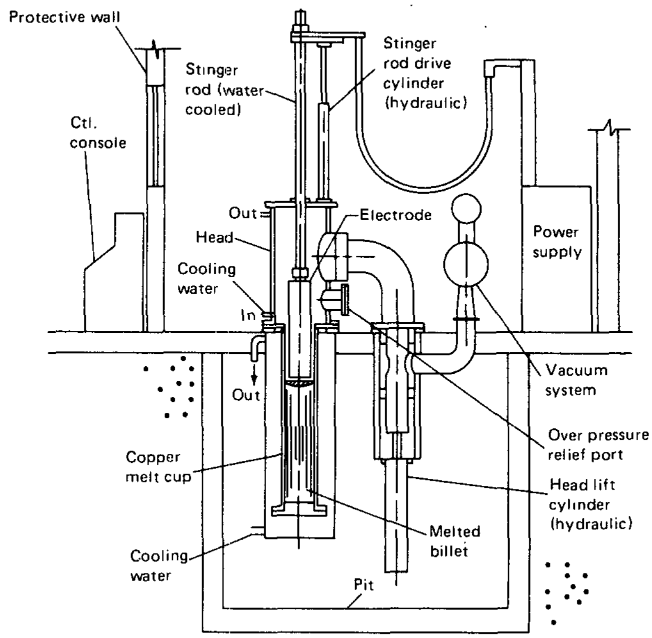

Figure A-1-2.3(c) Example of Vacuum Arc Melter.

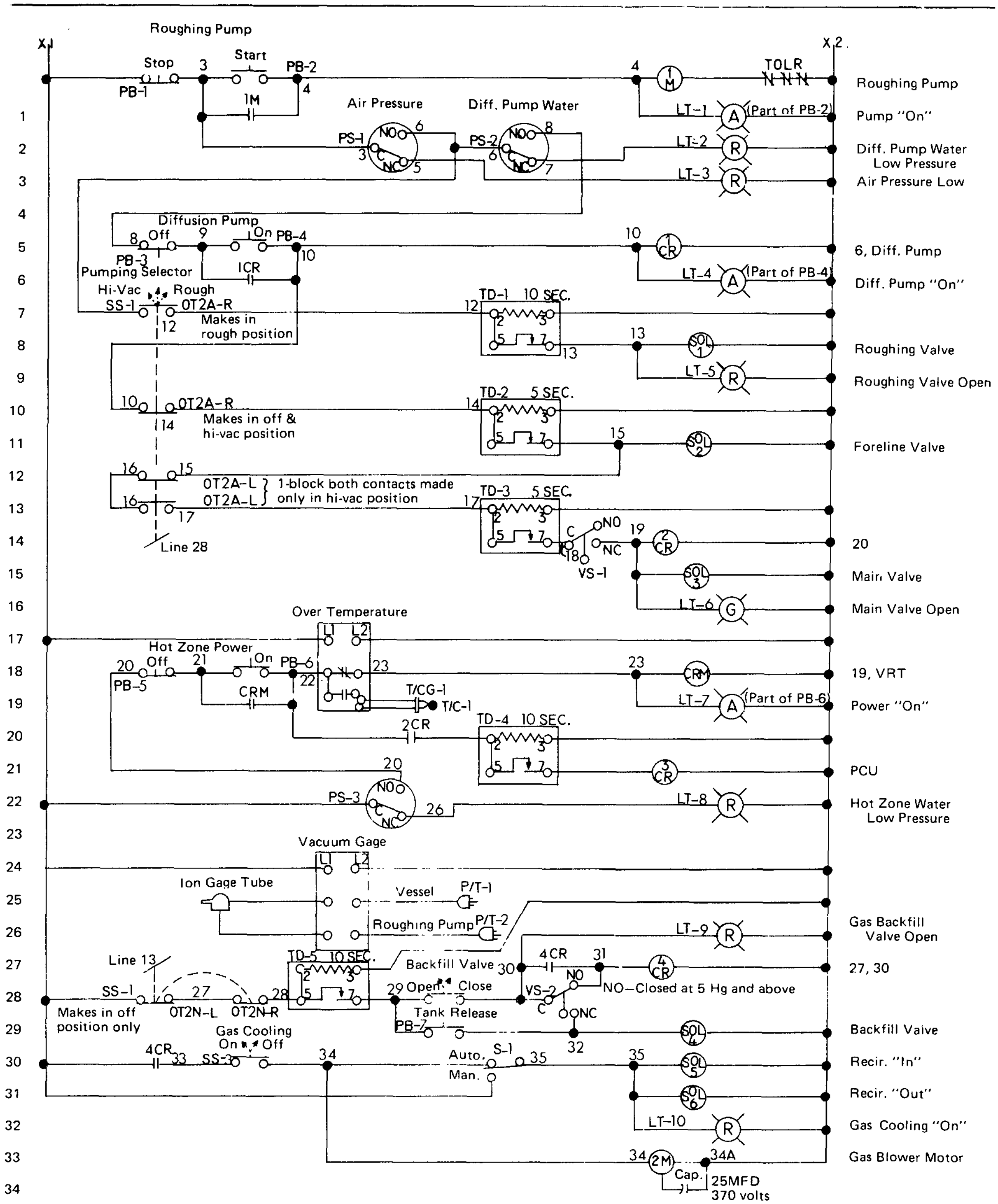

Figure A-1-7(a) Example of Control Wiring Diagram.

