86D

NFPA 86D
Standard for Industrial Furnaces Using Vacuum as an Atmosphere
1995 Edition

NFPA

National Fire Protection Association, 1 Batterymarch Park, PO Box 9101, Quincy, MA 02269-9101
An International Standards-Making Organization

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Policy Adopted by NFPA Board of Directors on December 3, 1982

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

1995 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 22-25, 1995, in Denver, CO. It was issued by the Standards Council on July 21, 1995, with an effective date of August 11, 1995, and supersedes all previous editions.

This edition of NFPA 86D was approved as an American National Standard on August 11, 1995.

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.

The 1990 edition was a complete revision, incorporating a variety of technical and editorial changes. This included a new Appendix A and consolidated appendix information in accordance with the NFPA *Manual of Style.*

This edition of NFPA 86D provides correlation with NFPA 86, *Standard for Ovens and Furnaces,* and NFPA 86C, *Standard for Industrial Furnaces Using a Special Processing Atmosphere.* It also refines and updates this standard to current technologies, provides increased requirements in several areas, and expands the explanatory material in the appendices.

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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.

Committee Scope: This Committee shall have primary responsibility for documents on control of fire and explosion hazards in drying ovens for japan, enamel, and other finishes, bakery ovens, core ovens, annealing and heat treating furnaces, and other special atmosphere furnaces, including equipment for other special atmospheres.

NFPA 86D-1995
Standard for Industrial Furnaces Using Vacuum as an Atmosphere
Reference: 5-3.3.1
Errata: 86D-95-01

1. In the last sentence of the Exception in 5-3.3.1, change the reference from "5-3.3.1" *to* "5-3.3.3."

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Standard for

Industrial Furnaces Using Vacuum as an Atmosphere

1995 Edition

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 13 and Appendix G.

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 the 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; hazardous materials; noise levels; heat stress; and local, state, and federal regulations (EPA and OSHA).

Causes of practically all failures can be traced to human error. The most significant failures are:

(a) Inadequate training of operators;

(b) Lack of proper maintenance;

(c) Improper application of equipment.

Users and designers must utilize engineering skill to bring together that proper combination of controls and training necessary for the safe operation of the equipment. This standard classifies furnaces as follows:

Class A ovens and furnaces are heat utilization equipment operating at approximately atmospheric pressure wherein there is a potential explosion or fire hazard that could be occasioned by the presence of flammable volatiles or combustible materials processed or heated in the furnace.

Such flammable volatiles or combustible materials can, for instance, originate from the following:

(a) Paints, powders, inks, and adhesives from finishing processes, such as dipped, coated, sprayed, and impregnated materials;

(b) The substrate material;

(c) Wood, paper, and plastic pallets, spacers, or packaging materials; or

(d) Polymerization or other molecular rearrangements.

Potentially flammable materials, such as quench oil, water-borne finishes, cooling oil, or cooking oils, that present a hazard are ventilated according to Class A standards.

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

Class C ovens and 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 can use any type of heating system and includes a special atmosphere supply system(s). Also included in the Class C classification are integral quench furnaces and molten salt bath furnaces.

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

Chapter 1 General

1-1 Scope.

1-1.1 This standard shall apply to ovens and furnaces operating above ambient temperatures to over 5000°F (2760°C) and at pressures normally below atmospheric to 10^{-8} torr (1.33×10^{-6} Pa).

1-1.2* Types of Furnaces. The user's requirements for vacuum processing determine the type of furnace walls, the size of the 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 can be other special types.

NOTE: For more detailed information on the various types of furnaces, reference should be made to Table A-1-1.2. This table describes the heating system requirement and notes the principal items supplied as a part of the furnace that include the following:

(a) Vacuum system;

(b) Heating system;

(c) Cooling system;

(d) Process atmosphere cycle;

(e) Material handling;

(f) Instrument controls;

(g) Hazards of heating systems; and

(h) Personnel safety hazards.

All of these items are included in the table for each of the ten principal furnace types.

1-1.2.1* The cold-wall furnace types are further described as furnaces that are 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*.

1-1.2.2* The hot-wall furnace can be either a fuel-fired or an electrically heated furnace. Fuel-fired burner controls and safeguards shall be provided as indicated in NFPA 86C, *Standard for Industrial Furnaces Using a Special Processing Atmosphere*.

1-1.2.3* 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.

1-1.3 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 requirements of ASME *Boiler and Pressure Vessel Code*, Section VIII. (*See 3-2.14 and 3-2.15.*)

1-1.4 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.

NOTE: High-voltage supply used for electron beam, plasma arc, or ion discharge furnace units might have unique safety considerations.

1-1.5 Cooling System. Cold-wall vacuum furnaces shall be specifically designed to maintain the vacuum furnace vessel at proper temperatures. The furnace vessel walls shall be maintained at safe temperatures when the furnace operates at maximum temperatures.

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

1-2 Purpose. Since the heat processing of materials can involve a serious fire and explosion hazard, endangering the furnace and the building in which the process is located and possibly the lives of employees, adequate safeguards shall be provided as appropriate for the location, equipment, and operation of such furnaces.

1-3 Application.

1-3.1 This entire standard shall apply to new installations or alterations or extensions to existing equipment.

Exception: Section 1-5 and Chapter 11 shall apply to all operating equipment.

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.

1-3.2 Section 1-5 and Chapter 11 shall apply to all operating furnaces.

1-3.3 No standard can guarantee the elimination of furnace fires and explosions. Technology in this area is under constant development, which is reflected in fuel, special processing atmospheres, flammable vapors, and quench systems, with regard to the type of equipment and the characteristics of the various fluids. Therefore, the designer is cautioned that the standard is not a design handbook. The standard does not eliminate the need for the engineer or for competent engineering judgment. It is intended that a designer capable of applying more complete and rigorous analysis to special or unusual problems shall have latitude in the development of furnace designs. In such cases, the designer shall be responsible for demonstrating and documenting the safety and validity of the design.

1-4* Approvals, Plans, and Specifications.

1-4.1 Before new equipment is installed or existing equipment remodeled, complete plans, sequence of operations, and specifications shall be submitted for approval to the authority having jurisdiction.

1-4.1.1 Plans shall be drawn and shall show all essential details with regard to location, construction, ventilation, piping, and electrical safety equipment. A list of all combustion, control, and safety equipment giving manufacturer and type number shall be included.

1-4.1.2 Wiring diagrams and sequence of operations for all safety controls shall be provided. Ladder-type schematic diagrams are recommended.

1-4.2 Any deviation from this standard shall require special permission from the authority having jurisdiction.

1-4.3 Electrical. All wiring shall be in accordance with NFPA 70, *National Electrical Code®*, NFPA 79, *Electrical Standard for Industrial Machinery*, and as described hereafter.

NOTE 1: NFPA 70, *National Electrical Code*, is a reference source for safe practices and wiring methods. Where it is considered that variation from the required wiring methods as currently specified in the NFPA 70 is necessary to provide greater safety of the installation, such variations should be required to meet with the approval of all authorities having jurisdiction and should be required to be the sole responsibility of the parties initiating such variation.

NOTE 2: NFPA 497A, *Recommended Practice for Classification of Class I Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas*, 2-6.4, is referenced with regard to certain equipment with open flames and hot surfaces. NFPA 497A permits exceptions to general rules in NFPA 70, *National Electrical Code*, Article 500, that otherwise would dictate the use of explosionproof or intrinsically safe electrical apparatus where flammable materials (such as atmospheres) are used. Normally, ovens or furnaces are unclassified internally because safety depends upon ventilation and not upon the elimination of sources of ignition.

1-5 Operator and Maintenance Personnel Training.

1-5.1 The selection of alert and competent personnel shall be required.

NOTE: It is recognized that the knowledge and training of personnel is vital to safe furnace operation and maintenance.

1-5.2 All operating, maintenance, and appropriate supervisory personnel shall be thoroughly instructed and trained under the direction of a qualified person(s) and shall be required to demonstrate understanding of the equipment and its operation to ensure knowledge of and practice of safe operating procedures.

1-5.3 All operating, maintenance, and appropriate supervisory personnel shall receive regularly scheduled retraining and testing to maintain a high level of proficiency and effectiveness.

1-5.4 Personnel shall have access to operating instructions at all times.

1-5.5 Operator training shall include, where applicable:

(a) Combustion of fuel-air mixtures;

(b) Explosion hazards;

(c) Sources of ignition, including autoignition (e.g., by incandescent surfaces);

(d) Functions of control and safety devices;

(e) Handling of special atmospheres;

(f) Handling of low-oxygen atmospheres;

(g) Handling and processing of hazardous materials;

(h) Confined space entry procedures;

(i) Vacuum technology; and

(j) Operating instructions. (*See 1-5.6.*)

1-5.6 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, inert gas, or other essential utilities; and

(e) Maintenance procedures.

1-6 Equipment Maintenance. All equipment shall be maintained in accordance with the manufacturer's instructions.

1-7 Safety Labeling.

1-7.1 A suitable, clearly worded, and prominently displayed safety design data form or manufacturer's nameplate shall be provided stating the safe operating conditions for which the furnace system was designed, built, altered, or extended.

1-7.2 A warning label shall be provided by the manufacturer stating that the equipment shall be operated and maintained according to instructions. This label shall be permanently affixed to the furnace.

Chapter 2 Definitions

2-1 Definitions. The following definitions shall apply to NFPA 86, *Standard for Ovens and Furnaces;* NFPA 86C, *Standard for Industrial Furnaces Using a Special Processing Atmosphere;* and NFPA 86D, *Standard for Industrial Furnaces Using Vacuum as an Atmosphere*:

Absorbent. A material that, when it comes into contact with a liquid or gas, extracts one or more substances for which it has an affinity and is altered physically or chemically during the process.

Absorption. The taking up of matter in bulk by other matter, as in the dissolving of a gas by a liquid.

Adsorbate. A solid, liquid, or gas that is adsorbed as molecules, atoms, or ions by such substances as charcoal, silica, metals, water, and mercury.

Adsorbent. A solid or liquid that adsorbs other substances; for example, charcoal, silica, metals, water, and mercury.

Adsorption. The surface retention of solid, liquid, or gas molecules, atoms, or ions by a solid or liquid.

Afterburner. See "Incinerator, Fume."

Air.

Combustion. All the air introduced with fuel to supply heat in a furnace.

Primary. All air supplied through the burner.

Reaction. All the air that, when reacted with gas in an endothermic generator by the indirect addition of heat, becomes a special atmosphere gas.

Secondary. All the combustion air that is intentionally allowed to enter the combustion chamber in excess of primary air.

Air Makeup Unit, Direct Fired. A Class B fuel-fired heat utilization unit operating at approximately atmospheric pressure used to heat outside replacement air for the process or building.

Air System.

High Pressure. A system using air pressure of 5 psig (34 kPa) or higher.

Low Pressure. A system using air pressure of less than 5 psig (34 kPa).

Analyzer, Gas. A device that measures concentrations, directly or indirectly, of some or all components in a gas or mixture.

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, 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 that is in a position to determine compliance with appropriate standards for the current production of listed items.

Aspirator, Proportioning. See "Mixer, Air Jet."

Authority Having Jurisdiction. 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, or 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 or her 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.

Backfire Arrester (Preventer). A flame arrester installed in fully premixed air-fuel gas distribution piping to terminate flame propagation therein, shut off fuel supply, and relieve pressure resulting from a backfire.

Bath, Molten Salt. See "Furnace, Molten Salt Bath."

Blower, Roots. A compressor in which a pair of hourglass-shaped members rotate within a casing to deliver large volumes of gas at a relatively low pressure increase. (*See "Pump, Rotary Blower."*)

Burn-In. The procedure used in starting up a special atmosphere furnace to replace air within the heating chamber(s) and vestibule(s) with flammable special atmosphere.

Burn-Out. The procedure used in shutting down or idling a special atmosphere to replace flammable atmosphere within the heating chamber(s) and vestibule(s) with a nonflammable atmosphere.

Burner. A device or group of devices used for the introduction of fuel, air, oxygen, or oxygen-enriched air into a furnace at the required velocities, turbulence, and concentration to maintain ignition and combustion of fuel.

Atomizing. A burner in which oil is divided into a fine spray by an atomizing agent, such as steam or air.

Atmospheric. A burner used in the low-pressure fuel gas or atmospheric system that requires secondary air for complete combustion.

Blast. A burner delivering a combustible mixture under pressure, normally above 0.3 in. w.c. (75 kPa), to the combustion zone.

Combination Fuel Gas and Oil. A burner that can burn either fuel gas or oil, or both simultaneously.

Dual-Fuel. A burner designed to burn either fuel gas or oil, but not both simultaneously.

Line. A burner whose flame is a continuous "line."

Multiple Port. A burner having two or more separate discharge openings or ports.

Nozzle Mixing. A burner in which the fuel and air are introduced separately to the point of ignition.

Premix. A burner in which the fuel and air are mixed prior to the point of ignition.

Pressure Atomizing. A burner in which oil under high pressure is forced through small orifices to emit liquid fuel in a finely divided state.

Radiant. A burner designed to transfer a significant part of the combustion heat in the form of radiation.

Radiant Tube. A burner designed to provide a long flame within a tube to ensure substantially uniform radiation from the tube surface.

Rotary Atomizing. A burner in which oil is atomized by applied centrifugal force, such as by a whirling cone or plate.

Self-Piloted. A burner in which the pilot fuel is issued from the same ports as the main flame or merges with the main flame to form a common flame envelope with a common flame base.

Burner System. One or more burners operated as a unit.

Check, Safe-Start. A checking circuit incorporated in a safety-control circuit that prevents light-off if the flame-sensing relay of the combustion safeguard is in the unsafe (flame-present) position due to component failure within the combustion safeguard or due to the presence of actual or simulated flame.

Cock, Supervising. A special approved cock incorporating in its design a means for positive interlocking with a main fuel safety shutoff valve so that, before the main fuel safety shutoff valve can be opened, all individual burner supervising cocks must be in the fully closed position.

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

Combustion Safety Circuitry. That portion of the oven control circuitry that contains the contacts for the required safety interlocks and the excess temperature limit controller(s). These contacts are arranged in series ahead of the safety shutoff valve(s') holding medium.

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

Controller.

Continuous Vapor Concentration. A device that measures, indicates, and directly or indirectly controls the concentration of a flammable vapor-air mixture in percentage of the lower explosive limit (LEL).

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

Programmable. A digital 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 to control, through digital or analog inputs and outputs, various types of machines or processes.

Temperature. A device that measures the temperature and automatically controls the input of heat into the furnace.

Cryogenic Fluid. A fluid produced or stored at very low temperatures. In the context of this standard, cryogenic fluid generally refers to gases made at low temperatures and stored at the user site in an insulated tank for use as an atmosphere or atmosphere constituent (e.g., nitrogen, argon, carbon dioxide, hydrogen, oxygen).

Damper, Cut-Away. A restricting airflow device that, when placed in the maximum closed position, allows a minimum amount of airflow past the restriction. Cut-away dampers normally are placed in the exhaust or fresh air intake ducts to ensure that the required minimum amount of exhaust or fresh air is handled by the ventilating fans.

Displacement. The volume swept out in one stroke by a piston moving in a cylinder, as in the case of an engine, pump, or compressor.

Fire Check, Automatic. A flame arrester equipped with a check valve to shut off the fuel gas supply automatically if a backfire occurs.

Flame Arrester. A device installed in the small branch piping of a fully premixed air-fuel gas mixture to retard a flame front originating from a backfire.

Flame Propagation Rate. The speed at which a flame progresses through a combustible fuel-air mixture. This rate is a function of the temperature and the mixture conditions existing in the combustion space, burner, or piping under consideration.

Flame Rod. A detector that employs an electrically insulated rod of temperature-resistant material that extends into the flame being supervised, with a voltage impressed between the rod and a ground connected to the nozzle or burner. The resulting electrical current, which passes through the flame, is rectified, and this rectified current is detected and amplified by the combustion safeguard.

Flame, Supervised. A flame whose presence or absence is detected by a flame sensor connected to a combustion safeguard.

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

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

Fuel Gas. Gas used for heating, such as natural gas, manufactured gas, undiluted liquefied petroleum gas (vapor phase only), liquefied petroleum gas-air mixtures, or mixtures of these gases.

Fuel Gas System.

High Pressure. A system using the kinetic energy of a jet of 1 psig (7 kPa) or higher gas pressure to entrain from the atmosphere all, or nearly all, the air required for combustion.

Low Pressure or Atmospheric. A system using the kinetic energy of a jet of less than 1 psig (7 kPa) gas pressure to entrain from the atmosphere a portion of the air required for combustion.

Fuel Oil. Grades 2, 4, 5, or 6 fuel oils as defined in ASTM D396, *Standard Specifications for Fuel Oils.*

Furnace.

Atmosphere. A furnace built to allow heat processing of materials in a special processing atmosphere.

Batch. A furnace into which the work charge is introduced all at once.

Class A. An oven or furnace that has heat utilization equipment operating at approximately atmospheric pressure wherein there is a potential explosion or fire hazard that could be occasioned by the presence of flammable volatiles or combustible materials processed or heated in the furnace.