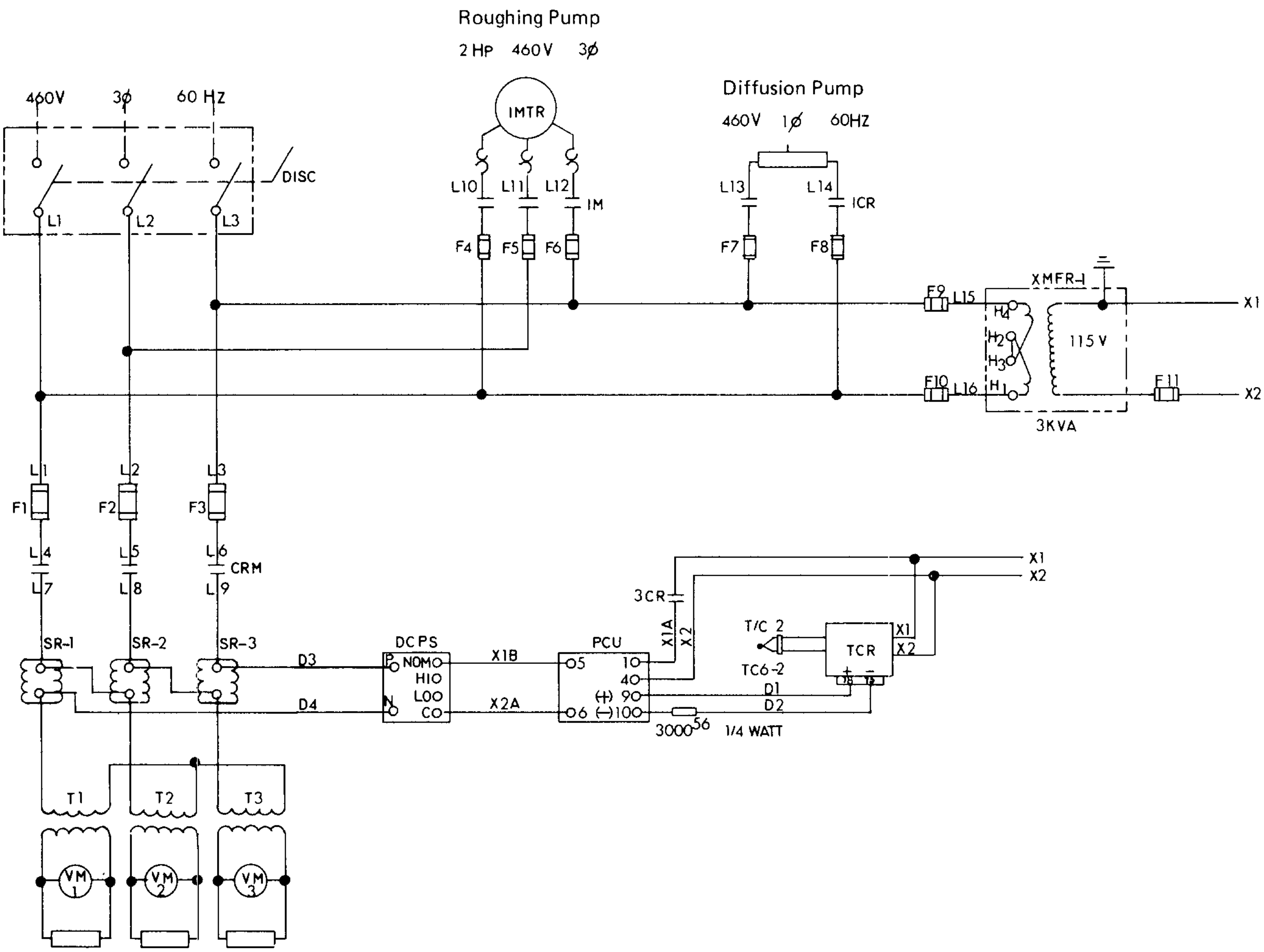

Figure A-1-7(b) Example of Control Wiring Diagram.

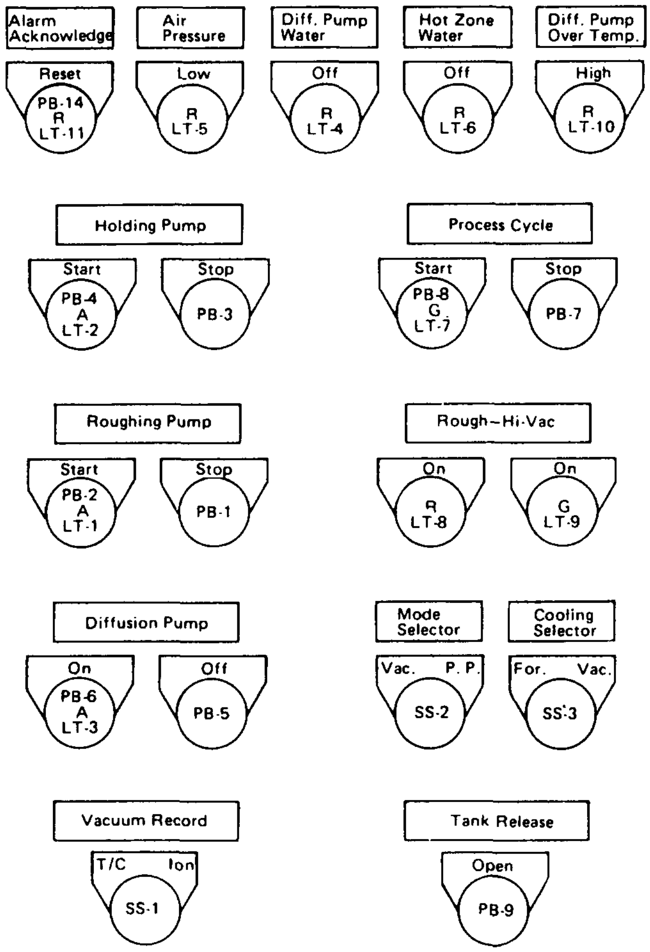

Figure A-1-7(c) Example of Control Panel.

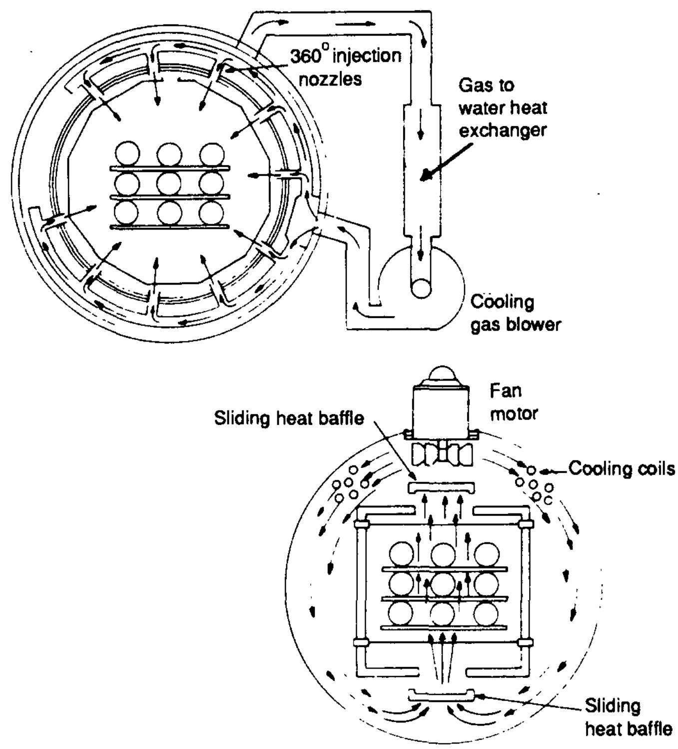

Figure A-3-4.4 Examples of Some Gas Quenching Methods.

A-3.3.3 When dissimilar metals are heated in contact with each other, particularly when oxide-free and in a vacuum furnace, they can react and form alloys or a eutectic. The result is an alloy that melts at a considerably lower temperature than the melting points of either base metal.

Some eutectic forming materials are listed with critical melting temperature. Operating temperatures near or above these points should be carefully considered.

Table A-3-3.3 Eutectic Melting Temperatures

Moly/Nickel	2310°F	(1266°C)
Moly/Titanium	2210°F	(1210°C)
Moly/Carbon	2700°F	(1482°C)
Nickel/Carbon	2310°F	(1166°C)
Nickel/Tantalum	2450°F	(1343°C)
Nickel/Titanium	1730°F	(943°C)

A-5-3.2 Types of Vacuum Gages.

A. Mechanical Gages. The bellows and diaphragm mechanical gages operate on a differential between atmospheric and process pressure. They are compensated for atmospheric pressure changes and calibrated for absolute pressure units. They are not suited for high-vacuum work, being limited to approximately 1 mm Hg (133 Pa) absolute. Readout is approximately linear except when calibrated in altitude units. Electrical output is available.

B. McLeod Gage. For high-vacuum work the McLeod gage is often used as a primary standard for the calibration of other, more easily used instruments. The gage is limited to intermittent sampling rather than continuous use. It operates on the principle of compressing a large known volume (V_1) of gas at unknown system pressure (P_1) into a much smaller volume (V_2) at a known higher pressure (P_2). From Boyle's Law at constant temperature we derive P_1 equals P_2V_2/V_1. The gage is then calibrated to read P_1 directly.