NOTE: Such flammable volatiles or combustible materials can, for instance, originate from the following:

(a) Paints, powders, inks, and adhesives from finishing processes, such as dipped, coated, sprayed, and impregnated materials;

(b) The substrate material;

(c) Wood, paper, and plastic pallets, spacers, or packaging materials; or

(d) Polymerization or other molecular rearrangements.

Potentially flammable materials, such as quench oil, water-borne finishes, cooling oil, or cooking oils, that present a hazard are ventilated according to Class A standards.

Class B. An oven or furnace that has heat utilization equipment operating at approximately atmospheric pressure wherein there are no flammable volatiles or combustible materials being heated.

Class C. An oven or furnace that has a potential hazard due to a flammable or other special atmosphere being used for treatment of material in process. This type of furnace can use any type of heating system and includes a special atmosphere supply system(s). Also included in the Class C classification are integral quench furnaces and molten salt bath furnaces.

Class D. An oven or furnace that operates at temperatures above ambient to over 5000°F (2760°C) and at pressures normally below atmospheric using any type of heating system. These furnaces can include the use of special processing atmospheres.

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

Molten Salt Bath. A furnace that employs salts heated to a molten state. These do not include aqueous alkaline baths, hot brine, or other systems utilizing salts in solution.

Plasma Arc. A furnace that employs the passage of an electric current between either a pair of electrodes or between electrodes and the work, and ionizing a gas (such as argon) and transferring energy in the form of heat.

Gas, Ballast. Atmospheric air or a "dry" gas that is admitted into the compression chamber of rotary mechanical pumps to prevent condensation of vapors in the pump oil by maintaining the partial pressure of the condensable vapors below the saturation value (also called "vented exhaust").

Gas, Inert. See "Special Atmosphere, Inert (Purge Gas)."

Gas, Reaction. A gas that, when reacted with air in an endothermic generator by the addition of heat, becomes a special atmosphere gas.

Gauge, Vacuum. A device that indicates the absolute gas pressure in a vacuum system.

Guarded. Covered, shielded, fenced, enclosed, or otherwise protected by such means as suitable covers or casings, barriers, rails or screens, mats, or platforms.

Heater.

Dielectric. A heater similar to an induction heater, but using frequencies that generally are higher (3 MHz or more) than those used in induction heating. This type of heater is useful for heating materials that commonly are thought to be nonconductive. Examples of uses include heating plastic preforms before molding, curing glue in plywood, drying rayon cakes, and other similar applications.

Direct-Fired External. A heating system in which the burners are in a combustion chamber effectively separated from the work chamber and arranged so that products of combustion from the burners are discharged into the work chamber by a circulating fan or blower.

Direct-Fired Internal. A heating system in which the burners are located within the work chamber.

Heating System.

*Direct-Fired.** A heating system in which the products of combustion enter the work chamber.

Indirect-Fired. A heating system in which the products of combustion do not enter the work chamber.

Indirect-Fired Internal. A heating system of gastight radiators containing burners not in contact with the oven atmosphere. Radiators might be designed to withstand explosion pressures from ignition of air-fuel mixtures in the radiators.

Induction. A heating system by means of which a current-carrying conductor induces the transfer of electrical energy to the work by eddy currents. (*See NFPA 70, National Electrical Code, Article 665.*)

Radiant Tube. A heating system with tubular elements open at one or both ends. Each tube has an inlet burner arrangement where combustion is initiated, a suitable length where combustion occurs, and an outlet for the combustion products formed.

Resistance. A system in which heat is produced by current flow through a resistive conductor. Resistance heaters can be of the open type, with bare heating conductors, or insulated sheath type, with conductors covered by a protecting sheath that can be filled with electrical insulating material.

Tubular. A form of radiant heater in which resistive conductors are enclosed in glass, quartz, or ceramic envelopes that can contain a special gas atmosphere.

Ignition Systems, Burner.

Automatic-Ignited Burner. A burner ignited by direct electric ignition or by an electric-ignited pilot.

Direct Electric Ignition. Ignition of flame by an electric-ignition source, such as a high-voltage spark or hot wire, without the use of a separate pilot burner.

Manual-Ignited Burner. A burner ignited by a portable torch manually placed in proximity to the burner nozzle.

Semiautomatic-Ignited Burner. A burner ignited by direct electric ignition or by an electric-ignited pilot, where the electric ignition is manually activated.

Ignition Systems, Heating Equipment.

Automatic-Lighted Heating Equipment. A furnace in which fuel to the main burner(s) is turned on automatically and ignited automatically.

Manual-Lighted Heating Equipment. A furnace in which fuel to the main burner(s) can be turned on only by hand and is manually or semiautomatically ignited under the supervision of the operator.

Semiautomatic-Lighted Heating Equipment. The same as automatic-lighted heating equipment except that, on each light-off, fuel to the main burner(s) can be turned on only by hand and is manually or semiautomatically ignited under the supervision of the operator.

Implosion. The rapid inward collapsing of the walls of a vacuum component or device as the result of failure of the walls to sustain the atmospheric pressure. This can be followed by an outward scattering of pieces of the wall if the wall material is not ductile, thus causing possible danger to nearby equipment and personnel.

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

Incinerator, Fume. Any separate or independent combustion equipment or device that entrains the process exhaust for the purpose of direct thermal or catalytic destruction, which can include heat recovery.

Insulation, Vacuum-Type. A highly reflective double-wall structure with high vacuum between the walls; used as insulation in cryogenic systems for the reduction of heat transfer.

Interlock.

Proved Low-Fire Start. A burner start interlock in which a control sequence ensures that a high-low or modulated burner is in the low-fire position before the burner can be ignited.

Safety. A device required to ensure safe start-up and safe operation and to cause safe equipment shutdown.

Labeled. Equipment or materials to which has been attached a label, symbol, or other identifying mark of an organization that is 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.

Limiting Oxidant Concentration (LOC). The concentration of oxidant below which a deflagration cannot occur. Materials other than oxygen can act as oxidants.

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.

LOC. See "Limiting Oxidant Concentration."

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

Mixer.

Air-Fuel Gas. A system that combines air and fuel gas in the proper proportion for combustion.

Air Jet. A mixer using the kinetic energy of a stream of air issuing from an orifice to entrain the fuel gas required for combustion. In some cases, this type of mixer can be designed to entrain some of the air for combustion as well as the fuel gas.

Gas Jet [Atmospheric Inspirator (Venturi) Mixer]. A mixer using the kinetic energy of a jet of fuel gas issuing from an orifice to entrain all or part of the air required for combustion.

Proportional. A mixer comprised of an inspirator that, when supplied with air, draws all the fuel gas necessary for combustion into the airstream, and a governor, zero regulator, or ratio valve that reduces incoming fuel gas pressure to approximately atmospheric.

Mixing Blower. A motor-driven blower to supply air-fuel gas mixtures for combustion through one or more fuel burners or nozzles on a single-zone industrial heating appliance or on each control zone of a multizone installation. Mixing machines operated at 10 in. w.c. (2.49 kPa) or less static pressure shall be considered mixing blowers.

Mixing Machine. A mixer using mechanical means to mix fuel and air and to compress the resultant mixture to a pressure suitable for delivery to its point of use. Mixers in this group utilize either a centrifugal fan or some other type of mechanical compressor with a proportioning device on its intake through which fuel and air are drawn by the fan or compressor suction.

Muffles. Enclosures within a furnace to separate the source of heat from the work and from any special atmosphere that might be required for the process.

Operator. An individual trained and responsible for the start-up, operation, shutdown, and emergency handling of the furnace and associated equipment.

Outgassing. The release of adsorbed or occluded gases or water vapor, usually by heating, such as from a vacuum tube or other vacuum system.

Oven. See "Furnace."

Oven, Low-Oxygen. An oven that utilizes a low-oxygen atmosphere to evaporate solvent to facilitate solvent recovery. These ovens normally operate at high solvent levels and can operate safely in this manner by limiting the oxygen concentration within the oven enclosure.

Pilot. A flame that is used to light the main burner.

Burn-off. A pilot that ignites the flame curtain or special processing atmosphere discharging from the furnace or generator.

Continuous. A pilot that burns throughout the entire period that the heating equipment is in service, whether or not the main burner is firing.

Expanding. A pilot that burns at a set turndown throughout the entire period that the heating equipment is in service, but burns without turndown during light-off of the main burner.

Intermittent. A pilot that burns during light-off and while the main burner is firing.

Interrupted. A pilot that is ignited and burns during light-off and is automatically shut off at the end of the trial-for-ignition period of the main burner(s).

Proved. A pilot flame supervised by a combustion safeguard that senses the presence of the pilot flame.

Pilot Flame Establishing Period. The interval of time during light-off that a safety-control circuit allows the pilot fuel safety shutoff valve to remain open before the combustion safeguard proves the presence of the pilot flame.

Pressure.

Partial. The pressure that is exerted by one component of a mixture of gases if it is present alone in a container.

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

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

Pump.

Diffusion. A vacuum pump in which a stream of heavy molecules, such as those of mercury or oil vapor, carries gas molecules out of the volume being evacuated.

Gas Ballast. A mechanical pump (usually of the rotary type) that uses oil to seal the clearances between the stationary and rotating compression members. The pump is equipped with an inlet valve through which a suitable quantity of atmospheric air or "dry" gas (ballast gas) can be admitted into the compression chamber to prevent condensation of vapors in the pump oil by maintaining the partial pressure of the condensable vapors in the oil below the saturation value (sometimes called a "vented-exhaust mechanical pump").

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

Rotary Blower. A pump without a discharge valve that moves gas by the propelling action of one or more rapidly rotating members provided with lobes, blades, or vanes, such as a roots blower. It is sometimes called a "mechanical booster pump" where used in series with a mechanical backing (fore) pump.

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

Roughing. The pump used to reduce the system pressure to the level at which a diffusion or other vacuum pump can operate.

NOTE: The roughing pump also can be used as the backing (fore) pump for the diffusion pump, or the roughing pump can be shut off and a smaller pump can be used as the backing (fore) pump where the gas load is relatively small.

Vacuum. A compressor for exhausting air and noncondensable gases from a space that is to be maintained at subatmospheric pressure.

Pump-Down Factor. The product of the time to pump down to a given pressure and the displacement (for a service factor of 1) divided by the volume of the system ($F = t\ D/V$).

Purge. The replacement of a flammable, indeterminate, or high-oxygen-bearing atmosphere with another gas that, when complete, results in a nonflammable final state.

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

Regulator, Pressure. A device that maintains a constant outlet pressure under varying flow.

Roughing Line. A line running from a mechanical pump to a vacuum chamber through which preliminary pumping is conducted to a vacuum range at which a diffusion pump or other high vacuum pump can operate.

Safeguard, Combustion. A safety control directly responsive to flame properties; it senses the presence or absence of flame and de-energizes the fuel safety valve in the event of flame failure within 4 seconds of the loss of flame signal.

Safety Device. An instrument, control, or other equipment that acts, or initiates action, to cause the furnace to revert to a safe condition in the event of equipment failure or other hazardous event. Safety devices are redundant controls, supplementing controls utilized in the normal operation of a furnace system. Safety devices act automatically, either alone or in conjunction with operating controls, when conditions stray outside of design operating ranges and endanger equipment or personnel.

Separator, Oil. An oil reservoir with baffles used to minimize the discharge of oil mist from the exhaust of a rotary mechanical vacuum pump.

Shall. Indicates a mandatory requirement.

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

Special Atmosphere. Prepared gas or gas mixtures that are introduced into the work chamber of a furnace to replace air, generally to protect or intentionally change the surface of the material undergoing heat processing (heat treatment).

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 so that, if the flow of this component gas or liquid ceases, the total flow of the special atmosphere in the furnace is not sufficient to maintain a positive pressure in that furnace.

Flammable. Gases that are known to be flammable and predictably ignitible where mixed with air.

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

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

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

Standard. A document that contains only mandatory provisions using the word "shall" to indicate requirements. Explanatory material may be included only in the form of fine-print notes, in footnotes, or in an appendix.

Switch.

Atomizing Medium Pressure. A pressure-activated device arranged to effect a safety shutdown or to prevent the burner system from being actuated in the event of inadequate atomizing medium pressure.

Combustion Air Pressure. A pressure-activated device arranged to effect a safety shutdown or to prevent the burner system from being actuated in the event the combustion air supplied to the burner or burners falls below that recommended by the burner manufacturer.

Differential Flow. A switch that is activated by the flow of a gaseous or liquid fluid. This flow is detected by measuring pressure at two different points to produce a pressure differential across the sensor.

Flow. A switch that is activated by the flow of a fluid in a duct or piping system.

High Fuel Pressure. A pressure-activated device arranged to effect a safety shutdown of the burner system in the event of abnormally high fuel pressure.

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

Low Fuel Pressure. A pressure-activated device arranged to effect a safety shutdown of the burner system in the event of abnormally low fuel pressure.

Rotational. A device that usually is driven directly by the fan wheel or fan motor shaft. When the speed of the fan shaft or drive motor reaches a certain predetermined rate to provide a safe minimum airflow, a switch contact closes.

Tank.

Integral Liquid or Salt Media Quench Type. A tank connected to the furnace so that the work is under a protective atmosphere from the time it leaves the heating zone until it enters the tank containing a combustible, noncombustible, or salt quench medium.

Open Liquid or Salt Media Quench Type. A tank in which work from the furnace is exposed to air before and upon entering the tank containing a combustible, noncombustible, or salt quench medium.

Temperature, Ignition. The lowest temperature at which a gas-air mixture can ignite and continue to burn. This also is referred to as the autoignition temperature.

NOTE: When burners supplied with a gas-air mixture in the flammable range are heated above the autoignition temperature, flashbacks can occur. In general, such temperatures range from 870°F to 1300°F (466°C to 704°C). A much higher temperature is needed to ignite gas dependably. The temperature necessary is slightly higher for natural gas than for manufactured gases, but for safety with manufactured gases, a temperature of about 1200°F (649°C) is needed, and, for natural gas, a temperature of about 1400°F (760°C) is needed.

Time.

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").

Roughing. The time required to pump a given system from atmospheric pressure to a pressure at which a diffusion pump or other high vacuum pump can operate.

Trial-for-Ignition Period (Flame-Establishing Period). The interval of time during light-off that a safety-control circuit allows the fuel safety shutoff valve to remain open before the combustion safeguard is required to supervise the flame.

Turndown, Burner. The ratio of maximum to minimum burner fuel-input rates.

Vacuum. A space in which the pressure is far below atmospheric pressure so that the remaining gases do not affect processes being carried out in the space.

High. A vacuum with a pressure between 1×10^{-3} torr and 1×10^{-5} torr (millimeters of mercury).

Low. A vacuum with a pressure between 760 torr and 1×10^{-3} torr (millimeters of mercury).

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 should be permitted to be considered as part of the vacuum system. A complete vacuum system contains all pumps, gauges, valves, and other components necessary to carry out a particular process.

Valve.

Air Inlet. A valve used for letting atmospheric air into a vacuum system. The valve also is called a vacuum breaker.

Safety Shutoff. A normally closed (closed when de-energized) valve installed in the piping that closes automatically to shut off the fuel or atmosphere gas in the event of abnormal conditions or during shutdown. The valve can be opened either manually or by a motor-operator, but only after the solenoid coil or other holding mechanism is energized.

Ventilated. A system provided with a method to allow circulation of air sufficient to remove an excess of heat, fumes, or vapors.

Ventilation, Proven. A sufficient supply of fresh air and proper exhaust to outdoors with a sufficiently vigorous and properly distributed air circulation to ensure that the flammable vapor concentration in all parts of the furnace or furnace enclosure is safely below the lower explosive limit at all times.

Zero Governor (also called "atmospheric regulator"). A diaphragm-type regulator that maintains the fuel gas pressure at atmospheric or zero gauge pressure.

Chapter 3 Location and Construction

3-1 Location.

3-1.1 General.

3-1.1.1 Furnaces and related equipment shall be located to protect personnel and buildings from fire or explosion hazards. Hazards to be considered include molten metal or other molten material spillage, quench tanks, hydraulic oil ignition, overheating of material in the furnace, and escape of fuel, processing atmospheres, or flue gases.

3-1.1.2 Furnaces shall be located to protect them from damage by external heat, vibration, and mechanical hazards.

3-1.1.3 Furnaces shall be located to make maximum use of natural ventilation, to minimize restrictions to adequate explosion relief, and to provide sufficient air supply for personnel.

3-1.1.4 Where furnaces are located in basements or enclosed areas, sufficient ventilation shall be supplied to provide required combustion air and to prevent the hazardous accumulation of vapors.

3-1.1.5 Furnaces designed for use with special atmospheres or fuel gas with a specific gravity greater than air shall be located at or above grade and shall be located to prevent the escape of the special atmosphere or fuel gas from accumulating in basements, pits, or other areas below the furnace.

3-1.2 Structural Members of the Building.

3-1.2.1 Furnaces shall be located and erected so that the building structural members are not affected adversely by the maximum anticipated temperatures (*see 3-1.4*) or by the additional loading caused by the furnace.

3-1.2.2 Structural building members shall not pass through or be enclosed within a furnace.

3-1.3 Location in Regard to Stock, Processes, and Personnel.

3-1.3.1 Furnaces shall be located to minimize exposure to power equipment, process equipment, and sprinkler risers. Unrelated stock and combustible materials shall be maintained at a fire-safe distance but not less than 2½ ft (0.76 m) from a furnace, a furnace heater, or ductwork.

3-1.3.2 Furnaces shall be located to minimize exposure to people from the possibility of injury from fire, explosion, asphyxiation, and hazardous materials and shall not obstruct personnel travel to exitways.

3-1.3.3 Furnaces shall be located to prevent an ignition source to flammable coating dip tanks, spray booths, storage and mixing rooms for flammable liquids, or exposure to flammable vapor or combustible dusts.

Exception: This requirement shall not apply to integral quench systems.

NOTE 1: The hazard is particularly severe where vapors from dipping operations could flow by means of gravity to ignition sources at or near floor level.

NOTE 2: See NFPA 30, *Flammable and Combustible Liquids Code*; NFPA 33, *Standard for Spray Application Using Flammable and Combustible Materials*; and NFPA 34, *Standard for Dipping and Coating Processes Using Flammable or Combustible Liquids*.

3-1.3.4 Equipment shall be protected from corrosive external processes and environments.

NOTE: Fumes or materials from adjacent processes or equipment that normally are not corrosive could produce corrosive conditions where introduced into the furnace environment. (*See NFPA 325, Guide to Fire Hazard Properties of Flammable Liquids, Gases, and Volatile Solids.*)

3-1.4 Floors and Clearances.

3-1.4.1 Furnaces shall be located with adequate space above and on all sides to allow inspection and maintenance. Provisions also shall be included for the installation of automatic sprinklers and the proper functioning of explosion vents, if applicable.

3-1.4.2* Furnaces shall be constructed and located to keep temperatures at combustible floors, ceilings, and walls below 160°F (71°C).

3-1.4.3 Where electrical wiring is present in the channels of certain types of floors, the wiring shall be installed in accordance with NFPA 70, *National Electrical Code*, Article 356.

3-1.4.4 Floors in the area of mechanical pumps, oil burners, or other equipment using oil shall be provided with a noncombustible, nonporous surface to prevent floors from becoming soaked with oil.

3-2 Furnace Design.

3-2.1 Furnaces and related equipment shall be designed to minimize the fire hazard inherent in equipment operating at elevated temperatures.

3-2.2 Furnace components exposed simultaneously to elevated temperature and air (oxygen) shall be constructed of noncombustible material.

3-2.3 Furnace structural supports and material handling equipment shall be designed with adequate factors of safety at the maximum operating conditions, including temperature. Furnaces shall withstand the strains imposed by expansion and contraction, as well as static and dynamic mechanical load.

3-2.4 Heating devices and heating elements of all types shall be constructed or located to resist mechanical damage from falling work, material handling, or other mechanical hazards.

3-2.5 Furnace and related equipment shall be designed and located to allow access for required inspection and maintenance.

3-2.5.1 Ladders, walkways, and access facilities, where provided, shall be designed in accordance with 29 CFR 1910.24 through 29 CFR 1910.29, and ANSI A14.3, *Safety Requirements for Fixed Ladders*.

3-2.5.2 Means shall be provided to allow for safe entry by maintenance and other personnel. (*See also A-11.*)

3-2.6 Radiation shields, refractory material, and insulation shall be retained or supported so they do not fall out of place under designed use and with proper maintenance.

3-2.7 External parts of furnaces that 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. Bursting discs or panels, mixer openings, or other parts of the furnace from which flame or hot gases could be discharged shall be located or guarded to prevent injury to personnel.

Exception: Where impractical to provide adequate shields or guards, warning signs or permanent floor markings shall be provided to be visible to personnel entering the area.

3-2.8 Properly located observation ports shall be provided to allow the operator to observe the lighting and operation of individual burners. Observation ports shall be protected properly from radiant heat and physical damage.

Exception: Where observation ports are not practical, other means of visually verifying the lighting and operation of individual burners shall be provided.

3-2.9 Closed cooling systems shall have a means of relief to protect all portions of the system, if the system pressure can exceed the design pressure. Flow switches shall be provided with audible and visual alarms.

3-2.10 Open cooling systems utilizing unrestricted sight drains readily observable by the operator shall not require flow switches.

3-2.11* Furnaces shall be designed to minimize fire hazards due to the presence of combustible products or residue in the furnace.

3-2.12 Furnace hydraulic systems shall utilize fire-resistant fluids.

Exception: Other hydraulic fluids shall be permitted to be used if failure of hydraulic system components cannot result in a fire hazard, subject to approval by the authority having jurisdiction.

> NOTE: Drawings for fluid power diagrams should be in accordance with ANSI Y14.17, *Drafting Practice*, and ANSI Y32.10, *Graphic Symbols for Fluid Power Diagrams*.

3-2.13 The metal frames of furnaces shall be electrically grounded.

3-2.14 Water-cooled components, such as vacuum vessels, shall be designed with minimum wall thicknesses in accordance with corrosion tables and vessel standards. (*See ASME Boiler and Pressure Vessel Code, Section VIII. Also see 3-2.14 and 3-2.15 of this document.*)

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

3-2.15 Where the vacuum chamber operates at a positive internal pressure of greater than 15 psig (103.4 kPa), the vacuum chamber shall be designed and constructed in accordance with ASME *Boiler and Pressure Vessel Code*, Section VIII, Division 1.

> NOTE: The additional pressure due to water in the cooling jacket should be considered in calculating maximum pressure differentials.

3-3 Explosion Relief.

3-3.1 Fuel-fired furnaces and furnaces that contain flammable liquids, gases, or combustible dusts shall be equipped with unobstructed explosion relief for freely relieving internal explosion pressures.

Exception: Explosion relief shall not be required on furnaces with shell construction having $^3/_{16}$-in. (4.8-mm) or heavier steel plate shells reinforced with structural steel beams and buckstays that support and retain refractory insulating materials required for temperature endurance, which make them unsuitable for the installation of explosion relief.

> NOTE: For additional information regarding relief of equipment and buildings housing the equipment, see NFPA 68, *Guide for Venting of Deflagrations*.

3-3.2 Explosion relief shall be designed as a ratio of relief area to furnace volume. The recommended design is 1 ft^2 (0.093 m^2) of relief area for each 15 ft^3 (0.424m^3) of furnace volume. Hinged panels, openings, or access doors equipped with approved explosion-relief hardware shall be permitted to be included in this ratio of 1:15.

3-3.3 Explosion-relief panels or doors shall be arranged so that, when open, the full vent opening provides an effective relief area. The operation of relief panels to their full capacity shall not be obstructed.

NOTE 1: Guard rails might be needed to prevent movable equipment from obstructing relief openings, and warning signs should be posted on the vents.

NOTE 2: Where practical, an explosion-relief vent should be located close to each known source of ignition.

3-3.4 Explosion-relief panels shall be located or retained so that personnel are not exposed to injury by the relief panel.

3-3.5 Where explosion relief is required, explosion-relief panels shall activate at a surge pressure that does not exceed the design pressure of the oven enclosure.

NOTE: Industry experience indicates that a typical oven enclosure built to withstand a minimum of 0.5 psig (3.45 kPa) surge overpressure with explosion-relief panels having a maximum weight per area of 5 lb/ft^2 (24.4 kg/m^2) meets the requirements of 3-3.5.

3-3.6 Explosion-relief vent panels for a long furnace shall be reasonably distributed throughout the entire furnace length. However, the maximum distance between explosion-relief vent panels shall not exceed five times the oven's smallest inside dimension (width or height).

NOTE: The intent of providing explosion relief in furnaces is to limit damage to the furnace and to reduce the risk of personnel injury due to explosions. To achieve this, relief panels and doors should be sized so that their inertia does not preclude their ability to relieve internal explosion pressures.

3-4 Ventilation and Exhaust System.

NOTE: For additional information, see NFPA 31, *Standard for the Installation of Oil-Burning Equipment*; NFPA 54, *National Fuel Gas Code*; and NFPA 91, *Standard for Exhaust Systems for Air Conveying of Materials*.

3-4.1 Building Makeup Air. A sufficient quantity of makeup air shall be admitted to oven rooms and buildings to provide the air volume required for oven safety ventilation and adequate combustion air.

3-4.2 Ductwork.

3-4.2.1 Ventilating and exhaust systems, where applicable, shall be installed in accordance with NFPA 91, *Standard for Exhaust Systems for Air Conveying of Materials*.

Exception: Where modified in this document.

3-4.2.2 Rectangular and square ducts shall be permitted.

3-4.2.3 Wherever furnace ducts or stacks pass through combustible walls, floors, or roofs, noncombustible insulation or clearance, or both, shall be provided to prevent combustible surface temperatures from exceeding 160°F (71°C).

3-4.2.4 Where ducts pass through noncombustible walls, floors, or partitions, the space around the duct shall be sealed with noncombustible material to maintain the fire rating of the barrier.

NOTE: Ducts passing through fire walls should be avoided.

3-4.2.5 Ducts shall be constructed entirely of sheet steel or other noncombustible material capable of meeting the intended installation and conditions of service. The installation shall be of adequate strength and rigidity and shall be protected where subject to physical damage.

3-4.2.6 Ducts handling fumes that leave a combustible deposit shall be provided with clean-out doors.

3-4.2.7 No portions of the building shall be used as an integral part of the duct.

3-4.2.8 All ducts shall be made tight throughout and shall have no openings other than those required for the operation and maintenance of the system.

NOTE: All interior laps in the duct joints should be made in the direction of the flow.

3-4.2.9 All ducts shall be thoroughly braced where required and substantially supported by metal hangers or brackets.

3-4.2.10 Ducts handling flammable vapors shall be designed to minimize the condensation of the vapors out of the exhaust airstream onto the surface of the ducts.

3-4.2.11 Ducts handling combustible solids shall be designed to minimize the accumulation of solids within the ducts.

3-4.2.12 Hand holes for damper, sprinkler, or fusible link inspection or resetting and for purposes of residue cleanout shall be equipped with tight-fitting doors or covers.

3-4.2.13 Exposed hot fan casings and hot ducts [temperature exceeding 160°F (71°C)] shall be guarded by location, guard rails, shields, or insulation to prevent injury to personnel.

3-4.2.14 Exhaust ducts shall not discharge near openings or other air intakes that allow re-entry of effluents into the building.

3-4.2.15 A suitable collecting and venting system for radiant tube heating systems shall be provided. (*See Section 4-5.*)

3-4.2.16 Pump Vents. Mechanical vacuum pumps with capacity larger than 15 ft^3/min (7 × 10^{-3}m^3/sec) shall be vented to a safe location in accordance with all applicable codes and air pollution control regulations.

3-4.2.17 Oil Drip Legs. An oil drip leg in accordance with the vacuum pump manufacturer's recommendation shall be designed into the vent piping system.

3-4.2.18 Vent Piping. Vent piping shall be free from gas or oil leaks and shall be of noncombustible pipe construction.

3-4.2.19 Oil Mist Separators. Consideration shall be given to the provision of an oil mist separator where the discharge vapor concentration is excessive.

3-5 Mountings and Auxiliary Equipment.

3-5.1 Furnace systems shall have provisions to prevent injury to personnel during maintenance or inspection. Such equipment shall be permitted to be motion stops, lockout devices, or other safety mechanisms.

3-5.2 To the extent practical, instrumentation and control equipment shall be brought to a common location and mounted for ease of observation, adjustment, and maintenance. Protection from physical and temperature damage and ambient hazards shall be provided.

3-5.3 Auxiliary equipment such as conveyors, racks, shelves, baskets, and hangers shall be noncombustible and designed to facilitate cleaning.

3-6 Pumping Systems.

3-6.1 Pumping systems shall consist of pumps; valves and associated piping and wiring; 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 might be the ejector, liquid ring, mechanical, cryopump, or diffusion type.

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

3-6.2 Mechanical pumps utilizing hydrocarbon oils shall not be used for pumping gases with oxygen contents greater than 25 percent by volume.

3-6.3 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 should be considered.

3-6.4 A fluid level gauge shall be installed on those diffusion pumps with a pump fluid capacity over 1 qt (0.95 L).

3-6.5 Where petroleum or other combustible fluids are used, the system shall be designed to minimize the possibility of fluid release that might result in a fire or explosion.

3-6.6 Sufficient cooling shall be provided for diffusion pumps to prevent excess vapors from backstreaming into furnace chambers and for mechanical pumps to prevent overheating of the pump fluids.

3-7 Vacuum Gauges and Controls.

3-7.1 Vacuum gauges and vacuum controls shall be selected for a particular system with consideration to vacuum level, sensitivity, and expected contamination.

NOTE: Vacuum gauges might contain controlling devices to operate equipment sequentially.

3-7.2 Suitable vacuum gauges shall be installed so levels of vacuum can be ascertained in the furnace chamber and between vacuum pumps of multipump systems.

3-7.3 Vacuum gauge controls that operate in conjunction with sequential controls shall be interlocked to prevent damage to the furnace components or work load.

3-7.4 Hot wire filament gauges shall not be used at pressures above 1×10^{-1} torr (13.3 Pa) in the presence of explosive vapors or combustible atmospheres.

3-8 Vacuum Piping Systems.

3-8.1 Vacuum pipe lines, valves, and manifolds shall be designed to withstand differential pressures, shall have sufficient conductance for the application, and shall have a maximum leak rate as required by the process but not greater than the leak rate specified by the furnace manufacturer.

NOTE: Pipes and manifolds should be as short and as large in cross section as practicable while remaining consistent with proper maintenance and economic considerations.

3-8.2 Pipes, valves, and manifolds shall be mounted to provide protection against damage by heat, vibration, and mechanical hazard.

3-8.3 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 when the control switch for the fore pump is in the "off" position.

3-8.4 Where applicable, a bypass shall be provided between the furnace and roughing and the fore pump so that the chamber can be rough-pumped while the diffusion pump remains isolated.

3-8.5 Inlet gas quenching valves shall be designed to operate at applicable pressures on the gas side and on the vacuum side.

3-8.6 Where pressurized backfilling is employed, a pressure-relief valve shall be provided on the furnace. 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 5-19.*)

3-9 Water-Cooling Systems.

3-9.1 The 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.

NOTE: Integral liquid quench systems are covered in Chapter 7.

3-9.2 Closed cooling systems shall be provided with a pressure-relief valve to prevent the rupture of the lines, coils, and chamber due to accidental overheating of the cooling water.

3-9.3 Interlocks shall be provided to prevent heating system operation without proper flow of the exit cooling water.

3-9.4 Consideration shall be given to the provision of flow indicators or temperature gauges on exit cooling lines.

3-9.5 If cooling water is discharged into an open drain, provisions shall be made for visual inspection of waterflow at outlets.

3-9.6 If heat from the electric power terminals can damage seals during processing cycles, provision shall be made to cool the terminals.

3-9.7 Where 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.

3-10 Gas-Quenching Systems. See also 5-19.3.

NOTE: After the thermal cycle has been completed, the work load either is 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 (13.8 kPag to 82.7 kPag) 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).

3-10.1 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, heat damage, and mechanical damage while loading or unloading the furnace.

3-10.1.1 Heat exchangers, components, and connections shall be free from water and air leaks.

3-10.1.2 Heat exchangers shall be mounted to prevent vibration or thermal damage that could cause a rupture during processing cycles.

3-10.1.3 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 or pressure attained in the furnace.

3-10.2 External Heat Exchangers. External heat exchangers used for the purpose of extracting heat from a recirculating cooling gas shall be enclosed in a vacuum-tight chamber that has a leak rate not exceeding the leak rate specified by the manufacturer for the furnace chamber.

3-10.2.1 Heat exchangers, components, and connections shall be free from water and air leaks.

3-10.2.2 Heat exchangers shall be mounted to prevent vibration or thermal damage that could cause a rupture during processing cycles.

3-10.2.3 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 or pressure attained in the furnace.

3-10.3 Fans and Blowers.

3-10.3.1 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 furnace manufacturer.

3-10.3.1.1 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.

3-10.3.1.2 Where motor windings are exposed to argon gas or other ionizing gases, the voltage on the motor shall be limited to 260 volts maximum.

3-10.3.2 External Fans and Blowers. External fans and blowers shall be enclosed in a vacuum-tight chamber or casing that has a leak rate not exceeding the leak rate specified for the furnace.

3-10.3.3 Fans and blowers that are automatically sequenced in the processing cycle shall have a manual override control.

3-10.4 Quenching Gas.

3-10.4.1 The recirculating gas shall be one that is not harmful to the heating elements, furnace heat shields or insulation, or work when introduced at the quenching temperature.

3-10.4.2 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.

3-10.4.3 All lines shall be vacuum-tight with a maximum leak rate as specified for the furnace chamber.

3-11 Heating Elements and Insulation.

3-11.1 Material for heating elements shall have a vapor pressure lower than the lowest pressure at the manufacturer's specified maximum temperature.

3-11.2 Internal electrical insulation material shall remain nonconductive through the full range of vacuum and temperature limits specified by the manufacturer.

3-12 Heat Baffles and Reflectors.

3-12.1 Baffles, reflectors, and hangers shall be designed to minimize warpage due to expansion and contraction.

3-12.2 Baffles, reflectors, and hangers shall be of heat-resistant material that minimizes sag, rupture, or cracking under normal operating limits specified by the manufacturer.