C. Thermal Gages. The operation of a thermal gage is based on the theory that energy dissipated from a hot surface is proportional to the pressure of the surrounding gas. Some makes of thermal gages are subject to contamination by vaporized materials and this possibility should be checked on with the gage manufacturer.

(1) *Thermocouple Gage.* The thermocouple gage contains a "V"-shaped filament with a small thermocouple attached to the point. At low absolute pressures the cooling effect on the heated filament is proportional to the pressure of the surrounding gas. Thus, the thermocouple electro-magnetic field (emf) can be used to indicate pressure. In order to compensate for ambient temperature, an

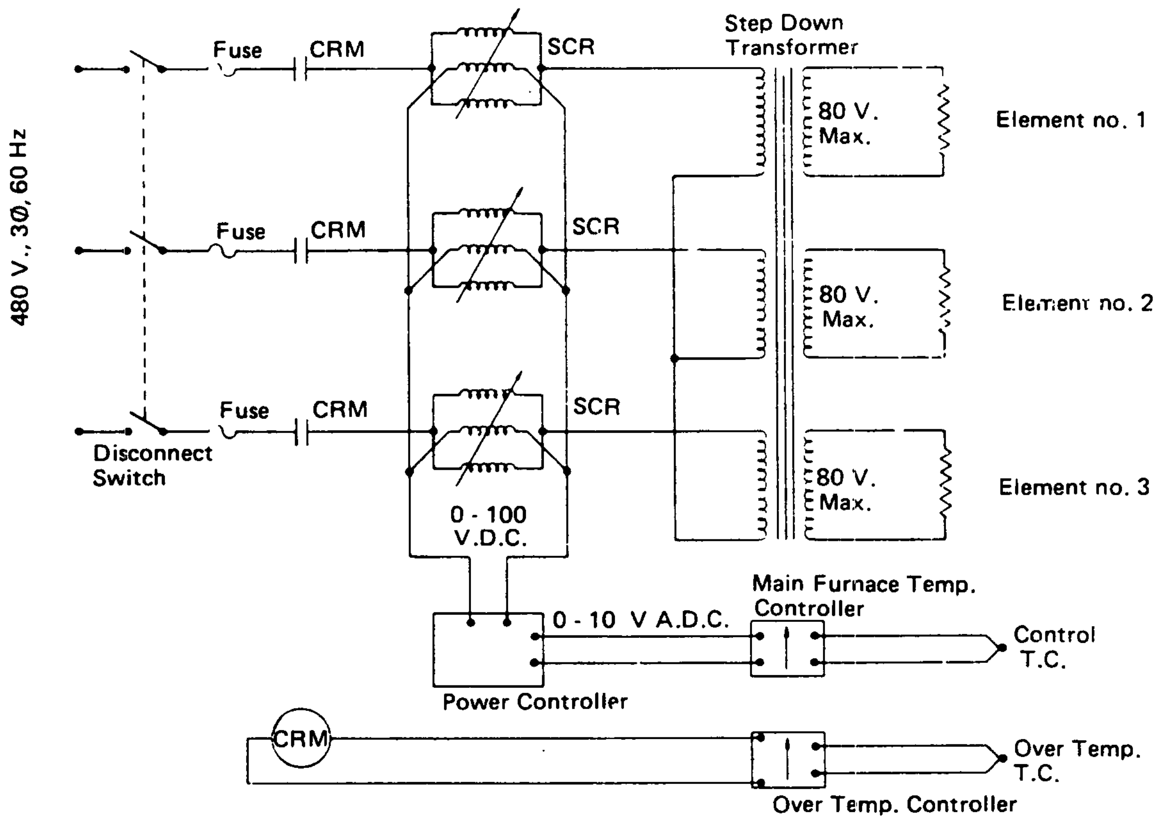

Figure A-3-2.1 Example of Power Supply.

identical second unit is sealed in an evacuated tube. The differential output of the 2 thermocouples is proportional to the pressure.

(2) *Pirani Gage.* The Pirani gage employs a Wheatstone bridge circuit. This circuit balances the resistance of a tungsten filament sealed off in high vacuum against that of a tungsten filament that can lose heat by conduction to the gas being measured. In the Pirani gage, the resistance of the filament rather than its temperature is used as an indication of pressure.

(3) *Bimetal Gage.* A bimetallic spiral is heated by a stabilized power source. Any change of pressure causes a change of temperature and, thus, a deflection of the spiral, which is linked to a pointer on scale, to indicate pressure.

D. Ionization Gages. Two types of ionization gages are discussed here. They are: (1) the hot cathode gage (hot filament), and (2) cold cathode gage (also called the "Phillips" or discharge gage). The principle of operation is that collisions between molecules and electrons result in formation of ions. The rate of ion formation varies directly with pressure. Measurement of the ion current can be translated into units of gas pressure.

(1) *Hot Filament Gage.* This gage is constructed like an electron tube. It has a tungsten filament surrounded by a coil grid, which in turn is surrounded by a collector plate. Electrons emitted from heated filament are accelerated toward the positively charged coil grid. The accelerated electrons pass through the coil grid into the space between it and the negatively charged collector plate. Some electrons collide with gas molecules from the vacuum system to produce positive ions. The positive current is a function of the number of ions formed and hence is a measure of the pressure of the system.

Ionization gage sensing elements are extremely delicate and must be carefully handled. Their filaments can burn out if accidentally exposed to high pressures above 1×10^{-3} mm Hg (1.3×10^{-1} Pa) absolute. The advantages of this type of gage are high sensitivity and the ability to measure extremely high vacuums.

(2) *Cold Cathode Gages.* Cold cathode gages employ the principle of the measurement of an ion current produced by a high-voltage discharge. Electrons from the cathode of the sensing element are caused to spiral as they move across a magnetic field to the anode. With this spiraling, the electron mean free path greatly exceeds the distance between electrodes. Therefore, the possibility of a collision with gas molecules present is increased, producing greater sensitivity (due to greater ion current) and thus sustaining the cathode discharge at lower pressure (i.e., high vacuum).

The sensing elements are rugged and are well suited to production applications where unskilled help might make filament burnout a problem.

A-7-1.1 Chemical Vapor Deposition.

A. General. Chemical Vapor Deposition (CVD) is a process of reacting gaseous constituents to form a film on a surface. It can be used to produce thin films, thick films, or monolithic structures. In a typical CVD process the gaseous reactants, usually involving halides, are injected into a heated volume at reduced pressure where they react to form a solid material plus gaseous byproducts that may be corrosive, toxic, or flammable.

B. The Furnace. Hot Wall Furnace Designs are employed using muffles of alloy suitable for the temperature and corrosion conditions encountered at temperatures up to 1000°C (1832°F). Heating is by an external electric furnace capable of uniform reproducible temperature control. Quartz muffles are employed where corrosion conditions demand and the scale of the operation is sufficiently small to enable the degree of care and delicate handling required to avoid breakage.

Reaction temperatures above 1000°C (1832°F) require cold wall furnace technology most generally utilizing graphite hot zones. If the CVD reaction involves a product that can damage the heating element and/or impair the effeciency of the insulation a graphite muffle with inert pump out and gas injection provisions is utilized in conjunction with gas blanketing outside to ensure that the reactants are confined. (*See Figure A-7-1.1.*)

C. Vacuum System. CVD reaction pressures that range between 0.5 and 500 Torr employ rotary mechanical oil sealed pumps often in series with a mechanical blower. A throttle valve controlled by a vacuum gage that should be corrosion resistant and capable of measuring total absolute pressure irrespective of composition maintains the desired pressure in the reaction chamber.