3-12.3 Baffles and reflectors shall be accessible and removable for the purpose of cleaning and repairing.

Chapter 4 Furnace Heating Systems

4-1 General.

4-1.1 For the purpose of this chapter, the term "furnace heating system" shall include the heating source, the associated piping and wiring used to heat the furnace, and the work therein as well as the auxiliary quenches, atmosphere generator, and other components.

4-1.2 Electrical. All wiring shall be in accordance with NFPA 70, *National Electrical Code*, NFPA 79, *Electrical Standard for Industrial Machinery*, and as described hereafter.

NOTE 1: NFPA 70, *National Electrical Code*, is a reference source for safe practices and wiring methods. Where it is considered that variation from the required wiring methods as currently specified in NFPA 70 is necessary to provide greater safety of the installation, such variations should be required to meet with the approval of all authorities having jurisdiction and should be required to be the sole responsibility of the parties initiating such variation.

NOTE 2: NFPA 497A, *Recommended Practice for Classification of Class I Hazardous (Classified) Locations for Electrical*

Installations in Chemical Process Areas, 2-6.4, should be referenced with regard to certain equipment with open flames and hot surfaces. NFPA 497A permits exceptions to general rules in NFPA 70, *National Electrical Code*, Article 500, that otherwise would dictate use of explosionproof or intrinsically safe electrical apparatus where flammable materials (such as atmospheres) are used. Normally, ovens or furnaces are unclassified internally because safety depends upon ventilation and not upon the elimination of sources of ignition.

4-1.3 All components of the furnace heating system and control cabinet shall be grounded.

4-2 Fuel Gas-Fired Units.

4-2.1 Scope.

4-2.1.1* This section shall apply to furnace heating systems fired with commercially distributed fuel gases such as natural gas, mixed gas, manufactured gas, liquefied petroleum gas (LP-Gas) in the vapor phase, and LP-Gas/air systems. This section also shall apply to the gas-burning portions of dual-fuel or combination burners.

NOTE: Additional safety considerations that are beyond the scope of this standard should be given to dirt-laden gases, sulfur-laden gases, high-hydrogen gases, and low-Btu waste gases.

4-2.1.2 Burners, along with associated mixing, valving, and safety controls and other auxiliary components, shall be properly selected for the intended application, suitable for the type and pressure of the fuel gases to be used, and suitable for the temperatures to which they are subjected.

4-2.2 Combustion Air.

4-2.2.1 The fuel-burning system design shall provide for an adequate supply of clean combustion air for proper burner operation.

NOTE: Inlet air filters can be used on combustion blowers where required to screen out solid matter.

4-2.2.2 Precautions shall be taken to prevent insufficiently diluted products of combustion from short-circuiting back into the combustion air.

NOTE: This requirement should not prevent the use of properly designed flue gas recirculation systems.

4-2.2.3 Where primary or secondary combustion air is provided mechanically, combustion airflow or pressure shall be proven and interlocked with the safety shutoff valves so that fuel gas cannot be admitted prior to establishment of combustion air and so that the gas is shut off in the event of combustion air failure.

4-2.2.4 In the case of an exothermic generator, loss of fuel gas shall cut off the combustion air.

4-2.2.5 Where a secondary air adjustment is provided, adjustment shall include a locking device to prevent an unintentional change in setting.

4-2.3 Fuel Gas Supply Piping.

4-2.3.1 A remotely located shutoff valve shall be provided to allow the fuel to be turned off in an emergency and shall be located so that fire or explosion at a furnace does not prevent access to this valve.

4-2.3.2 Installation of LP-Gas storage and handling systems shall comply with NFPA 58, *Standard for the Storage and Handling of Liquefied Petroleum Gases*.

4-2.3.3 Piping from the point of delivery to the equipment isolation valve shall comply with NFPA 54, *National Fuel Gas Code*. *(See 4-2.4.2.)*

4-2.4 Equipment Fuel Gas Piping.

4-2.4.1 Manual Shutoff Valves and Cocks.

4-2.4.1.1 Individual manual shutoff valves for equipment isolation shall be provided for shutoff of the fuel to each piece of equipment.

4-2.4.1.2 Manual shutoff valves shall have permanently affixed visual indication of the valve position.

NOTE 1: Valves with removable wrenches should not allow the wrench handle to be installed perpendicular to the fuel gas line when the valve is open.

NOTE 2: Quarter-turn valves should be used.

4-2.4.1.3 It shall be the user's responsibility to ensure that separate wrenches (handles) remain affixed to the valve and that they are oriented properly with respect to the valve port.

4-2.4.1.4 Valves and cocks shall be maintained in accordance with the manufacturer's instructions.

NOTE: Particular attention should be given to the need for proper lubrication of lubricated plug cocks.

4-2.4.2 Piping and Fittings.

4-2.4.2.1 Material for the piping and fittings that connect the equipment manual isolation valve to the burner shall meet the requirements of NFPA 54, *National Fuel Gas Code*.

4-2.4.2.2 Piping, fittings, and valves shall be sized to provide proper flow rates and pressure to maintain a stable flame over the burner operating range.

4-2.4.3* Fuel Filters and Strainers. For new installations, a gas filter or strainer shall be installed in the fuel gas piping to protect the downstream safety shutoff valves.

4-2.4.4 Pressure Regulators and Pressure Switches.

4-2.4.4.1 A pressure regulator shall be furnished wherever the plant supply pressure exceeds that required for proper burner operation or wherever the plant supply pressure is subject to excessive fluctuations.

Exception: An automatic flow control valve shall be permitted to meet this requirement, provided it can compensate for the full range of expected source pressure variations.

4-2.4.4.2 Regulators and switches shall be vented to a safe location where vented gas cannot re-enter the building without extreme dilution. The terminating end shall be protected against water entry and shall be bug-screened. Vent piping shall be of adequate size to allow normal regulator and switch operation.

Exception No. 1: Vent piping from regulators and switches shall be permitted to terminate within a building where used with lighter-than-air fuel gases, provided the vent contains a restricted orifice and discharges into a space large enough and with sufficient natural ventilation so that the escaping gases do not present a hazard and cannot re-enter the work area without extreme dilution.

Exception No. 2: Vent piping shall not be required for regulators and switches where used with lighter-than-air fuel gases at 1 psig (7 kPa) inlet pressure or less, provided the vent connection contains a restricted orifice and discharges into a space large enough, or is ventilated well enough, so that the escaping gases do not present a hazard.

Exception No. 3: Fuel gas regulators and zero governors shall not be required to be vented if backloaded from combustion air lines, air-gas mixture lines, or combustion chambers, provided that gas leakage through the backload connection does not create a hazard.

4-2.4.4.3 Fuel gas regulators and zero governors shall not be backloaded from oxygen or oxygen-enriched air lines.

4-2.4.4.4 Vent lines from multiple furnaces shall not be manifolded together.

4-2.4.4.5 Vent lines from multiple regulators and switches of a single furnace, where manifolded together, shall be piped in such a manner that diaphragm rupture of one vent line does not backload the others.

4-2.5 Flow Control Valves. Where the minimum or the maximum flow of combustion air or the fuel gas is critical to the safe operation of the burner, flow valves shall be equipped with an appropriate limiting means and with a locking device to prevent an unintentional change in the setting.

4-2.6 Air-Fuel Gas Mixers.

4-2.6.1 General. This section shall apply only to mixtures of fuel gas with air and not to mixtures of fuel gas with oxygen or oxygen-enriched air. Oxygen shall not be introduced into air-fuel gas mixture piping, fuel gas mixing machines, or air-fuel gas mixers.

NOTE 1: In the design, fabrication, and utilization of mixture piping, it should be recognized that the air-fuel gas mixture might be in the flammable range.

NOTE 2: See Chapters 1 and 3 for guidance on building ventilation, building explosion relief, the installation of electrical equipment, and equipment, location.

4-2.6.2 Proportional Mixing.

4-2.6.2.1 Piping shall be designed to provide a uniform mixture flow of proper pressure and velocity as needed for stable burner operation.

4-2.6.2.2 Valves or other obstructions shall not be installed between a proportional mixer and burners. Fixed orifices shall be permitted for purposes of balancing.

4-2.6.2.3 Any field-adjustable device built into a proportional mixer (e.g., gas orifice, air orifice, ration valve) shall be arranged with an appropriate locking device to prevent unintentional changes in the setting.

4-2.6.2.4 Where a mixing blower is used, an approved safety shutoff valve shall be installed in the fuel gas supply connection that shuts off the fuel gas supply automatically when the blower is not in operation and in the event of a fuel gas supply failure.

4-2.6.2.5 Mixing blowers shall not be used with fuel gases containing more than 10 percent free hydrogen (H_2).

4-2.6.2.6 Mixing blowers having a static delivery pressure of more than 10 in. w.c. (2.49 kPa) shall be considered mixing machines.

4-2.6.3 Mixing Machines.

4-2.6.3.1* Automatic fire checks shall be provided in piping systems distributing flammable air-fuel gas mixtures from a mixing machine. The automatic fire check shall be installed as close as practical to the burner inlet(s), and the manufacturer's installation guidelines shall be followed.

4-2.6.3.2 A separate, manually operated gas valve shall be provided at each automatic fire check for shutting off the flow of air-fuel mixture through the fire check after a flashback has occurred. The valves shall be located upstream as close as practicable to the inlets of the automatic fire checks.

CAUTION: These valves shall not be reopened after a flashback has occurred until the fire check has cooled sufficiently to prevent reignition of the flammable mixture and has been properly reset.

4-2.6.3.3* A backfire arrester with a safety blowout device shall be provided near the outlet of each mixing machine producing a flammable air-fuel gas mixture. The manufacturer's installation guidelines shall be followed.

4-2.6.3.4 A listed safety shutoff valve shall be installed in the fuel gas supply connection of any mixing machine. This valve shall be arranged to shut off the fuel gas supply automatically when the mixing machine is not in operation or in the event of an air or fuel gas supply failure.

Exception: Where listed safety shutoff valves are not available for the service intended, the selected device shall require approval by the authority having jurisdiction.

4-2.7 Fuel Gas Burners.

4-2.7.1 All burners shall maintain the stability of the designed flame shape, without flashback or blow-off, over the entire range of turndown that is encountered during operation where supplied with combustion air (oxygen-enriched air or oxygen) and the designed fuels in the proper proportions and in the proper pressure ranges.

NOTE: Burner operation could be adversely affected where other than the designed fuels are used.

4-2.7.2 All pressures required for safe operation of the combustion system shall be maintained within the proper ranges throughout the firing cycle.

4-2.7.3 Burners shall have the ignition source sized and located in a position that provides safe and reliable ignition of the pilot or main flame.

4-2.7.3.1 Self-piloted burners shall have a safe and reliable transition from pilot flame to main flame.

4-2.7.3.2 For burners that cannot be ignited safely at all firing rates, positive provision shall be made to reduce the burner firing rates during light-off to a lower level, which ensures a safe and reliable ignition of the main flame (forced low-fire start).

4-2.8 Fuel Ignition.

4-2.8.1 The ignition source (e.g., electric spark, hot wire, pilot burner, handheld torch) shall be applied effectively at the proper point and with sufficient intensity to ignite the air-fuel mixture.

NOTE: A burner is suitably ignited when combustion of the air-fuel mixture is established and stable at the discharge port(s) of the nozzle(s) or in the contiguous combustion tunnel.

4-2.8.2 Fixed ignition sources shall be mounted to prevent unintentional changes in location and in direction with respect to the main flame.

4-2.8.3 Pilot burners shall be considered burners, and all provisions of Section 4-2 shall apply.

4-2.9 Dual-Fuel and Combination Burners. Where fuel gas and fuel oil are to be fired individually (dual-fuel) or simultaneously (combination), the provisions of Sections 4-2, 4-3, and 5-12 shall apply equally to the respective fuels.

4-3 Oil-Fired Units.

4-3.1 Scope.

4-3.1.1* This section shall apply to combustion systems for furnaces fired with No. 2, No. 4, No. 5, and No. 6 industrial fuel oils as specified by ASTM D396, *Standard Specifications for Fuel Oils*. It also includes the oil-burning portions of dual-fuel and combination burners.

4-3.1.2 Additional considerations that are beyond the scope of this standard shall be given to other combustible liquids not specified in 4-3.1.1.

4-3.1.3 Burners, along with associated valving, safety controls, and other auxiliary components, shall be suitable for the type and pressure of the fuel oil to be used and for the temperatures to which they are subjected.

4-3.2 Combustion Air.

4-3.2.1 The fuel-burning system design shall provide for an adequate supply of clean combustion air for proper burner operation.

NOTE: Inlet air filters can be used on combustion blowers where required to screen out solid matter.

4-3.2.2 Precautions shall be taken to prevent insufficiently diluted products of combustion from short-circuiting back into the combustion air.

NOTE: This requirement should not prevent the use of properly designed flue gas recirculation systems.

4-3.2.3 Where primary or secondary combustion air is provided mechanically, combustion airflow or pressure shall be proven and interlocked with the safety shutoff valves so that oil cannot be admitted prior to establishment of combustion air and so that the oil is shut off in the event of combustion air failure.

4-3.2.4 Where a secondary air adjustment is provided, adjustment shall include a locking device to prevent an unintentional change in setting.

4-3.3 Oil Supply Piping.

4-3.3.1 Storage tanks, their installation and supply piping materials shall comply with NFPA 31, *Standard for the Installation of Oil-Burning Equipment*.

4-3.3.2 A remotely located shutoff valve shall be provided to allow the fuel to be turned off in an emergency and shall be located so that fire or explosion at a furnace does not prevent access to this valve.

NOTE: A positive displacement oil pump may be permitted to serve as a valve by shutting off its power.

4-3.3.3 Where a shutoff is installed in the discharge line of an oil pump that is not an integral part of a burner, a pressure-relief valve shall be connected to the discharge line between the pump and the shutoff valve and arranged to return surplus oil to the supply tank or to bypass it around the pump, unless the pump includes an internal bypass.

4-3.3.4 All air from the supply and return piping shall be purged initially, and air entrainment in the oil shall be minimized.

NOTE 1: A long circulating loop, consisting of a supply leg, a back-pressure regulating valve, and a return line back to the storage tank, is a means of reducing air entrainment.

NOTE 2: Manual vent valves might be needed to bleed air from the high points of the oil supply piping.

4-3.3.5 Suction, supply, and return piping shall be adequately sized with respect to oil pump capacity.

4-3.3.6* Wherever a section of oil piping can be shut off at both ends, relief valves or expansion chambers shall be used to release the pressure caused by thermal expansion of the oil.

4-3.4 Equipment Oil Piping.

4-3.4.1 Manual Shutoff Valves and Cocks.

4-3.4.1.1 Individual manual shutoff valves for equipment isolation shall be provided for shutoff of the fuel to each piece of equipment.

4-3.4.1.2 Manual shutoff valves shall be installed to avoid oil spillage during servicing of supply piping and associated components.

4-3.4.1.3 Manual shutoff valves shall display a permanently affixed visual indication of the valve position.

NOTE 1: Valves with removable wrenches should not allow the wrench handle to be installed perpendicular to the fuel gas line when the valve is open.

NOTE 2: Quarter-turn valves should be used.

4-3.4.1.4 It shall be the user's responsibility to ensure that separate wrenches (handles) remain affixed to the valve and that they are oriented properly with respect to the valve port.

4-3.4.1.5 Valves and cocks shall be maintained in accordance with the manufacturer's instructions.

NOTE: Particular attention should be given to the need for proper lubrication of lubricated plug cocks.

4-3.4.2 Piping and Fittings.

4-3.4.2.1 Equipment piping shall be in accordance with NFPA 31, *Standard for the Installation of Oil-Burning Equipment*.

4-3.4.2.2 Piping, fittings, and valves shall be sized to provide proper flow rates and pressure to maintain a stable flame over the burner operating range.

4-3.4.3 Oil Filters and Strainers.

4-3.4.3.1 An oil filter or strainer shall be installed in the oil piping to protect the downstream components.

4-3.4.3.2 The degree of filtration shall be compatible with the size of the most critical clearance being protected.

NOTE: Customarily, a filter or strainer is installed in the supply piping to protect the pump. However, this filter or strainer mesh usually is not sufficiently fine for burner and valve protection.

4-3.4.3.3 The filter or strainer shall be suitable for the intended pressure, temperature, and service.

4-3.4.4 Pressure Regulators. A pressure regulator shall be furnished wherever the plant supply pressure exceeds that required for proper burner operation or wherever the plant supply pressure is subject to excessive fluctuations.

Exception: An automatic flow control valve shall be permitted to meet this requirement, provided it can compensate for the full range of expected source pressure variations.

4-3.5 Flow Control Valves. Where the minimum or the maximum flow of combustion air or the fuel oil is critical to the safe operation of the burner, flow valves shall be equipped with an appropriate limiting means and with a locking device to prevent an unintentional change in the setting.

4-3.6 Oil Atomization.

4-3.6.1* Oil shall be atomized to droplet size as required for proper combustion throughout the firing range.

4-3.6.2 The atomizing device shall be accessible for inspection, cleaning, repair, replacement, and other maintenance as required.

4-3.7 Oil Burners.

4-3.7.1 All burners shall maintain the stability of the designed flame shape over the entire range of turndown that is encountered during operation where supplied with combustion air (oxygen-enriched air or oxygen) and the designed fuels in the proper proportions and in the proper pressure ranges.

4-3.7.2 All pressures required for the safe operation of the combustion system shall be maintained within the proper ranges throughout the firing cycle.

4-3.7.3 The burner shall be supplied with fuel oil of the proper grade that has been preconditioned to the required viscosity.

4-3.7.4 Burners shall have the ignition source sized and located in a position that provides safe and reliable ignition of the pilot or main flame.

4-3.7.4.1 Self-piloted burners shall have a safe and reliable transition from pilot flame to main flame.

4-3.7.4.2 For burners that cannot be ignited safely at all firing rates, positive provision shall be made to reduce the burner firing rates during light-off to a lower level, which ensures a safe and reliable ignition of the main flame (forced low-fire start).

4-3.7.5 If purging of oil passages upon normal termination of a firing cycle is required, it shall be done prior to shutdown with the initial ignition source present and with all associated fans and blowers in operation.

4-3.8 Fuel Ignition.

4-3.8.1 The ignition source (e.g., electric spark, hot wire, pilot burner, handheld torch) shall be applied effectively at the proper point and with sufficient intensity to ignite the air-fuel mixture.

NOTE: A burner is suitably ignited when combustion of the air-fuel mixture is established and stable at the discharge port(s) of the nozzle(s) or in the contiguous combustion tunnel.

4-3.8.2 Fixed ignition sources shall be so mounted to prevent unintentional changes in location and in direction with respect to the main flame.

4-3.8.3 Pilot burners shall be considered burners, and all provisions of Section 4-2 shall apply.

4-3.9 Dual-Fuel and Combination Burners. Where fuel gas and fuel oil are to be fired individually (dual-fuel) or simultaneously (combination), the provisions of Sections 4-2, 4-3, and 5-12 shall apply equally to the respective fuels.

4-4 Oxygen-Enhanced Fuel-Fired Units.

4-4.1* Scope. This section shall apply to combustion systems using oxygen (oxy-fuel) or oxygen-enriched air with gas or liquid fuels. The requirements shall be in addition to those in Sections 4-2 and 4-3 and Chapter 5.

4-4.2 Combustion Systems Utilizing Oxygen.

4-4.2.1 Oxygen storage and delivery systems shall comply with NFPA 50, *Standard for Bulk Oxygen Systems at Consumer Sites*.

4-4.2.2 Oxygen shall not be introduced into inlet or discharge piping of air compressors or blowers that are internally lubricated with petroleum oils, greases, or other combustible substances.

4-4.3 Oxygen Piping and Components.

4-4.3.1 Design, materials of construction, installation, and tests of oxygen piping shall comply with the applicable sections of ANSI B31.3, *Chemical Plant and Petroleum Refinery Piping*.

4-4.3.2 Materials and construction methods used in the installation of the oxygen piping and components shall be compatible with oxygen.

NOTE: CGA G-4.4, *Industrial Practices for Gaseous Oxygen Transmission and Distribution Piping Systems*, specifies maximum gas velocity criteria, materials of construction, installation methods, joining methods, metering methods, use of filters, and specifications for oxygen-compatible sealing materials, gasket materials, and thread sealants.

4-4.3.3 Piping and components that come in contact with oxygen shall be cleaned prior to admitting gas.

NOTE: See CGA G-4.1, *Cleaning Equipment for Oxygen Service*.

4-4.3.4 Air introduced into oxygen passages in burners, such as cooling air, shall be free of oil, grease, and other combustible materials.

NOTE: This requirement is intended to prevent the contamination of surfaces that must be clean for oxygen service from the oil normally present in plant compressed air.

4-4.3.5 A remotely located shutoff valve shall be provided to allow the oxygen to be turned off in an emergency and shall be located so that fire or explosion at a furnace does not prevent access to this valve.

4-4.3.6 Oxygen from pressure-relief devices and purge outlets shall not be released into pipes or manifolds where it can mix with fuel.

4-4.3.7 Oxygen from pressure-relief devices and purge outlets shall be released to a safe location.

4-4.3.8 Means shall be provided to prevent oxygen, fuel, or air to intermix in burner supply lines due to valve leakage, burner plugging, or other system malfunctions.

4-4.3.9 Oxygen piping and components shall be inspected and maintained.

NOTE: See CGA G-4.4, *Industrial Practices for Gaseous Oxygen Transmission and Distribution Piping Systems.*

4-4.3.10 If glass tube flowmeters are used in oxygen service, safeguards against personnel injury from possible rupture shall be provided.

4-4.3.11* The piping fed from a cryogenic supply source shall be protected from excessive cooling by means of an automatic low-temperature shutoff device.

4-4.3.12 Piping and controls downstream of an oxygen pressure-reducing regulator shall be able to withstand the maximum potential upstream pressure or shall be protected from overpressurization by means of a suitable pressure-relief device.

4-4.4 Oxygen Flow Control Valves.

4-4.4.1 Where the minimum or the maximum flow of oxygen or oxygen-enriched air is critical to safe operation of the burner, flow control valves shall be equipped with an appropriate limiting means and locking device to prevent an unintentional change in the setting.

4-4.4.2 An oxygen pressure regulator shall be furnished wherever the source oxygen pressure exceeds that required for proper burner operation or wherever the source pressure is subject to excessive fluctuations.

Exception: An automatic flow control valve shall be permitted to meet this requirement, provided it can compensate for the full range of expected source pressure variations and complies with 4-4.4.1.

4-4.5 Oxygen-Enriched Combustion Air.

4-4.5.1 Filters shall be installed in the air blower intake to minimize contamination of the oxygen-enriched air piping.

4-4.5.2 Devices, such as diffusers, used to disperse oxygen into an airstream shall be designed to prevent jet impingement of oxygen onto interior surfaces of the air piping.

NOTE: Diffusers commonly are used to disperse oxygen into an airstream effecting rapid and complete mixing of the oxygen into the air. High-velocity impingement of oxygen is a potential fire hazard.

4-4.5.3 Oxygen-enriched combustion air shall not be introduced into a burner before the oxygen has been uniformly mixed into the airstream.

4-4.5.4 Branching of the enriched-air piping shall not be permitted before a uniform mixture of oxygen and air has been attained.

4-5 Flue Product Venting.

4-5.1 A means shall be provided to ensure adequate ventilation for the products of combustion on fuel-fired equipment.

4-5.2 Collecting and venting systems for radiant tube-type heating systems shall be of sufficient capacity to prevent an explosion or fire hazard due to the flow of unburned fuel through the radiant tubes. The system shall be capable of dilution of the rated maximum input capacity of the system to a noncombustible state.

Exception: These requirements shall not apply to radiant tube-type heating systems provided with two safety shutoff valves interlocked with combustion safeguards.

4-6 Electrically Heated Units.

4-6.1 Scope. This section includes all types of heating systems where electrical energy is used as the source of heat.

4-6.2 Safety Equipment. Safety equipment, including airflow interlocks, time relays, and temperature switches, shall be in accordance with Chapter 5.

4-6.3 Electrical Installation. All parts of the electrical installation shall be in accordance with NFPA 70, *National Electrical Code*.

4-6.4 Resistance Heating Systems.

4-6.4.1 The provisions of 4-6.4.1 through 4-6.4.3 shall apply to resistance heating systems, including infrared lamps, such as quartz, ceramic, and tubular glass types.

4-6.4.2 Construction.

4-6.4.2.1 The heater housing shall be constructed to provide access to heating elements and wiring.

4-6.4.2.2 Heating elements and insulators shall be supported securely or fastened so that they do not become easily dislodged from their intended location.

4-6.4.2.3 Heating elements that are electrically insulated from and supported by a metallic frame shall have the frame electrically grounded.

4-6.4.2.4 Open-type resistor heating elements shall be supported by electrically insulated hangers and shall be secured to prevent the effects of motion induced by thermal stress, which could result in adjacent segments of the elements touching one another, or the effects of touching a grounded surface.

4-6.4.2.5 External parts of furnace heaters that are energized at voltages that could be hazardous as specified in NFPA 70, *National Electrical Code*, shall be guarded.

4-6.4.3 Heater Locations. Heaters shall not be located directly under the product being heated where combustible materials can drop and accumulate.

4-6.5 Induction and Dielectric Heating Systems.

4-6.5.1 Induction and dielectric heating systems shall be designed and installed in accordance with NFPA 70, *National Electrical Code*, with special reference to Article 665.

4-6.5.2 Construction.

4-6.5.2.1 Combustible electrical insulation shall be reduced to a minimum.

NOTE: Transformers should be of the dry, high-fire point, or less flammable liquid type. Dry transformers should have a 150°C (270°F) rise insulation in compliance with NEMA TR 27, *Commercial, Institutional and Industrial Dry-Type Transformers,* Section 4.03.

4-6.5.2.2 Protection shall be installed to prevent overheating of any part of the equipment in accordance with NFPA 70, *National Electrical Code.*

4-6.5.2.3 Where water-cooling is used for transformers, capacitors, electronic tubes, spark gaps, or high-frequency conductors, cooling coils and connections shall be arranged so that leakage or condensation does not damage the electrical equipment. The cooling-water supply shall be interlocked with the power supply so that loss of water cuts off the power supply. Consideration shall be given to providing individual pressure flow interlocks for parallel waterflow paths.

4-6.5.2.4 Where forced ventilation by motor-driven fans is necessary, the air supply shall be interlocked with the power supply. An air filter shall be provided at the air intake.

4-6.5.2.5 The conveyor motor and the power supply of dielectric heaters of the conveyor type used to heat combustible materials shall be interlocked to prevent overheating of the material being treated.

4-6.5.2.6 Dielectric heaters used for treating highly combustible materials shall be designed to prevent a disruptive discharge between the electrodes.

4-7 Fluid Heating Systems.

4-7.1 Scope. This section shall apply to all types of heating systems where water, steam, or heat transfer fluids are the source of heat through the use of heat exchangers supplied from a central heater or generator.

4-7.2 General.

4-7.2.1 Piping and fittings shall be in accordance with ANSI B31.1, *Power Piping.* Suitable relief valves shall be provided where needed.

4-7.2.2 Enclosures or ductwork for heat exchanger coils shall be of noncombustible construction with suitable access openings provided for maintenance and cleaning.

4-7.2.3 Heat exchangers or steam coils shall not be located on the floor of an oven or in any position where paint drippings or combustible material can accumulate on the coils.

4-7.3 Safety Devices.

4-7.3.1 Control equipment and application to heating systems shall be in accordance with Chapter 5.

4-7.3.2 System equipment shall be operated within the temperature and pressure limits specified by the supplier or manufacturer of the heat transfer medium and by the manufacturer of the equipment.

4-7.3.3 On circulating liquid systems, the following interlocks shall be provided to shut off the heater automatically:

(a) Low liquid level;

(b) Low circulation rate; and

(c) High liquid temperature.

4-7.3.4 To avoid an abnormally high temperature at coil surfaces, pressure in heat exchanger coils shall be maintained at the minimum pressure necessary to provide the required drying temperature.

NOTE: This usually is accomplished by an automatic pressure regulating device.

4-7.3.5 Recirculation directly over the heat exchanger coils shall not be used if lint or other light combustibles could be carried back to and deposited on the coil surfaces.

Exception: Where the recirculated atmosphere is properly filtered.

4-8 Power Supply.

4-8.1* The power supply shall transform the relatively high-voltage power line to low-voltage, high-current power suitable for energizing the heating elements.

NOTE 1: Consideration should be given to furnishing the power supply with a means of proportional control.

NOTE 2: Generally this is accomplished with either a saturable core reactor transformer, an adjustable autotransformer, a solid-state, silicon-controlled rectifier unit, or an electronic ignition system or equivalent. Figure A-4-8.1 is a schematic diagram of a power supply. (The design of the power supply is specific for each individual furnace and size.)

4-8.2 The power supply shall contain a stepdown transformer, a control device such as an SCR power control unit, 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 1: The power supply output voltage should be limited to prevent electrical breakdown or internal furnace arcing. As the atmospheric pressure is reduced in the hot zone area and in 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.

NOTE 2: With a three-phase power supply, every attempt should be made to provide balanced line currents across all three phases as a result of the heating element load.

4-8.3 Electrical 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, or insulation.

4-9 Heating Elements.

4-9.1 The design can take several forms, such as rods, bars, sheets, or cloth, but shall be limited to materials that do not vaporize under minimum vacuum and maximum temperature.

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

4-9.2 The heating element placement and geometry shall be considered carefully 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 to prevent contact with work pieces or fixtures and to prevent contact with furnace heat shields 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.

4-9.3* 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, a reaction occurs easily in the solid state. Some eutectic temperatures are provided in Table A-4-9.3.

4-9.4 Heating element connections shall be designed to minimize arcing and disassembly problems.

4-9.5 The heating element power terminal and vessel feed-through shall be designed with consideration for vacuum integrity and heating effects. Vacuum mating surfaces shall be free from dirt and scratches and equivalent to O-ring designs.

4-9.6 Power terminal connection points to power supply cables shall be covered or housed to prevent high-current electrical hazard to personnel.

4-10 Furnace Thermal Insulation and Heat Shields.

NOTE: The heat energy produced by the heating elements transfers into the work principally by means of 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.

4-10.1 Insulation shall not break down at specified vacuum levels and temperatures.

NOTE: Examples of proper insulation include graphite wool, alumina/silica fibers, and other materials.

4-10.2 Multiple layers of metal heat shields shall be acceptable, assuming these materials comply with temperature and vacuum requirements.

NOTE: Molybdenum, tantalum, tungsten, palladium, and 304/316 stainless steel are examples of acceptable metals to be used for heat shields.

4-10.3 Careful attention shall be given to retain either the insulation or heat shields to prevent contact with the heating elements.

4-10.4* 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 5 Safety Equipment and Application

5-1 Scope.

5-1.1 This chapter shall apply to safety equipment and its application to furnace heating and ventilation systems. Section 5-3 shall apply to all safety controls included in this standard.

5-1.2 For the purpose of this chapter, the term "furnace heating system" shall include the heating source, associated piping and wiring used to heat the furnace, auxiliary quenches, and the work therein.

NOTE 1: For the protection of personnel and property, careful consideration should be given to the supervision and monitoring of conditions that could cause, or could lead to, a real or potential hazard on any installation.

NOTE 2: The presence of safety equipment on an installation cannot, in itself, ensure absolute safety of operation.

NOTE 3: There is no substitute for a diligent, capable, well-trained operator.

NOTE 4: Highly repetitive operational cycling of any safety device can reduce its life span.

5-2 General.

5-2.1 All safety devices shall be listed for the service intended. Safety devices shall be applied and installed in accordance with this standard and the manufacturer's instructions.

Exception: Where listed devices are not available for the service intended, the selected device shall require approval by the authority having jurisdiction.

5-2.2 Electric relays and safety shutoff valves shall not be used as substitutes for electrical disconnects and manual shutoff valves.

5-2.3 A shutdown of the heating system by any safety feature or safety device shall require manual intervention of an operator for re-establishment of normal operation of the system.

5-2.4 Regularly scheduled inspection, testing, and maintenance of all safety devices shall be performed. (*See Chapter 11.*)

5-2.4.1 It shall be the responsibility of the equipment manufacturer to provide operating instructions that cover start-up, shutdown, emergencies, and procedures for inspection, testing, and maintenance.

5-2.4.2 It shall be the responsibility of the user to establish, schedule, and enforce the frequency and extent of the inspection, testing, and maintenance program, as well as the corrective action to be taken. Documented safety inspections and testing shall be performed at least annually.

NOTE: Actual operating conditions affect the frequency and extent of these programs.

5-2.5 Safety devices shall be installed, used, and maintained in accordance with the manufacturer's instructions.

5-2.6 Safety devices shall be located or guarded to protect them from physical damage.

5-2.7 Safety devices shall not be removed or rendered ineffective.

5-2.8 Safety devices shall not be bypassed electrically or mechanically.

5-2.9* Electrical power for safety-control circuits shall be single-phase, one-side grounded, with all breaking contacts in the "hot" ungrounded, fuse-protected or circuit breaker-protected line, and shall not exceed 120-volt potential.

5-3 Programmable Controllers.

5-3.1 Scope. A programmable controller is defined as a general purpose industrial processor capable of applications for safety and control purposes. This section shall apply to the use of programmable controllers in safety circuits.

5-3.2 General.

5-3.2.1 The supplier of the application software for the programmable controller shall provide the end user and the authority having jurisdiction with the documentation needed to verify that all related safety devices and safety logic are functional before the programmable controller is placed in operation.

5-3.2.2 In the event of a power failure, the programmable controller (hardware and software) shall not prevent the system from reverting to a safe default condition. A safe condition shall be maintained upon the restoration of power.

5-3.2.3 The control system shall have a separate manual emergency switch, independent of the programmable controller, that initiates a safe shutdown.

> **CAUTION:** For some applications, additional manual action might be required to bring the process to a safe condition.

5-3.2.4 Any changes to hardware or software shall be documented, approved, and maintained in a file on the site.

5-3.2.5 The internal status of the programmable controller shall be monitored. In the event of a programmable controller failure, the system shall annunciate and cause the system to revert to a safe condition.