Operating conditions can severely limit pump life in a variety of mechanisms that include:

(1) Oil sludging and loss of lubricity

(2) By corrosive attack, usually hydrochloric acid

(3) By abrasion from tramp deposition product.

Several means to combat these rigorous conditions are available depending on the specifics of materials involved.

D. Gas Management. Gases in controlled quantity may be delivered to the reaction chamber by means of rotameters with needle valves in basic systems or alternatively by electronic mass flow controllers and readouts in systems that can employ programmable control. Typically 3 gas components are involved; the precursor which contains the element or compound to be deposited; the reducer such as hydrogen or ammonia; a diluent such as argon or nitrogen to influence structure, density, or other characteristics of the deposit. Particular care is exercised to ensure that the reactor is in a correct operating mode prior to the introduction of gases. Purging connections adjacent to the gas supply connections prevent escape into the shop environment when the system is opened.

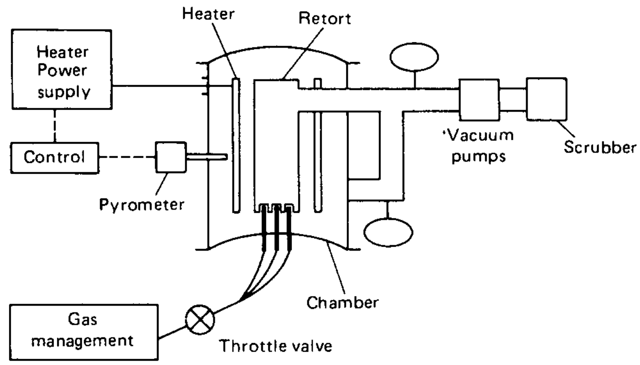

Figure A-7-1.1 Example of High Temperature CVD System.

E. Handling By-Product. A common reaction by-product is HCL gas. Optimum system design avoids hydrolyzing until it reaches a trap or a scrubber where it can be neutralized. Toxic and corrosive constituents are burned or captured chemically as appropriate.

F. Special Furnace Requirements. Requirements on the furnace design for CVD service include:

(1) Use of austenitic stainless steel interior surfaces of the chamber.

(2) Avoidance of nonferrous metals in valves and piping that may be exposed to reactants and by-products.

(3) Provisions of adequate clamping of access closures to avoid leakage when operating near atmospheric pressure.

(4) Provisions of pressure relief devices, i.e., corrosion resistant relief valves or rupture discs properly vented.

(5) Provision of NFPA approved auxiliaries when operating with flammable mixtures.

A-11-2 Maintenance Checklist.

A. General. A program of regular inspection and maintenance of the vacuum furnace is essential to the safe operation of the equipment and should be instituted and followed rigorously. Basic heating devices, such as heating elements or induction coils, should be designed for ease of maintenance. If special tools are required, these should be supplied by the furnace manufacturer.

B. Vacuum System. Mechanical vacuum pumps should be checked and repaired as required. A partial list follows:

Drive belts are not worn.

Drive belts' tension is proper.

No oil leaks at the shaft seals.

Correct oil level.

Oil is free of dirt and water accumulation.

Drip legs are drained.

Mounting bolts are tight.

Vacuum lines and vibration couplings are tight.

The high-vacuum diffusion pump should be checked and repaired as required. A partial list follows:

Correct waterflow for cooling.

Heating elements are tight and indicate proper electrical parameters.

Oil level is correct.

Oil is not contaminated.

Control vacuum valves should be checked and repaired. A partial list follows:

Air supply filter drained and operating.

Air supply oiler filled to correct level and operating.

Pilot valves not leaking excess air.

Moving O-ring seals cleaned or changed where indicating excess wear.

Numerous stationary and moving vacuum seals, O-Rings and other rubber gaskets are associated with the main vacuum vessel. These seals should be inspected properly to ensure cleanliness, freedom from cracks or gouges, and retention of elasticity. The main front and rear door or bottom head, where work regularly passes, should receive particular attention.

C. Hot Zone (Resistance Heaters).

(1) *Power Supply.* The power supply should be inspected and corrected as required. A partial list follows:

Primary and secondary wiring and cables tight and free from overheating.

Proper ventilation and air cooling or proper waterflow per unit or transformer.

Control relays or contactors should be free of contact pitting or arcing, which could result in contact welding.

Power supply voltage should be maintained within reasonable limits to ensure against overloading.

NOTE: Under voltage can result in operational failure of any one of the numerous vacuum furnace systems.

(2) *Thermocouples.* A regular replacement program should be established for all control and safety thermocouples.

NOTE: Effective life of thermocouples varies depending on the environment and process, temperature and vacuum, and these factors must be considered in setting up a replacement program.

(3) *Instrumentation.* Temperature and vacuum instrumentation should be set up on a regular calibration and test schedule.

Many components of the vacuum furnace require water cooling; drain lines should be inspected for proper flow and temperature of the cooling water. Pressure regulators, strainers, and safety vents should be inspected for proper setting and maintained free from dirt and contamination.

If an evaporative cooling tower is integral to the furnace system, the tower should be cleaned, motor and bearings greased, and water strainer cleaned on a regular basis.

(4) *Interlocks and Alarms.* Periodic checks of all safety interlocks and alarms should be performed. Particular attention should be given to overtemperature safety devices, low air pressure, insufficient cooling water, vacuum, oil temperature, and low oil alarms.

(a) The following continuous observations should be made:

(i) Review auxiliary vacuum instrumentation for proper indication of system performance, i.e., foreline, holding pump, mechanical pump, and diffusion pump operating temperature.

(ii) Review power instrumentation and trim or zone control settings.

(iii) Check instrumentation for "on conditions," chart paper, and active operation.

(iv) Check oil level in mechanical pumps and diffusion pump.

(v) Check mechanical vacuum pump, blowers, gas fans, and oil pumps for unusual noise or vibration. Review V-Belt drive, belt tension, and belt fatigue.

(vi) Check quench gas pressure and available capacity.

(vii) Check for proper operation of ventilation equipment if required in the particular installation.

(b) The following regular shift observations should be made:

(i) Review auxiliary vacuum instrumentation for proper indication of system performance, i.e., foreline, holding pump, mechanical pump, and diffusion pump operating temperature.

(ii) Review power instrumentation and trim or zone control settings.

(iii) Check instrumentation for "on conditions," chart paper, and active operation.

(iv) Check oil level in mechanical pumps and diffusion pump.

(v) Check mechanical vacuum pump, blowers, gas fans, oil pumps for unusual noise or vibration. Review V-Belt drive, belt tension and belt fatigue.

(vi) Check quench gas pressure and available capacity.

(c) The following weekly checks should be made:

(i) Review hot zone for normal condition of heating elements, heat shields or retainers, insulators, and work support or mechanism.

(ii) Test thermocouples and lead wires for broken insulators, shorts, and loose connections.

(iii) Test visible or audible alarms for proper signals.

(d) The following monthly observations should be made:

(i) Test interlock sequence of all safety equipment. Manually make each interlock fail, noting that related equipment shuts down or stops as required.

(ii) Inspect all electrical switches and contacts, repair as required.

(iii) Test all temperature instrument fail-safe devices, making certain that the control instrument or recorder drives in the proper direction.