5-3.2.6 System access shall be limited by incorporating measures to prevent unauthorized access to the programmable controller or its logic, which could result in hazards to personnel or equipment.

> **CAUTION:** Modems and networks require special measures to provide the necessary security.

5-3.3 Combustion Safety Circuitry.

5-3.3.1 Programmable controller-based systems listed for combustion safeguard service shall be permitted where applied in accordance with the manufacturer's instructions.

> NOTE: Programmable controllers not listed for combustion safeguard service may be permitted to be used only to monitor equipment, with the exception that isolated programmable controller contacts (not directly connected to a power source) may be permitted to be wired in series with the safety circuits specified in 5-3.3.1.

5-3.3.2 Purge, ignition trials, and other burner safety sequencing shall not be performed by any device not listed for such service.

5-3.3.3 Where a programmable controller is used in conjunction with the combustion safety circuitry, the combustion safety interlocks, combustion safeguards, and excess temperature limits shall be wired to directly de-energize the safety shutoff valves, and their operation shall cause the system to revert to a safe default condition.

5-3.4 Hardware.

5-3.4.1 A failure of programmable controller hardware shall cause the system to revert to a safe default condition.

NOTE: Failure modes include, but are not limited to:

(a) Failure of CPU to execute the program;

(b) Failure of the system to recognize changes in input or output status;

(c) Failure of the I/O module to scan input and output signals;

(d) Failure of input to respond to the action of the connected device;

(e) Failure of the program to consult input or external information sources correctly;

(f) Failure of output to respond to CPU instructions; and

(g) Failure of a memory location or register.

5-3.4.2 A programmable controller shall be provided with a watchdog timer external to the CPU and memory. Failures detected by the watchdog timer shall cause the system to revert to a safe default condition.

5-3.4.3 System operation shall be tested and verified for compliance with this standard and the original design criteria whenever the programmable controller is replaced, repaired, or updated.

5-3.5 Software.

5-3.5.1 Whenever application software that contains safety logic or detection logic is modified, system operation shall be verified for compliance with this standard and the original design criteria.

5-3.5.2 The software for the programmable controller shall reside in some form of nonvolatile storage (memory that retains information on loss of system power).

5-3.5.3 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 be separated from all other programming.

5-3.5.4 Unauthorized change or corruption of software shall cause the system to revert to a safe default condition.

5-4 Safety Control Application for Fuel-Fired Heating Systems.

5-4.1 Preignition (Prepurge, Purging Cycle).

5-4.1.1 Prior to each furnace heating system start-up, provision shall be made for the removal of all flammable vapors and gases that might have entered the heating chambers during the shutdown period.

5-4.1.2 A timed preignition purge shall be provided. At least 4 standard cubic feet (SCF) of fresh air or inert gas per cubic foot (4 m^3/m^3) of heating chamber volume shall be introduced during the purging cycle.

5-4.1.2.1 To begin the timed preignition purge interval, the following conditions shall be satisfied:

(a) The minimum required preignition airflow shall be proven;

(b) The safety shutoff valve(s) shall be closed (*see 5-7.2.2 for proof of closure requirements.*); and

(c) The flame safeguard shall detect no signal.

5-4.1.2.2 The minimum required preignition purge airflow shall be proven and maintained throughout the timed preignition purge interval.

5-4.1.2.3 Failure to maintain the minimum required preignition purge airflow shall stop the preignition purge and reset the purge timer.

5-4.1.3 A furnace heating system, either alone or as part of multiple furnaces feeding into one fume incinerator, shall not be purged into an operating incinerator.

Exception: A furnace heating system shall be permitted to be purged into an operating incinerator if it can be demonstrated that the flammable vapor concentration entering the fume incinerator cannot exceed 50 percent of the LEL.

5-4.1.4 Preignition purging of radiant tube-type heating systems shall be provided.

Exception: Omission of preignition purging of radiant tube-type heating systems shall be permitted where the systems are arranged and designed as follows:

(a) The tubes are of metal construction and open at one or both ends with heat recovery systems, if used, that are of explosion-resistant construction; or

(b) The entire radiant tube heating system, including any associated heat recovery system, is of explosion-resistant construction.

5-4.1.5 Prior to the reignition of a burner after a burner shutdown or flame failure, a preignition purge shall be accomplished.

Exception: Repeating the preignition purge shall not be required, provided:

(a) The heating chamber temperature exceeds 1400°F (760°C); or

(b) All of the following conditions are satisfied:

1. Each burner and pilot is supervised by a combustion safeguard in accordance with Section 5-9;

2. Each burner system is equipped with gas safety shutoff valves in accordance with Section 5-7; and

3. It can be demonstrated that the combustible concentration in the heating chamber cannot exceed 25 percent of the LEL.

CAUTION: Repeated ignition attempts can result in a combustible concentration greater than 25 percent of the LEL.

5-4.2 Trial for ignition of pilots or main burners shall not exceed 15 seconds.

Exception: A maximum of 60 seconds shall be permitted for ignition, provided:

(a) A written request for an extension of trial for ignition is approved by the authority having jurisdiction; and

(b) It is determined that 25 percent of the LEL cannot be exceeded in the extended time.

5-5 Ventilation Safety Devices.

5-5.1 Wherever a fan is essential to the operation of the oven or allied equipment, fan operation shall be proven and interlocked into the safety circuitry.

5-5.1.1 Electrical interlocks and flow switches shall be arranged in the safety-control circuit so that loss of ventilation or airflow immediately shuts down the heating system of the affected section, or, if necessary, loss of ventilation shall shut down the entire heating system as well as the conveyor.

5-5.1.2 Air pressure switches shall not be used to prove airflow where dampers downstream of the pressure switch can be closed to the point of reducing flow to an unsafe operating level.

5-5.1.3 Air suction switches shall not be used to prove airflow where dampers upstream of the pressure switch can be closed to the point of reducing flow to an unsafe operating level.

5-5.1.4 Means other than pressure and suction switches shall be used to prove airflow on systems where the air is contaminated with any substance that might condense or otherwise create a deposit and interfere with the performance of the switch.

5-5.2 Dampers capable of being adjusted to a position that can result in an unsafe condition shall be equipped with mechanical stops, cut-away dampers, or limit switches interlocked into the safety circuitry to ensure that dampers are in a proper operating position.

5-6 Combustion Air Safety Device.

5-6.1 Where the air from the exhaust or recirculating fans is required for combustion of the fuel, airflow shall be proven prior to an ignition attempt. Reduction of airflows to an unsafe level shall result in closure of the safety shutoff valves.

5-6.2 Where a combustion air blower is used, the minimum combustion air pressure required for proper burner operation shall be proven prior to each attempt at ignition.

5-6.3 Motor starters on equipment required for the combustion of the fuel shall be interlocked into the combustion safety circuitry.

5-6.4 A low pressure switch shall be used to sense and monitor combustion air pressure or differential pressure and shall be interlocked into the combustion safety circuitry.

5-6.5 Wherever it is possible for combustion air pressure to exceed a maximum safe operating pressure, as might occur where compressed air is utilized, a high pressure switch interlocked into the combustion safety circuitry shall be used.

5-7 Safety Shutoff Valves (Fuel Gas or Oil).

5-7.1 General.

5-7.1.1 Safety shutoff valves shall be utilized as a key safety control to protect against explosions and fires.

NOTE: Safety shutoff valves are used to effect a safe shutdown when de-energized by any safety device in a burner management system.

5-7.1.2 Safety shutoff valves shall automatically shut off the fuel to the burner system after interruption of the holding medium (such as electric current or fluid pressure) by any one of the interlocking safety devices or operating controls. Safety shutoff valves shall be self-closing and shall not be readily bypassed or blocked open.

5-7.1.3 Safety shutoff valves shall not be used as modulating control valves.

Exception: The use of listed safety shutoff valves designed as both a safety shutoff valve and a modulating valve, and tested for concurrent use, shall be permitted.

5-7.1.4 Valve components shall be of a material suitable for the fuel handled and ambient conditions.

5-7.1.5 Safety shutoff valves in systems containing particulate matter or highly corrosive fuel gas shall be operated regularly in accordance with the manufacturer's instructions to ensure their fail-safe operation.

5-7.1.6 Valves shall not be subjected to pressures in excess of the manufacturer's ratings.

5-7.1.7 If normal inlet pressure to the fuel pressure regulator immediately upstream from the valve exceeds the valve's pressure rating, a relief valve shall be provided and it shall be vented to a safe location.

5-7.1.8 Position indication shall be provided for safety shutoff valves to burners or pilots in excess of 150,000 Btu/hr (44 kW).

5-7.2 Fuel Gas Safety Shutoff Valves.

5-7.2.1 Each main and pilot fuel gas burner system shall be equipped with two safety shutoff valves piped in series.

Exception No. 1: If the main fuel gas burner system capacity is 400,000 Btu/hr (117 kW) or less, a single safety shutoff valve shall be permitted.

Exception No. 2: If the pilot fuel gas burner system capacity is 400,000 Btu/hr (117 kW) or less, a single safety shutoff valve shall be permitted.

Exception No. 3: A single safety shutoff valve shall be permitted on a radiant tube-fired burner system where:

(a) The tubes are of metal construction and open at one or both ends with heat recovery systems, if used, that are of explosion-resistant construction; or

(b) The entire radiant tube heating system, including any associated heat recovery system, is of explosion-resistant construction.

5-7.2.2 Where the main or pilot fuel gas burner system capacity exceeds 400,000 Btu/hr (117 kW), at least one of the safety shutoff valves required by 5-7.2.1 shall be proved closed and interlocked with the preignition purge interval. (*See 5-4.1.2.1.*)

5-7.2.3* A permanent and ready means for making tightness checks of all fuel gas safety shutoff valves shall be provided.

5-7.2.4 Tightness checks shall be performed in accordance with the manufacturer's instructions. Testing frequency shall be at least annually.

5-7.3 Oil Safety Shutoff Valves. Two safety shutoff valves shall be provided under any one of the following conditions:

(a) Where the pressure is greater than 125 psi (862 kPa);

(b) Wherever the fuel oil pump operates without the main oil burner firing, regardless of the pressure; or

(c) For combination gas and oil burners, where the fuel oil pump operates during the fuel gas burner operation.

NOTE: Where none of the conditions of 5-7.3(a) through (c) apply, a single safety shutoff valve should be permitted to be used.

5-8 Fuel Pressure Switches (Gas or Oil).

5-8.1 A low pressure switch shall be provided and shall be interlocked into the combustion safety circuitry.

5-8.2 A high gas pressure switch shall be provided and interlocked into the combustion safety circuitry. The switch shall be located downstream of the final pressure-reducing regulator.

Exception: For an oil system, a high pressure switch shall be not required where the fuel supply pressure to the burners cannot exceed the operating limits of the system.

5-8.3 Pressure switch settings shall be made in accordance with the operating limits of the burner system.

5-9 Combustion Safeguards (Flame Supervision).

5-9.1 Each burner flame shall be supervised by a combustion safeguard having a maximum flame failure response time of 4 seconds or less, interlocked into the combustion safety circuitry.

Exception No. 1: The flame supervision shall be permitted to be switched out of the combustion safety circuitry for a furnace zone when that zone temperature is at or above 1400°F (760°C). When the zone temperature drops below 1400°F (760°C), the burner shall be interlocked to allow its operation only if flame supervision has been re-established. A 1400°F (760°C) bypass controller shall be used for this purpose.

Exception No. 2: Omission of combustion safeguards on radiant tube-type heating systems shall be permitted where a suitable means of ignition is provided and the systems are arranged and designed as follows:

(a) The tubes are of metal construction and open at one or both ends with heat recovery systems, if used, that are of explosion-resistant construction; or

(b) The entire radiant tube heating system, including any associated heat recovery system, is of explosion-resistant construction.

Exception No. 3: Burners without flame supervision shall be permitted, provided these burners are interlocked to prevent their operation when the zone temperature is less than 1400°F (760°C). A 1400°F (760°C) bypass controller shall be used for this purpose.

5-9.2 Flame Supervision.

5-9.2.1 Each pilot and main burner flame shall be supervised independently.

Exception No. 1: One flame sensor shall be permitted to be used to supervise the main burner and pilot flames if an interrupted pilot is used.

Exception No. 2: One flame sensor shall be permitted to be used to supervise self-piloted burners, as defined in Chapter 2.

5-9.2.2* Line burners, pipe burners, and radiant burners, where installed immediately adjacent to one another or connected with suitable flame-propagating devices, shall be considered to be a single burner and shall have at least one flame safeguard installed to sense burner flame at the end of the assembly farthest from the source of ignition.

5-10 Fuel Oil Atomization (Other than Mechanical Atomization).

5-10.1 Adequate pressure of the atomizing medium shall be proven and interlocked into the combustion safety circuitry.

5-10.2 The low pressure switch used to supervise the atomizing medium shall be located downstream from all cocks, valves, and other obstructions that can shut off flow or cause excessive pressure drop of atomization medium.

5-11* Fuel Oil Temperature Limit Devices. Fuel oil temperature limit devices shall be provided and interlocked into the combustion safety circuitry if conditions allow the fuel oil temperature to rise above or fall below a predetermined safe level.

5-12 Multiple Fuel Systems.

5-12.1 Safety equipment in accordance with the requirements of this standard shall be provided for each fuel used. The fact that oil or gas is considered a standby fuel shall not reduce the safety requirements for that fuel.

5-12.2 Where dual-fuel burners are used, positive provision shall be made to prevent the simultaneous introduction of both fuels.

Exception: This requirement shall not apply to combination burners.

5-13 Air-Fuel Gas Mixing Machines.

5-13.1 A safety shutoff valve shall be installed in the fuel gas supply connection of any mixing machine.

5-13.2 This valve shall be arranged to shut off the fuel gas supply automatically when the mixing machine is not in operation or in the event of an air or fuel gas supply failure.

5-14 Oxygen Safety Devices.

5-14.1 Two oxygen safety shutoff valves in series shall be provided in the oxygen supply line.

Exception: If the capacity of the burner system is 400,000 Btu/hr (117 kW) or less, a single safety shutoff valve shall be permitted.

5-14.2 A filter or fine-mesh strainer shall precede the upstream safety shutoff valve.

5-14.3 There shall be a high oxygen flow or pressure limit interlocked into the combustion safety circuitry. The switch shall be located downstream of the final pressure regulator or automatic flow control valve.

5-14.4 There shall be a low oxygen flow or pressure limit interlocked into the combustion safety circuitry.

5-14.5 The oxygen safety shutoff valves shall shut automatically after interruption of the holding medium by any one of the interlocking safety devices.

5-14.6 Oxygen-Enriched Burners.

5-14.6.1 Where oxygen is added to a combustion air line, the oxygen and airflows shall be interlocked to prevent the initiation of oxygen flow prior to establishment of airflow.

5-14.6.2 Upon loss of oxygen flow, the flow of fuel shall be permitted to continue where there is no interruption in the flow of combustion air, provided the control system can revert automatically to a safe air-fuel ratio before a hazard due to a fuel-rich flame is created.

5-14.7 Burner systems employing water or other liquid coolants shall be equipped with a low coolant flow limit switch located downstream of the burner and interlocked into the combustion safety circuitry.

5-14.7.1 A time delay shall be permitted that allows the operator to take corrective action, provided an alarm is activated and it can be proved to the authority having jurisdiction that such a delay cannot create a hazard.

5-14.7.2 Coolant piping systems shall be protected from freezing and overpressurization.

5-15 Ignition of Main Burners—Fuel Gas or Oil.

5-15.1 If a reduced firing rate is required for safe and reliable ignition of the burner (forced low-fire start), an interlock shall be provided to prove the control valve is properly positioned prior to each attempt at ignition.

5-15.2 Electrical ignition energy for direct spark ignition systems shall be terminated after the main burner trial-for-ignition period.

Exception: Continuous operation of direct spark igniters shall be permitted for radiant tube-type heating systems that do not require combustion safeguards.

5-16 Excess Temperature Limit Controller.

5-16.1 An excess temperature limit controller shall be provided and interlocked into the combustion safety circuitry, unless it can be demonstrated that a safe temperature limit cannot be exceeded.

5-16.2 Operation of the excess temperature limit controller shall cut off the source of heat before the safe temperature is exceeded.

5-16.3 Operation of the excess temperature limit controller shall require manual reset before restart of the furnace or affected furnace zone.

5-16.4 Failure of the temperature-sensing element of the excess temperature limit controller shall cause the same response as an excess temperature condition.

> **CAUTION:** Where a thermocouple is used with an excess temperature limit controller, ruggedly constructed and conservatively rated thermocouples and extension wires shall be used to minimize the probability of a short circuit in the thermocouple or thermocouple extension wires. Thermocouple short circuits should not result in the action required by 5-16.4.

5-16.5 The temperature-sensing element of the excess temperature limit controller shall be suitable for the temperature and atmosphere to which it is exposed.

5-16.6 The temperature-sensing element of the excess temperature limit controller shall be located to sense the temperature most critical to safe operation.

5-16.7 The excess temperature limit controller set point shall be displayed in units of temperature (°F or °C).

5-16.8 The operating temperature controller and its temperature-sensing element shall not be used as the excess temperature limit controller.

5-17 1400°F (760°C) Bypass Controller.

5-17.1 Where permitted in accordance with 5-9.1 to switch the flame supervision out of the combustion safety circuitry or to bring unsupervised burners on-line, a 1400°F (760°C) bypass controller shall be used.

5-17.2 Failure of the temperature-sensing element shall cause the same response as an operating temperature less than 1400°F (760°C).

5-17.3 The temperature-sensing element of the 1400°F (760°C) bypass controller shall be suitable for the temperature and atmosphere to which it is exposed.

5-17.4 The temperature-sensing element of the 1400°F (760°C) bypass controller shall be located to sense the temperature most critical to safe operation.

5-17.5 The 1400°F (760°C) bypass controller set point shall not be set below 1400°F (760°C) and the set point shall be displayed in units of temperature.

5-17.6 Visual indication shall be provided to indicate when the 1400°F (760°C) bypass controller is in the bypass mode.

5-17.7 The operating temperature controller and its temperature-sensing element shall not be used as the 1400°F (760°C) bypass controller.

5-18 Electrical Heating Systems.

5-18.1 Heating Equipment Controls.

5-18.1.1* Electric heating equipment shall be equipped with a main disconnect device or with multiple devices to provide back-up circuit protection to equipment and to persons servicing the equipment. Such a disconnecting device(s) shall be made capable of interrupting maximum available fault current as well as rated load current. (*See* NFPA 70, *National Electrical Code.*)

5-18.1.2 Shutdown of the heating power source shall not inadvertently affect the operation of equipment such as conveyors, ventilation or recirculation fans, cooling components, and other auxiliary equipment.

5-18.1.3 Branch Circuits. 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.*

5-18.1.4* The capacity of all electrical devices used to control energy for the heating load shall be selected on the basis of continuous duty load ratings where fully equipped for the location and type of service proposed.

5-18.1.5 All controls using thermal protection or trip mechanisms shall be located or protected to preclude faulty operation due to ambient temperatures.

5-18.2 Excess Temperature Limit Controller.

5-18.2.1 An excess temperature limit controller shall be provided and interlocked into the heating control circuitry.

Exception: Where it can be demonstrated that a safe temperature limit cannot be exceeded.

5-18.2.2 Operation of the excess temperature limit controller shall cut off the source of heat before the safe temperature is exceeded.

5-18.2.3 Operation of the excess temperature limit controller shall require manual reset before restart of the furnace or affected furnace zone.

5-18.2.4 Failure of the temperature-sensing element of the excess temperature limit controller shall cause the same response as an excess temperature condition.

CAUTION: Where a thermocouple is used with an excess temperature limit controller, ruggedly constructed and conservatively rated thermocouples and extension wires shall be used to minimize the probability of a short circuit in the thermocouple or thermocouple extension wires. Thermocouple short circuits should not result in the action required by 5-18.2.4.

5-18.2.5 The temperature-sensing element of the excess temperature limit controller shall be suitable for the temperature and atmosphere to which it is exposed.

5-18.2.6 The temperature-sensing element of the excess temperature limit controller shall be located to sense the temperature most critical to safe operation.

5-18.2.7 The excess temperature limit controller set point shall be displayed in units of temperature (°F or °C).

5-18.2.8 The operating temperature controller and its temperature-sensing element shall not be used as the excess temperature limit controller.

5-19 Vacuum Furnace Systems.

5-19.1 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.

5-19.2* Indicating or recording vacuum gauges shall be employed to measure pressures in the vessel chamber and in the piping between the rough valve and the vacuum pump(s). Gauges shall have the capability to measure the expected lowest pressure achievable by the vacuum system.

NOTE: The calibration of all vacuum gauges should follow the standards specified by the American Vacuum Society. For a description of the various types of vacuum gauges, see A-5-19.2.

5-19.3 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.

5-19.4 Automatic valves shall be provided to close the holding pump, foreline, roughing, and main vacuum valves in the event of the failure of a power supply or other valve-actuating medium in order to prevent pump oil or air from passing through the system or causing damage to the furnace or load.

5-19.5 A warning label shall be permanently affixed to diffusion pumps covering safe methods of servicing pumps that reads as follows: "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 the pump and furnace hot zone."

5-20 Internal Quench Vacuum Furnaces.

5-20.1 Wherever a vacuum furnace has an internal liquid quench chamber, in addition to the above safety controls, the controls specified in this section shall be provided.

5-20.2 Automatic temperature controls shall be installed in pressure-type water-cooling and oil-cooling systems to ensure the desired jacket temperature.

5-20.3 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 shall be permitted to be used in emergencies.

5-20.4 Controls for the admittance and maintenance of special atmosphere within the quench chamber shall conform to the controls described in Section 8-2.

5-20.5 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.

5-20.6 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.

5-20.7 The quench tank shall be equipped with a low liquid level device arranged to sound an alarm, prevent the start of quenching, and shut off the heating medium in case of a low liquid level condition.

5-20.8 Excess temperature limit control shall be provided and interlocked to shut off the quench heating medium automatically and shall require operator attention in case of excessive quench medium temperature. Excess temperature limit control shall be interlocked to prevent the start of quenching in case of excessive quench medium temperature. Audible and visual alarms shall be provided.

5-20.9 Where agitation of the quench medium is required to prevent overheating, the agitation shall be interlocked to prevent quenching until the agitator has been started.

5-20.10 A reliable means shall be used to sample for water in quench oil.

Chapter 6 Fume Incinerators

6-1 General.

6-1.1* The design and construction of fume incinerators shall comply with all requirements of Class A ovens in this standard.

Exception: The requirements for explosion relief shall not apply to fume incinerators.

NOTE 1: Afterburner or fume incinerator systems might or might not employ catalysts or various heat exchange devices to reduce fuel usage.

NOTE 2: Structural supports, thermal expansion joints, protective insulation for incinerator housings, stacks, related ductwork, and heat recovery systems utilizing incinerator exhaust gases should be designed for operating temperatures of 450°F to 2000°F (232°C to 1093°C).

6-1.2 Design and operation of combustion systems and controls shall comply with all parts of this standard pertaining to direct-fired ovens.

CAUTION: An individual fume source, or multiple sources into one fume incinerator, might cause additional hazards if fed into an operating incinerator during the purge cycle of the source. (*See 5-4.1.3.*)

NOTE: Additional interlocks should be provided to ensure that proper operation is maintained in conjunction with the fume-generating process and that sufficient operating temperatures are sustained for acceptable thermal destruction of fumes.

6-1.3 Special precautions shall be taken to reduce the fire hazards where the relative location of equipment or the type of fumes generated are such that combustible liquids can condense or solids can be deposited between the generating process and the afterburner. (*See Chapters 3 and 12.*)

6-1.4 An excess temperature limit controller shall be provided to prevent the uncontrolled temperature rise in the fume incinerator. Operation of the excess temperature limit controller shall interrupt fuel to the fume incinerator burner and shall interrupt the source of fumes to the incinerator.

NOTE: Forms of operating protection should be permitted to include one or more of the following:

(a) Reduction or termination of fuel to the fume incinerator burner;

(b) Interruption of the fume-generating process;

(c) Dilution of hydrocarbon concentration with fresh air; or

(d) Partial emission stream bypass of the heat exchanger.

6-1.5 Direct Heat Recovery Systems.

6-1.5.1 An adequate supply of fresh air shall be introduced into the system to provide the oxygen necessary for combustion of hydrocarbons as well as primary burner fuel.

6-1.5.2 Where direct heat recovery systems are employed and portions of the incinerator exhaust gases are utilized as the heat source for one or more of the zones of the fume-generating oven, special precautions shall be taken to prevent recycling unburned solvent vapors.

NOTE: This type of system includes safety devices such as, but not limited to, proof-of-flow, interlocks, and temperature limits.

6-2 Catalytic Fume Incinerators.

6-2.1* An additional excess temperature limit controller shall be located downstream from the discharge of the catalyst bed for thermal protection of the catalyst elements. Operation of the excess temperature limit controller shall interrupt fuel to the burner and shall interrupt the source of fumes.

6-2.2 Sufficient process exhaust ventilation shall be provided to maintain vapor concentrations that cannot generate temperatures at which thermal degradation of the catalyst can occur.

NOTE: Concentrations at 25 percent LEL can produce a temperature rise near 600°F (316°C) that, where added to the required inlet temperature, results in temperatures generally considered to be within a range where thermal degradation occurs.

6-2.3 A differential pressure (ΔP) high limit switch, measuring across the catalyst bed, shall be used to detect particulate contamination. Operation of the high limit differential pressure switch shall interrupt fuel to the fume incinerator burner and shall interrupt the source of fumes to the incinerator.

NOTE: Oxidation performance of catalyst material is a function of temperature, velocity, and pressure drop (ΔP) through the bed, with the bed size and configuration directly related to these factors. Pressure drop across the bed fluctuates with temperatures and particulate contamination. Contamination can lead to reduced safety ventilation.

6-2.4 Where catalysts are utilized with direct heat recovery, a maintenance program shall be established, and frequent tests of catalyst performance shall be conducted so that unburned or partially burned vapors are not reintroduced into the process oven.

Chapter 7 Integral Liquid Quench Vacuum Furnaces

7-1 General.

NOTE: Integral liquid quench systems might be constructed within the furnace vacuum chamber or might 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 might be divided into three separate chambers: a loading vestibule, a hot vacuum chamber, and a 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 can be quenched by either vacuum, gas, or oil.

7-2 Requirements.

7-2.1 The vacuum chamber or quench vestibule, or both, 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, could be subject to the introduction or accumulation of water from a number of sources that, where exposed to the heat released from quenching of work, flash to steam. The resulting increase in volume causes overpressurization of the quench vestibule.

NOTE 2: The 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 dew point temperatures.

7-2.2 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 operation.

NOTE: The quench vestibule design and size depend on end use. If the quench vestibule doubles as an atmosphere-gas cooling chamber, forced cooling normally is required and is provided by water-filled jackets, plate coils, or tubing tracing.

7-2.3 If an intermediate door between the furnace and the quench vestibule is employed, it shall be closed during the quenching operation to serve as a baffle.

7-2.4 Manual facilities shall be provided to allow the door of the outer quench vestibule to be opened. Opening of this door under emergency conditions shall be an operating personnel decision.

7-3 Construction of Quenching Tanks.

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

7-3.1 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.

7-3.1.1 The quench tank shall be tested for leaks prior to use.

7-3.1.2 Where the elevator and work load are submerged, the quench tank shall be designed and operated with a maximum quench medium level of not less than 6 in. (15 cm) below the door or any opening into the furnace.

7-3.1.3 The quench tank shall have sufficient capacity to quench a maximum gross load with a maximum temperature rise that cannot exceed 50°F (10°C) below the flash point and cooling capabilities to recover the quench medium temperature between minimum design quench cycles.

7-3.2 Where hot-rolled steel plate is used, oil or other non-water-based coolants 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 permitted to 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 of the compatibility of materials and welding techniques employed.

Steel plate coils, attached by thermal contact cement to the external surfaces of the quench chamber, fabricated of hot-rolled steel plate, have produced acceptable heat transfer. Careful attention should be given to the design of the junction of the upper and lower chambers to minimize the possibility of water leakage into the quench reservoir.

Steel plate coils can be used with either water- or oil-type coolants, although the eventual plugging of their passages with rust and mineral deposits can be anticipated where water is used as a coolant. The use of stainless steel plate coils, while a more expensive construction method, considerably reduces 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. Where careful attention is given to the design of the junction of the upper and lower quench vestibule, the possibility of water leakage into the quench tank is minimized.

NOTE 3: Paragraph 7-3.2 does not apply to the vacuum furnace chamber.

7-3.3 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 always shall exceed that of the cooling water. A differential pressure switch shall be required and interlocked with the quench cycle.

7-4 Elevators.

7-4.1 The elevator's function shall be to immerse the work charge in the quench medium with minimum splashing. At termination of the timed quench cycle, the elevator shall be raised to the drain position at hearth level.

7-4.2 The elevating mechanism shall be supported substantially by structural members in order to handle the maximum rated loads.

7-4.3 Elevator guides or ways shall be provided to ensure uniform stabilized movement of the elevator in the confined areas of the quench tank.

7-4.4 Tray guides or stops shall be provided to ensure that the tray is positioned properly on the elevator.

7-5 Cooling Systems.

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

(a) An internal cooler, where a heat transfer medium is circulated through a heat exchanger within the quench tank.

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

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

7-5.1 Consideration shall be given to the use of corrosion-resistant materials for the construction of internal tank-cooled heat exchangers.

7-5.2 The heat exchanger shall be subjected to a minimum pressure test of 150 percent of the maximum designed working pressure after installation in a quench tank.

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

7-5.3 The heat exchanger shall be located within the quench tank in a manner to prevent mechanical damage by the elevator or the load to be quenched.

7-5.4 Water shall not be used as a heat transfer medium for internal coolers in combustible liquid oil quench tanks.

7-5.5 The cooling medium flow shall be controlled by an automatic temperature controller.

7-5.6 If it is possible to close off the internal heat exchanger completely, a pressure-relief valve shall be provided that terminates in a safe location.

NOTE: The tubes of the heat exchanger that are exposed to contact with water should be constructed of corrosion-resistant materials.

7-5.7 After fabrication, the heat exchanger 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 a similar test prior to being placed in service, and at periodic intervals thereafter, to ascertain that it is free of leaks.

7-5.8 The pressure of the quench medium through the heat exchanger shall be greater than the water pressure applied.

7-5.9 External air-cooled heat exchangers installed outdoors shall be reinforced structurally to withstand anticipated wind forces without damage at the elevation at which they are mounted.

7-5.10 External air-cooled heat exchangers that are installed outdoors or that utilize supplemental water cooling shall be constructed of materials that are suitably protected against corrosion.

7-5.11 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 close off the external heat exchanger completely, a pressure-relief valve shall be provided that terminates in a safe location.

7-5.12 External Air-Cooled System.

7-5.12.1 An external heat exchanger installed outdoors shall be provided with lightning protection if located in an exposed, rooftop location.

7-5.12.2 If the air-cooled heat exchanger is installed in a rooftop location, it shall be installed in a curbed or diked area and drained to a safe location outside of the building.

7-6 Electric Immersion Heaters.

7-6.1 Electric immersion heaters shall be of sheath-type construction.

7-6.2 Heaters shall be installed so that the hot sheath is fully submerged in the quench medium at all times.

7-6.3 The quench medium shall be supervised by:

(a) A temperature controller arranged to maintain the quench medium at the 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.

7-6.4 The electrical heating system shall be interlocked with the quench medium agitation or recirculation system to prevent localized overheating of the quench medium.

Chapter 8 Vacuum Furnaces Used With Special Flammable Atmospheres

8-1 General.

8-1.1* Flammable gases shall be permitted to be used in conjunction with vacuum furnaces for thermal processes such as carburizing, nitriding, brazing, sintering, and chemical vapor deposition.

NOTE: 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.

8-1.2 This section shall apply to any vacuum chamber or furnace in which a flammable gas is used at a pressure of one-half or more of its lower explosive limit in air.

NOTE: The lower explosive limit for hydrogen is 4 percent in air. This represents a pressure of 30 torr (0.39 Pa). In the interest of safety, a lower limit of one-half of this pressure [15 torr (0.19 Pa)] has been used. Other gases have other lower explosive limits. (*See Appendix F.*)

8-2 Safety Controls and Equipment.

8-2.1 Where flammable atmospheres are used, the vacuum systems and the systems used to introduce flammable and inert gases shall be interlocked in such a way that these systems operate automatically without the intervention of an operator.

8-2.2 In addition to the flammable gas, a supply of inert purge gas shall be available. The inert gas storage supply shall contain at all times sufficient gas to completely purge the system. The supply shall be a minimum of five 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.

8-2.3 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 allow adequate purging. Any automatic purge gas shutoff valve shall be interlocked to prevent introduction of flammable atmospheres if the valve is inoperable.

8-2.4 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.

8-2.5 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: Flammable gas should 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.

8-2.6 In the case of a multiple chamber-type or continuous-type vacuum furnace, each chamber shall be regarded as a separate system. Interlocks shall be provided that prevent the valves from opening between adjacent interconnecting chambers once a flammable atmosphere has been introduced into any 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.

8-2.7 The vacuum pumping system shall be interlocked with the supply gas system so that mechanical pumps continue to operate while flammable gas is in the vacuum chamber, whether or not the flammable gas is to flow through the pumps, or so that the vacuum pumping lines are backfilled with an inert atmosphere during this interval.

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

8-2.8 Mechanical pump gas ballast valves, which normally are furnished with mechanical vacuum pumps, shall be plugged or piped to a source of inert gas. Vacuum air release valves on roughing or forelines shall be piped to a source of inert gas.

8-2.9 Since hydrocarbon oils are used in mechanical vacuum pumps, the discharge reservoir and piping shall be maintained below any ignition temperature for the oil.

8-2.10 No manual air release valve shall be permitted in a vacuum furnace that is used with flammable atmospheres at a pressure of one-half or more of its lower explosive limit in air.

8-2.11 Each vacuum chamber that is used with flammable atmospheres at a pressure of one-half or more of its lower explosive limit in air shall be equipped with a self-closing explosion venting device. (*See NFPA 68, Guide for Venting of Deflagrations.*)

8-2.12 Special attention shall be given to door clamping for chambers used with flammable gases. Consideration shall be given to the use of pneumatic clamps interlocked to ensure that doors are tightly and positively closed.