(iv) Clean all water, gas compressor, and pump strainers.

(v) Test automatic or manual turn-down equipment.

(vi) Change mechanical pump oil and diffusion pump oil, if required.

(vii) Test pressure relief valves, and clean if necessary.

(viii) Inspect air, inert gas, water, and hydraulic lines for leaks.

(e) The following periodic checks should be made:

NOTE: Frequency of maintenance of the following will depend on the recommendations of the equipment manufacturer.

(i) Inspect vacuum chamber O-ring and other gaskets for proper sealing.

(ii) Review the vacuum chamber vessel for evidence of hot spots indicating improper water cooling.

(iii) Review furnace internals in detail for heating element, heat shield, and work support or mechanism failure or deterioration.

(iv) Lubricate instrumentation, motors, drives, valves, blowers, compressors, pumps, and other components.

(v) With brush or other devices remove major buildup of oxides and contamination from the hot zone and accessible areas of the cold wall chamber. Blow out contaminate with a dry air hose.

(vi) Run furnace to near maximum design temperature and maximum vacuum to burn out furnace contamination.

(vii) Install new exhaust valve springs and discs and clean and flush oil from the mechanical vacuum pumps. Replace spring and O-ring in the gas ballast valves.

(viii) Run blank-off test for mechanical vacuum pump to ensure meeting process parameters.

Appendix B Pump Data

This Appendix is not a part of the requirements of this NFPA document, but is included for information purposes only.

Table B-1 Pump Ranges

Type of Pump	Range of Vacuum
Centrifugal or Reciprocating Mechanical	760 Torr to 10 Torr (101 kPa to 1.3 kPa)
Steam Ejector	760 Torr to 0.050 Torr (101 kPa to 6.7 Pa)
Rotary Oil Sealed Mechanical	760 Torr to 0.050 Torr (101 kPa to 6.7 Pa)
Blowers (Mechanical Boosters)	1 Torr to 001 Torr (133 Pa to 1.3 × 10^1 Pa)
Oil Ejector	0.5 Torr to .001 Torr (66 Pa to 1.3 × 10^1 Pa)
Diffusion	.300 Torr to 10^{-7} Torr (40 Pa to 1.3 × 10^{-5} Pa)
*Cryogenic Devices (i.e., liquid nitrogen cold traps)	.001 Torr (1.3 × 10^{-1} Pa)
*Getter	.001 Torr (1.3 × 10^{-1} Pa)
*Ion Molecular	.001 Torr (1.3 × 10^{-1} Pa)

*Generally associated with small specialized systems.

Below are approximate minimum commercial absolute pressure capabilities of the principal types of vacuum pumps.

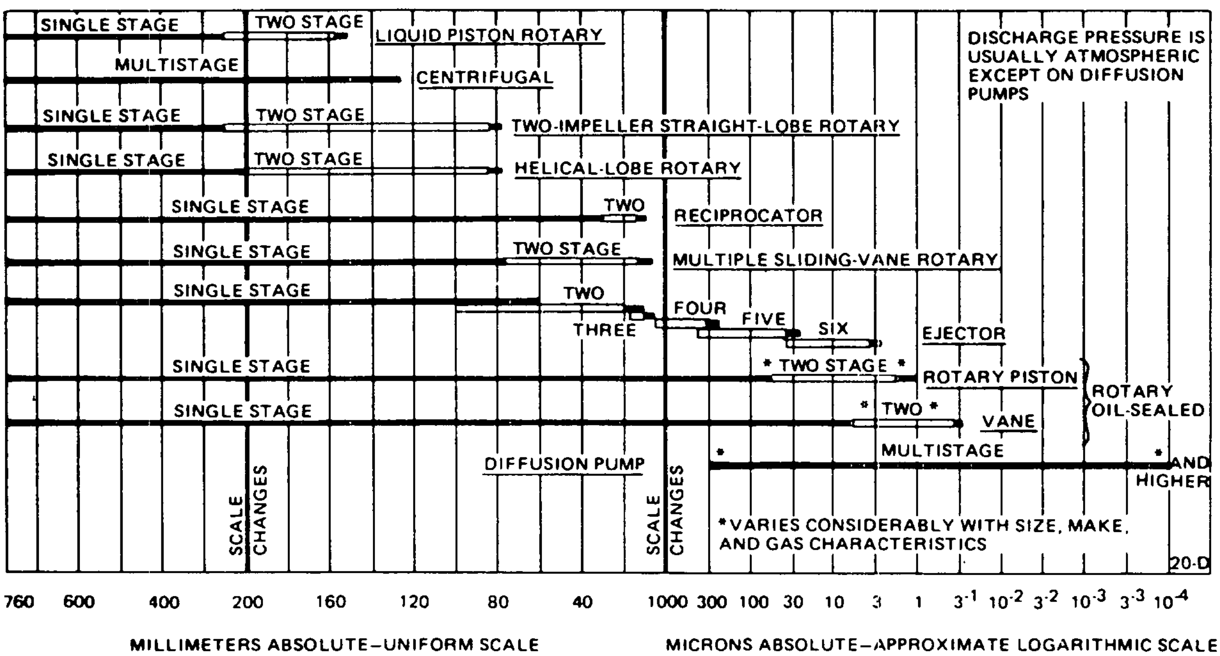

Figure B-1 Pump Ranges.

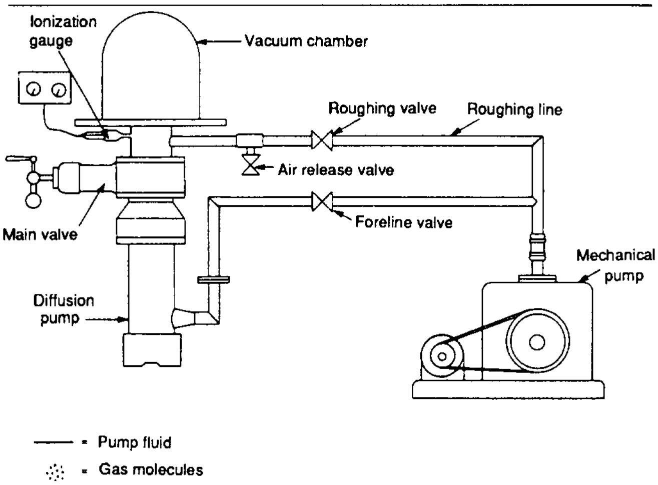

Figure B-2 Typical Vacuum System.

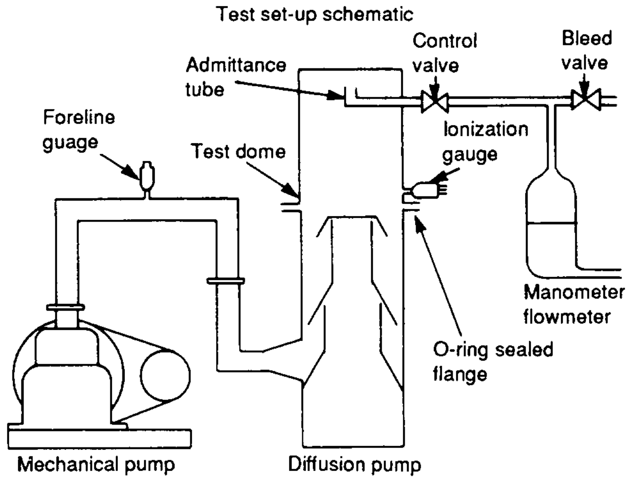

Figure B-4 Typical test setup used to determine effective pumping speeds with variables indicated in the speed curve graph.

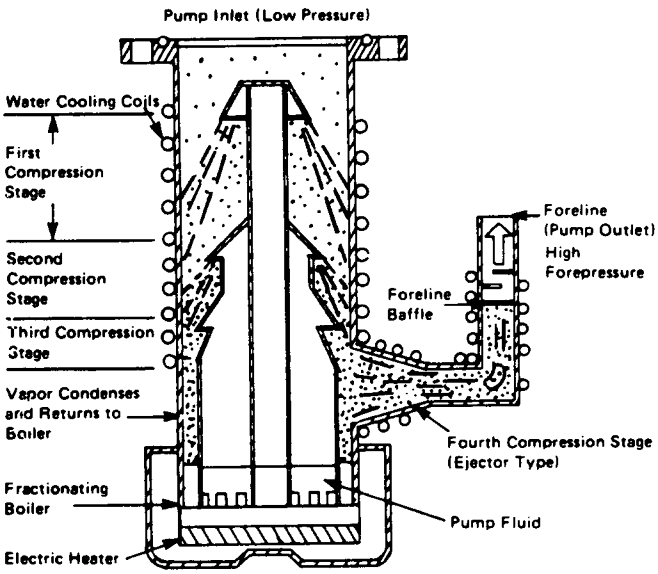

Figure B-3 How a Diffusion Pump Works.

Appendix C Engineering Data

This Appendix is not a part of the requirements of this NFPA document, but is included for information purposes only.

Table C-1 Conversion of Gas Flows*

Unit	Torr · | · s^{-1}	Micron · cu ft · min^{-1}	atm · cm^3 · h^{-1}	Micron · | · s^{-1}
Torr · | · s^{-1}	1	2120	4738	10^3
Micron · cu ft-min^{-1}	$4.719 \cdot 10^{-4}$	1	2.236	0.4719
atm · cm^3 · h^{-1}	$2.110 \cdot 10^{-4}$	0.447	1	0.21
Micron · | · s^{-1}	10^{-3}	2.120	4.738	1

Table C-2 Conversion of Pumping Speeds*

Unit	$l \cdot s^{-1}$	$m^3 \cdot h^{-1}$	cu ft $\cdot$ min^{-1}
$l \cdot s^{-1}$	1	3.60	2.12
$m^3 \cdot h^{-1}$	0.278	1	0.589
cu ft $\cdot$ min^{-1}	0.472	1.70	1

* conversion is effected by multiplying with the factors shown in the table.

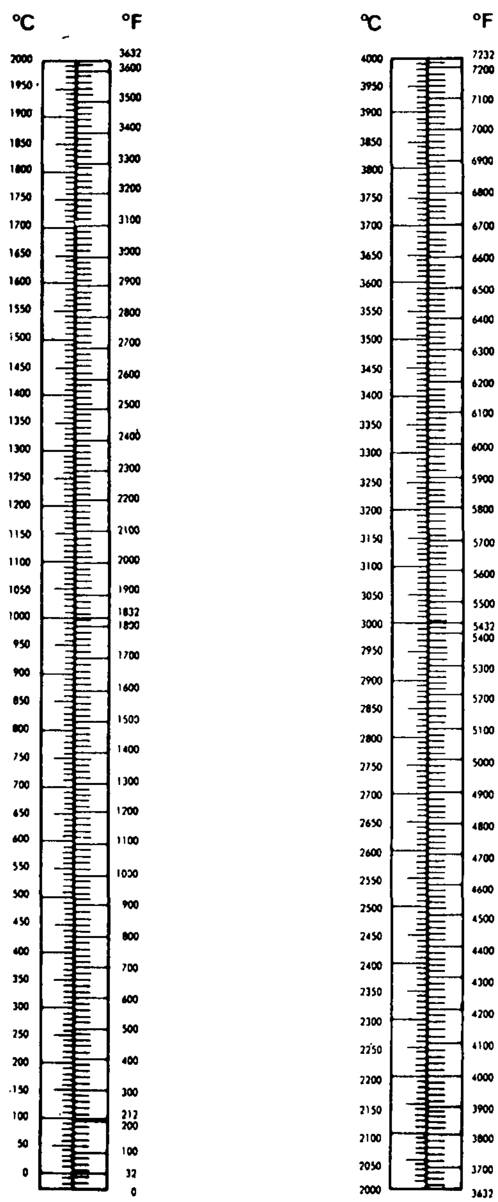

Figure C-1 Conversion from °C to °F.

Table C-3 Physical Constants

Volume of 1 mol (molecular weight M in g) of all gases at
760 Torr and 0 °C: 22.416 l
1 Torr and 20 °C: 18280 l

Number of molecules in 1 mol (Loschmidt number):
$N_L = 6.023 \cdot 10^{23}$

Number of molecules in 1 litre of an ideal gas under normal conditions:
$N = 2.688 \cdot 10^{22}$

Boltzmann constant:
$k = 1.381 \cdot 10^{-16}$ [erg · °K^{-1}]

General gas constant:
$R = 8.315 \cdot 10^{7}$ [erg · °K^{-1} · mol^{-1}]
$R = 8.315$ [Ws · °K^{-1} · mol^{-1}]
$R = 62.36$ [Torr · l · °K^{-1} · mol^{-1}]

Absolute temperature:
T[°K] = 273.16 + t[°C]

Mass of a molecule:
$\mu = 1.67 \cdot 10^{-24}$ M[g]

Electrical elementary charge:
$e = 1.6 \cdot 10^{-19}$[As]

Electron volt:
$1\ eV = 1.6 \cdot 10^{-19}$[Ws]

Table C-4 Conversion of Units of Pressure

Unit	Torr mm Hg	Micron μ	Pa	atm	Microbar μ b	Millibar mb	Bar b	inch Hg	lb · (sq ft)$^{-1}$	lb · (sq in.)$^{-1}$ = psi
1 Torr = 1 mm mercury column at 0°C	1	10^3	13.3	$1.3158 \cdot 10^{-3}$	1333.21	1.33321	$1.332 \cdot 10^{-3}$	$3.937 \cdot 10^{-2}$	2.7847	$1.934 \cdot 10^{-2}$
1 micron (μ)	10^{-3}	1	1.33×10^{-1}	$1.3158 \cdot 10^{-6}$	1.33321	$1.3332 \cdot 10^{-3}$	$1.3332 \cdot 10^{-4}$.	$3.937 \cdot 10^{-5}$	$2.7847 \cdot 10^{-3}$	$1.934 \cdot 10^{-5}$
1 Pa	13.3	1.33×10^{-1}	1	1.75×10^{-1}	1.77×10^5	1.77×10^3	1.77×10^{-1}	5.24	3.704×10^2	2.57
1 atm. (physical atmosphere)	760	$7.6 \cdot 10^5$	1.75×10^{-1}	1	$1.013 \cdot 10^6$	$1.013 \cdot 10^3$	1.013	29.92	2116.4	14.697
1 microbar (μb) = 1 dyn · cm^{-2}	$7.501 \cdot 10^{-4}$	0.7501	1.77×10^5	$9.8698 \cdot 10^{-7}$	1	10^{-3}	10^{-6}	$2.9533 \cdot 10^{-5}$	$2.0887 \cdot 10^{-3}$	$1.4503 \cdot 10^{-5}$
1 millibar (mb)	0.7501	$7.501 \cdot 10^2$	1.77×10^3	$9.8698 \cdot 10^1$	10^3	1	10^{-3}	$2.9533 \cdot 10^{-2}$	2.0887	$1.4503 \cdot 10^{-2}$
1 bar (b) (absolute atmosphere)	750.1	$7.501 \cdot 10^5$	1.77×10^{-1}	0.98698	10^6	10^3	1	29.533	2088.7	14.503
1 inch of mercury	25.4	$2.54 \cdot 10^4$	5.24	$3.342 \cdot 10^{-2}$	$3.386 \cdot 10^4$	33.86	$3.386 \cdot 10^{-2}$	1	70.731	0.49115
1 lb · (sq ft)$^{-1}$	0.3591	$3.591 \cdot 10^2$	3.704×10^2	$4.725 \cdot 10^{-4}$	478.756	0.4787	$4.787 \cdot 10^{-4}$	$1.4138 \cdot 10^{-2}$	1	$6.9445 \cdot 10^{-3}$
1 lb · (sq in.)$^{-1}$ = 1 psi	51.71	$5.171 \cdot 10^4$	2.57	$6.804 \cdot 10^{-2}$	$6.894 \cdot 10^4$	68.94	$6.894 \cdot 10^{-2}$	2.0358	143.997	1

Table C-5 Conversion Factors for Units of Measurement Used in Vacuum Engineering

Unit	Symbol	Conversion Factor	Unit	Symbol	Conversion Factor
1 mil	mil	0.00254 cm	1 centimetre	1 cm	393.7 mil
1 inch	in	2.54 cm	1 centimetre	1 cm	0.3937 in
1 foot	ft	30.48 cm	1 centimetre	1 cm	0.0328 ft
1 yard	yd	0.914 m	1 metre	1 m	1.094 yd
1 square inch	sq in	6.452 cm^2	1 square centimetre	1 cm^2	0.155 sq in
1 square foot	sq ft	929.0 cm^2	1 square metre	1 m^2	10.76 sq ft
1 square yard	sq yd	0.836 m^2	1 square metre	1 m^2	1.196 sq yd
1 cubic inch	cu in	16.39 cm^3	1 cubic centimetre	1 cm^3	0.061 cu in
1 US gallon	gal	3.785	1 litre	1 l	0.264 US gal
1 British gallon	gal	4.546	1 litre	1 l	0.2201 Brit. gal
1 cubic foot	cu ft	28.32	1 litre	1 l	0.035 cu ft
1 cubic yard	cu yd	0.765 m^3	1 cubic metre	1 m^3	1.308 cu yd
1 pound	lb	0.4536 kg	1 kilogram	1 kg	2.205 lb
1 short ton (USA)	sh tn	907.2 kg	1 ton	1 t	1.1023 sh tn (USA)
1 long ton (Brit)	l tn	1016.05 kg	1 ton	1 t	0.9841 l tn (Brit)
1 pound/square inch	psi	0.0007 kg mm^2	1 kilogram/square millimetre	1 kg mm^2	1423.0 psi
1 short ton/ square inch (USA)	sh tn $(sq\ in)^1$	1.406 kg mm^2	1 kilogram/square millimetre	1 kg mm^2	0.711 sh tn·$(sq\ in)^1$ (USA)
1 long ton/square inch (Brit)	l tn $(sq\ in)^1$	1.575 kg mm^{-2}	1 kilogram/square millimetre	1 kg mm^2	0.635 l tn·$(sq\ in)^1$ (Brit)
1 micron·cubic foot	" cu ft	0.0283 Torr· l	1 Torr·litre	1 Torr·l	35.31 micron· cu ft
1 micron litre	" l	10^3 Torr· l	1 Torr · litre	1 Torr · l	10^3 micron · l
1 Torr ·litre	Torr l	1.316 atm cm^3	1 atmosphere · cubic centimetre	1 atm · cm^3	0.759 Torr · l

Conversion is effected by multiplying with the factor shown in the table.

Table C-6 Physical Properties of Metals[1]

Metal	Symbol	Density at 20°C $[g \cdot cm^3]$	Melting point [°C]	Boiling point at 760 Torr [°C]	Heat of fusion $[cal \cdot g^{-1}]$	Specific heat at 20°C $[cal \cdot g^{-1} \cdot °C^{-1}]$	Thermal conductivity at 20°C $[cal \cdot s^{-1} \cdot cm^{-1} \cdot °C^{-1}]$	Linear coefficient of expansion at 20°C $[10^{-5} \cdot °C^{-1}]$	Specific electrical resistance $[10^{-6} \cdot \Omega \cdot cm]$	
Aluminum	Al	2.70	659	2447	96	0.214	0.503	2.38	2.66	(20°)
Antimony	Sb	6.68	630	1637	38.9	0.0503	0.045	1.08	39	(0°)
Arsenic	As	5.73	817 (36atm)	613	88.5 subl.	0.078	—	0.47	33.3	(20°)
Barium	Ba	3.5	710	1637	13.2	0.068	—	1.9	36	
Beryllium	Be	1.85	1283	2477	250 to 270	0.425	0.38	1.23	4.2	(20°)
Bismuth	Bi	9.80	271	1559	12.5	0.0294	0.02	1.34	106.8	(0°)
Boron amorph.	B	2.34	2027	3927	489	0.307	—	0.83 (20 to 750°)	$0.65 \cdot 10^{12}$	(20°)
Cadmium	Cd	8.64	321	765	12.9	0.055	0.22	3.18	6.83	(0°)
Caesium	Cs	1.87	28.5	705	3.77	0.052	0.044	9.7	36.6	(30°)
Calcium	Ca	1.55	850	1492	55.7	0.149	0.3	2.20	4.6	(20°)
Cerium	Ce	6.7	804	3467	15	0.049	0.026	0.85	75	(25°)
Chromium	Cr	7.2	1903	2665	61.5	0.068	0.16	0.62	12.8	(20°)
Cobolt	Co	8.9	1495	2877	62	0.102	0.165	1.42	5.68	(0°)
Copper	Cu	8.92	1084	2578	48.9	0.092	0.934	1.66	1.692	(20°)
Dysprosium	Dy	8.54	1407	2600	25.2	0.0413(0°)	0.024	0.86 (25°)	91	(25°)
Erbium	Er	9.05	1497	2900	24.5	0.0398(0°)	0.023	0.92 (25°)	86	(25°)
Europium	Eu	5.26	826	1439	15.15	0.0395(0°)	—	3.2 (50°)	81.0	(25°)
Gadolinium	Gd	7.89	1312	3000	23.6	0.0713(0°)	0.021	0.64 (25°)	134.0	(25°)
Gallium	Ga	5.91	29.75	1983	19.16	0.079	0.08 (30°)	1.8	56.8	(20°)
Germanium	Ge	5.35	937	2827	111.5	0.073	—	0.6	$60 \cdot 10^6$	(25°)
Gold	Au	19.3	1063	2709	14.96	0.031	0.71	1.43	2.44	(20°)
Hafnium	Hf	13.3	2222	(5227)	29.1	0.035	0.0533 (50°)	0.59 (0 to 1000°)	35.5	(20°)
Holmium	Ho	8.80	1461	2600	24.8	0.0391(0°)	—	0.95 (400°)	94	(25°)
Indium	In	7.3	156	2091	6.8	0.058	0.06	2.48	8.8	(22°)
Iridium	Ir	22.42	2454	(4127)	32.6	0.032	0.35	0.65	5.3	(0°)
Iron	Fe	7.86	1539	2857	66.2	0.107	0.175	1.17	10.7	(20°)
Lanthanum	La	6.15	920	3367	18	0.048	0.033	0.49 (25°)	57	(25°)
Lead	Pb	11.34	328	1751	5.7	0.0309	0.0827	2.91	22	(20°)
Lithium	Li	0.53	181	1331	158	0.79	0.17	5.6	8.55	(0°)
Magnesium	Mg	1.74	650	1104	82.2	0.25	0.376	2.58	4.46	(20°)
Manganese	Mn	7.44	1314	2051	63.7	0.115	—	2.2	185	(20°)
Mercury	Hg	13.55	-39	357	2.8	0.033	0.020	—	95.78	(20°)
Molybdenum	Mo	10.2	2610	4827	69	0.061	0.32	0.544	5.78	(27°)
Neodymium	Nd	7.0	1024	3027	18.0	0.0499(0°)	0.031	0.67 (25°)	64	(25°)
Nickel	Ni	8.9	1452	2839	73.0	0.105	0.22	1.33	7.8	(20°)
Niobium	Nb	8.55	2497	4927	68.5	0.064	0.125 (0°)	0.75	14.6	(20°)
Osmium	Os	22.48	(2700)	(4227)	35.0	0.039	—	0.46 (50°)	9.5	(0°)
Palladium	Pd	11.97	1550	3127	36.0	0.058	0.17	1.18	10.3	(20°)
Platinum	Pt	21.45	1770	3827	24.1	0.032	0.17	0.89	10.58	(20°)
Plutonium	Pu	19.81	640	3235	3	0.034	0.020 (25°)	5.5	146.45	(0°)
Potassium	K	0.86	63	766	14.6	0.177	0.232	8.3	6.1	(0°)
Praseodymium	Pr	6.78	935	3127	17	0.0458(0°)	0.028	0.48 (25°)	68	(25°)
Rhenium	Re	21.02	3180	5627	43	0.033	0.17	0.66	19.14	(0°)
Rhodium	Rh	12.44	1966	(3727)	50.5	0.059	0.36	0.85	4.7	(0°)
Rubidium	Rb	1.53	39	701	6.1	0.080	0.07 (39°)	9.0	11.6	(0°)
Ruthenium	Ru	12.4	2427	(3727)	60.3	0.057	—	0.91	7.16	(0°)
Samarium	Sm	7.54	1072	1900	17.3	0.0431	—	0.7 (25°)	92	(25°)
Scandium	Sc	2.99	1397	2897	85.3	0.1332	—	1.2 (25 to 100°)	66	(25°)
Selenium	Se	4.79	217	685	16.5	0.081	0.0007 to 0.001	3.7	12	(0°)
Silicon	Si	2.33	1415	2787	395	0.162	0.20	0.468	$1 \cdot 10^5$	(0°)
Silver	Ag	10.5	961	2162	25	0.056	1.0	2.06	1.59	(20°)
Sodium	Na	0.97	98	890	27.5	0.295	0.327	7.20	4.3	(0°)
Strontium	Sr	2.6	770	1367	25	0.176	—	2.3	23	(20°)
Tantalum	Ta	16.6	2997	5427	41.5	0.036	0.130	0.66	13.6	(25°)
Tellurium	Te	6.25	450	987	32	0.047	0.014	1.68	$52.7 \cdot 10^3$	(25°)
Terbium	Tb	8.27	1356	2800	24.5	0.041 (0°)	—	0.7 (25°)	116	(25°)
Thallium	Tl	11.85	304	1467	5.04	0.031	0.093	2.8	18	(0°)
Thorium	Th	11.66	1695	3667	19.8	0.028	0.09 (200°)	1.25	18	(25°)
Thulium	Tm	9.33	1545	1727	26	0.0381	—	1.16 (400°)	90	(25°)
Tin	Sn	7.28	232	2679	14.5	0.0542	0.16	2.3	11.5	(20°)
Titanium	Ti	4.5	1690	3286	104.5	0.137	0.0411	0.84	42	(20°)
Tungsten	W	19.3	3380	5527	46	0.032	0.40	0.44	5.5	(20°)

Metal	Symbol	Density at 20°C [g·cm³]	Melting point [°C]	Boiling point at 760 Torr [°C]	Heat of fusion [cal·g⁻¹]	Specific heat at 20°C [cal·g⁻¹·°C⁻¹]	Thermal conductivity at 20°C [cal·s⁻¹·cm⁻¹·°C⁻¹]	Linear coefficient of expansion at 20°C [10⁻⁵·°C⁻¹]	Specific electrical resistance [10⁻⁶·Ω·cm]	
Uranium	U	19.07	1130	3927	19.75	0.028	0.060	a_0+3,61 b_0-0,87 c_0-3,13	30	(25°)
Vanadium	V	6.11	1857	3377	82.5	0.127	0.07	0.83	24.8	(20°)
Ytterbium	Yb	6.98	824	1427	12.71	0.0347 (0°)	—	2.5 (25°)	28	(25°)
Yttrium	Y	4.47	1490	3107	46	0.074 (50°)	0.024	1.08	65	(25°)
Zinc	Zn	7.14	420	906	24.4	0.0925	0.27	2.97	5.75	(0°)
Zirconium	Zr	6.45	1852	4415	60.3	0.0659	0.057	0.5	44	(20°)

1) Compiled from:
Hampel, C.A.: Rare Metals Handbook, Reinhold Publishing Corporation Chapmann & Hall Ltd., London 1961.
Honig, R.E.: RCA-Review (June 1957) p. 195/204. (Vapour pressure of elements).
Stull and Sinke, Thermodynamic Properties of the Elements, Amer. Chem. Soc., Washington, DC (1956) and
Hodgman, D.: Handbook of Chemistry and Physics, Chemical Rubber Publishing Company, Cleveland, Ohio, 1959.

Appendix D Vacuum Symbols

This Appendix is not a part of the requirements of this NFPA document, but is included for information purposes only.

Reprinted from

The Journal of Vacuum Science and Technology

AVS Standard (tentative)

AVS 7.1 — 1966

Graphic Symbols in Vacuum Technology

Introduction

Purpose. The purpose of this standard is to establish a uniform system of graphic symbols in vacuum technology.

Definition and Application. The graphic symbols are a shorthand used to show graphically the functioning and interconnections of vacuum components in a single-line schematic or flow diagram.

A single-line diagram is one in which the graphic symbols are shown without regard to the actual physical location, size, or shape of the components.

A symbol shall be considered as the aggregate of all its parts.

The orientation of a symbol on a drawing, including a mirror image presentation, does not alter the meaning of the symbol.

A symbol may be drawn to any scale that suits a particular drawing.

Arrows should be omitted unless necessary for clarification.

Explanation. The graphic symbols are divided into two separate sections, general and specific symbols.

Wherever possible, the general symbol illustrates the function or appearance of a component without regard to special features.

The special symbols elaborate upon the general component categories with individual symbols that illustrate in detail the special features of the component. Wherever possible, the special symbol utilizes the general symbol outline.

For definitions of the terms used in the description column, see American Vacuum Society, *Glossary of Terms used in Vacuum Technology* (Pergamon Press, New York, 1958).