NOTE: Although a chamber can be pumped to 1×10^{-1} torr (0.0013 Pa), when backfilling, the door can open if not clamped.

8-2.13 Sight glasses shall be removed or valved off during operation with flammable gases. This shall not apply to sight glasses used solely for pyrometers.

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

8-3 Flammable Gases.

8-3.1 During processing, flammable gases normally shall be exhausted from vacuum furnaces by pumping them through the vacuum pumps, or by venting in continuous flow to the atmosphere, with or without ignition and burning.

8-3.2 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 any area where atmosphere circulation prevents concentration at ignition levels. Alternately, the pump discharge shall be permitted to be diluted with air in a volume sufficient to prevent concentration at ignition levels, or the discharge shall be permitted to be passed through a burner.

8-3.3 If the flammable gas is vented to the 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.

8-3.4 If the flammable gas is vented to the 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 monitored independently, with interlocks to shut off the flammable gas supply and initiate inert gas purge if the flame is not sensed.

8-3.5 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.

8-3.6 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.

8-3.7 Where flammable gas is exhausted through a vent, the vent valve shall not open until a pressure above atmosphere is attained in the chamber.

8-4 Removal of Flammable Gas.

8-4.1 Purging with Inert Gas.

8-4.1.1 The valve for admitting the inert gas to the furnace shall be opened and the valves supplying the flammable gas to the furnace then shall be closed, or the valves shall be operated simultaneously.

8-4.1.2 Where two consecutive readings of an analysis of the vent gas from the furnace indicate that less than 50 percent of the lower explosive limit of the process gas is being exhausted, the purge shall be considered complete.

8-4.2 Purging with Vacuum. 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 8-3.2.

8-5 Emergency Shutdown Procedure.

8-5.1 In the event of an electrical power failure or flammable gas failure, or both, the emergency purge gas standby system shall be actuated to purge the furnace immediately. The purge gas flow shall continue until at least five times the volume of the furnace has been provided.

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

(a) Heating system;

(b) Flammable atmosphere gas system; and

(c) Vacuum pumping system.

8-5.2 All flammable atmosphere gas valves to the furnace shall be closed.

8-5.3 Where two consecutive readings of an analysis of the exhausted gas from the furnace indicate that less than 50 percent of the lower explosive limit of the process gas is being exhausted, the purge shall be considered complete.

Chapter 9 Bulk Atmosphere Gas Storage Systems

9-1 Construction.

9-1.1 All storage tanks and cylinders shall comply with local, state, and federal codes relating to pressures and type of gas.

9-1.2 Vessels, controls, and piping shall be constructed to maintain their integrity under maximum design pressures and temperatures.

9-2 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.

9-3 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*; and

(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 should be made to ANSI K61.1, *Storage and Handling of Anhydrous Ammonia.*

Chapter 10 Vacuum Induction Furnaces

10-1 General.

10-1.1 For the purpose of this chapter, vacuum induction furnaces shall be those furnaces that use both induction heating as the heating source and a vacuum atmosphere as noted in Section 1-1.

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 can be direct by coupling, indirect by a secondary cylinder or susceptor, or by a combination of both of these methods. (*See Figure 10-1.1.*)

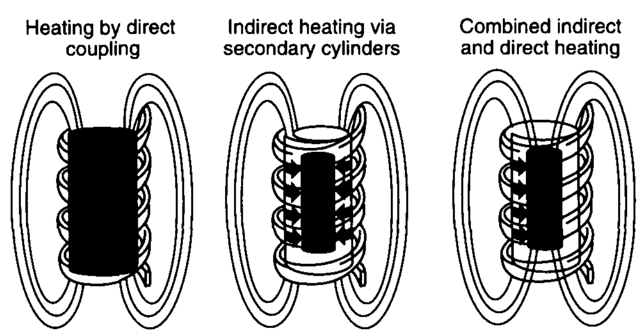

Figure 10-1.1 The three induction heating methods.

10-1.2 The types of induction furnaces described in this chapter are those furnaces used for melting, casting, sintering, hot pressing, outgassing, degassing, metal purification, general heat treating, brazing, and chemical vapor deposition.

10-1.3 All requirements for induction heating equipment specified in NFPA 70, *National Electrical Code*, also shall apply to this chapter.

10-2 Location.

10-2.1 Vacuum induction furnaces and their ancillary equipment shall be located to minimize the possibility of fire.

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

10-2.2 Consideration shall be given to the location of vacuum induction furnaces to prevent injury to all personnel.

10-3 Construction.

10-3.1 The basic vessel or vacuum chamber of an inductive vacuum furnace shall be designed in accordance with ASME *Boiler and Pressure Vessel Code*, Section VIII, Division 1. The vacuum tightness (leak rate) shall be specified in relation to the required operating vacuum level.

10-3.2 Water-cooled components shall be designed with wall thicknesses in accordance with corrosion tables and vessel standards. (*See ASME Boiler and Pressure Vessel Code, Section VIII.*)

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

10-3.3 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.

10-3.4 Susceptors, refractory materials, power cables, and insulation materials shall be retained or supported so that they do not fall out of place.

10-3.5 The furnace chamber design shall take into account the heating effect of the induction field and shall be of suitable size and materials to minimize the heating effect on its walls.

10-3.6 Where 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 burn-through of the chamber.

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

10-3.7 Wherever a coil or coils having multiple sections or multiple water pads are used, such coils or pads shall have separately valved water circuits to ensure continuity of cooling in the event of a water leak.

10-3.8 Water-cooled induction leads shall be of sufficient length and proper design to minimize any work-hardening as a result of movement.

10-3.9 Wherever an elevator is used, the elevating mechanism shall be supported substantially 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.

10-4 Heating Systems.

10-4.1 For the purpose of this chapter, the term "heating system" shall include an electrical power supply, induction coil, and related hardware.

10-4.2 All components, such as the vacuum chamber, power supply, and control cabinet, shall be grounded.

Exception: Induction coils shall not be required to be grounded. (See 10-5.7.)

10-4.3 It shall be the purpose of the power supply to transform the power line to a suitable voltage and current (and, where necessary, to 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 to the individual furnace and size.

NOTE 2: The power supply can include a transformer (or a motor generator), capacitors with control switches as necessary, a control device such as a saturable core reactor, primary fuses or circuit breakers for electrical protection, and an electrical disconnect switch for service. A power controller may be permitted to be used where necessary 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 in order 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 commences as a result of the field emission of electrons. For insulated induction coils, the operating voltage may be permitted to be higher in accordance with the dielectric of the insulating media chosen by the designer.

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

10-4.4 The geometry of the coil and its placement with respect to the susceptor or load shall be considered carefully to provide proper heating rate, maintain proper operating temperature, and meet temperature uniformity specifications.

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

10-4.5 The electrically energized induction coil shall be supported so that it does not come into contact with the susceptor or work pieces or fixtures and so that it avoids 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.

10-4.6 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.

10-4.7 In the case of an insulated or individually wrapped induction coil, the requirement of 10-4.6 also shall apply to the tape or insulation.

10-4.8 The design of the induction coil shall be considered carefully for proper match of impedance between the power supply, the coil, and the susceptor or work load.

10-4.9 The induction coil power terminal and vessel feed-through design shall be considered for vacuum integrity and induction heating effects.

NOTE: Generally, the feed-through flange should be of electrically nonconductive material, and the power feed-through leads should be grouped in close proximity.

10-4.10 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.

10-4.11 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.

10-5 Safety Controls.

10-5.1 All electrical safety controls and protective devices required for induction systems in NFPA 70, *National Electrical Code*, shall apply.

10-5.2 An interlock shall be provided to disconnect power to the furnace wherever opening the control cabinet door exposes persons to contact with hazardous voltages.

10-5.3 Where an open system is used, an open sight drain in the water coolant shall be provided for immediate, visible indication of waterflow in the cooling line of the induction coil.

10-5.4 The flow of the cooling water shall be monitored at the discharge of each induction coil circuit to shut down the power in the event of inadequate flow.

10-5.5 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 temperature of the cooling water is beyond the recommended temperature of operation, as specified by the design of the equipment.

NOTE: Separate indicator lights for malfunctions should be installed in the control circuit to indicate malfunctions. Light circuits should be reset by separate pushbutton switches when the malfunction has been corrected.

10-5.6 A molten metal leak detector shall be installed on all vacuum induction melting furnaces where the capacity for melting is more than 500 lb (227 kg) of metal. This detector shall sound an alarm indicating a leaking crucible whenever it senses molten metal in the refractory surrounding the crucible.

10-5.7 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.

10-5.8 Wherever an elevator is used in a vacuum induction melting furnace, the external door operation shall be interlocked so that it cannot be opened unless the elevator is in the proper position.

10-5.9 Also, where such an elevator is used, the crucible shall be interlocked so that it cannot be in the pour position unless the elevator is in the proper position.

Chapter 11* Inspection, Testing, and Maintenance

11-1 Responsibility of the Manufacturer and the User. The equipment manufacturer shall inform the user regarding the need for adequate operational checks and maintenance and shall provide complete and clear inspection, testing, and maintenance instructions. The final responsibility for establishing an inspection, testing, and maintenance program that ensures that the equipment is in proper working order shall be that of the user.

11-2* Checklist. The user's operational and maintenance program shall include all procedures that apply to the specific equipment. An operational and maintenance checklist shall be maintained and is essential to safe operation of the equipment.

Chapter 12 Fire Protection

12-1 General. Furnaces can present fire hazards to the surrounding area in which they are installed. Fixed fire extinguishing systems shall be provided to protect against such hazards as overheating, spillage of molten salts or metals, quench tanks, ignition of hydraulic oil, and escape of fuel. It shall be the user's responsibility 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 typically can be detected by heat waves.

NOTE 1: Hydrogen fires normally are not 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 are sprayed on adjacent equipment to cool the equipment and prevent its involvement in the fire. Combination fog and solid-stream nozzles are recommended to allow the widest adaptability in fire control. Small hydrogen fires are extinguished by dry chemical extinguishers or with carbon dioxide, nitrogen, and steam. Reignition can occur if a metal surface adjacent to the flame is not cooled with water or by other means.

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

12-2 Sprinkler and Spray Systems. Subject to the authority having jurisdiction, either automatic sprinkler or water spray systems shall be provided.

12-2.1 Automatic Sprinkler Systems. Automatic sprinkler installations shall be in accordance with NFPA 13, *Standard for the Installation of Sprinkler Systems.*

12-2.2 Water Spray Systems. Water spray systems shall be fixed systems and automatic in operation and shall be in accordance with NFPA 15, *Standard for Water Spray Fixed Systems for Fire Protection.*

12-3 Portable Protection Equipment.

12-3.1 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.*

12-3.2 Inside Hose Connections. Where small hose streams are required, they shall be installed in accordance with NFPA 13, *Standard for the Installation of Sprinkler Systems,* or NFPA 14, *Standard for the Installation of Standpipe and Hose Systems.*

Chapter 13 Referenced Publications

13-1 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.

13-1.1 NFPA Publications. National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101.

NFPA 10, *Standard for Portable Fire Extinguishers,* 1994 edition.

NFPA 13, *Standard for the Installation of Sprinkler Systems,* 1994 edition.

NFPA 14, *Standard for the Installation of Standpipe and Hose Systems,* 1993 edition.

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

NFPA 31, *Standard for the Installation of Oil-Burning Equipment,* 1992 edition.

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

NFPA 50A, *Standard for Gaseous Hydrogen Systems at Consumer Sites,* 1994 edition.

NFPA 54, *National Fuel Gas Code,* 1992 edition.

NFPA 58, *Standard for the Storage and Handling of Liquefied Petroleum Gases,* 1995 edition.

NFPA 70, *National Electrical Code,* 1996 edition.

NFPA 79, *Electrical Standard for Industrial Machinery,* 1994 edition.

NFPA 86, *Standard for Ovens and Furnaces,* 1995 edition.

NFPA 86C, *Standard for Industrial Furnaces Using a Special Processing Atmosphere,* 1995 edition.

NFPA 91, *Standard for Exhaust Systems for Air Conveying of Materials,* 1995 edition.

13-1.2 Other Publications.

13-1.2.1 ANSI Publications. American National Standards Institute, 1430 Broadway, New York, NY 10018.

ANSI A14.3, *Safety Requirements for Fixed Ladders,* 1992.

ANSI B31.1, *Power Piping,* 1992.

ANSI B31.3, *Chemical Plant and Petroleum Refinery Piping,* 1993.

13-1.2.2 ASME Publication. American Society of Mechanical Engineers, 345 East 47th Street, New York, NY 10017.

ASME *Boiler and Pressure Vessel Code,* 1992.

13-1.2.3 ASTM Publication. American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

ASTM D396, *Standard Specifications for Fuel Oils,* 1992.

13-1.2.4 U.S. Government Publications. Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

Code of Federal Regulations, Title 29, Part 1910.24

Code of Federal Regulations, Title 29, Part 1910.25

Code of Federal Regulations, Title 29, Part 1910.26

Code of Federal Regulations, Title 29, Part 1910.27

Code of Federal Regulations, Title 29, Part 1910.28

Code of Federal Regulations, Title 29, Part 1910.29

Appendix A Explanatory Material

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

A-1-1.2.3 Melting and Casting Furnaces.

(a) **Plasma Melting.**

1. Plasma melting is a process by which metal solids, powders, chips, and fines can be consolidated into ingot or slab form. Melting is accomplished by use of an ionized gas that transfers heat from the plasma torch to the material. The gas might 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 might 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.

2. The melt chamber operating pressure might 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 might be accomplished by the use of hearth melting, stirring action by torch manipulation, inductive stirring coils, or 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 high temperature with alarms for all circuits and power disruption for critical circuits, or both.

4. Solid-state power supplies are utilized to provide power to the torches, which range in size from 50 kW for

Table A-1-1.2 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
Multichamber	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
Water-Cooling Equipment	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
Pressure	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
Overheating	yes	yes	yes	yes	yes	yes	yes	yes	yes
Steam buildup	yes	yes	yes	yes	yes	yes	yes	yes	yes
Diffusion pump element	yes	yes	yes	yes	yes	op	yes	op	no
Pump element overheating	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 shutdown	yes	yes	yes	—	yes	yes	yes	yes	yes
H. Personnel Safety Hazards	yes	yes	yes	yes	yes	yes	yes	yes	yes

Yes — Equipment is provided or condition is present **op — Optional, and there might be a choice**

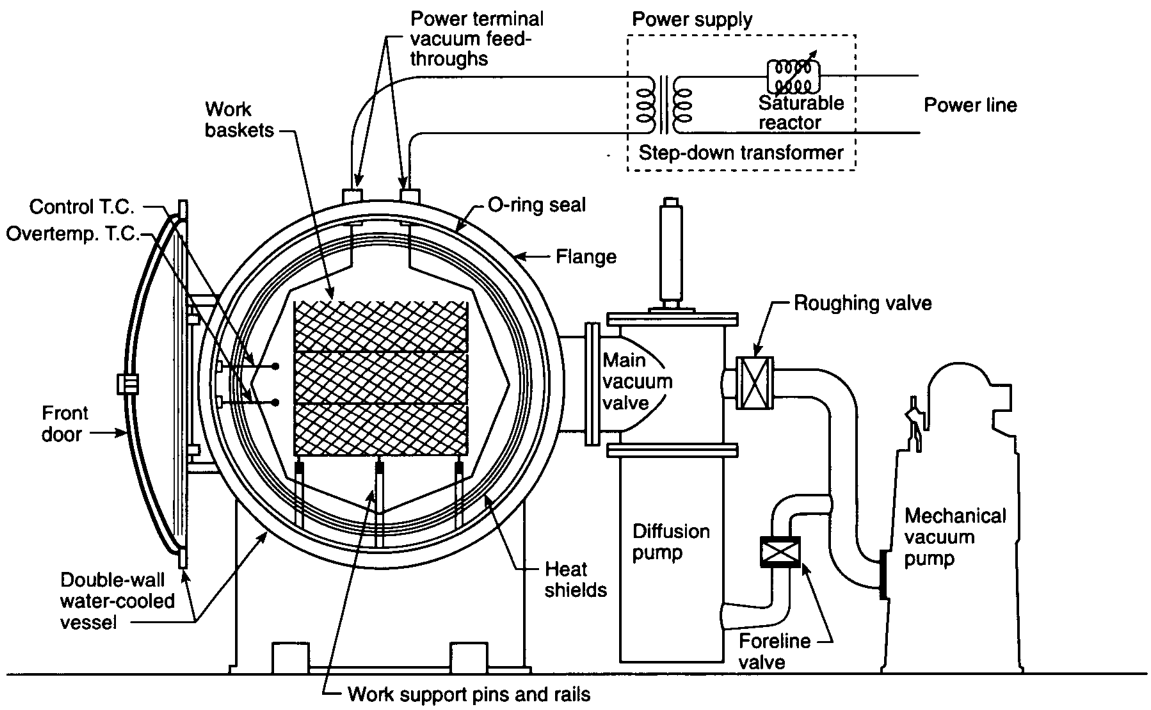

Figure A-1-1.2.1(a) Example of cold-wall, horizontal, front-loading vacuum furnace.

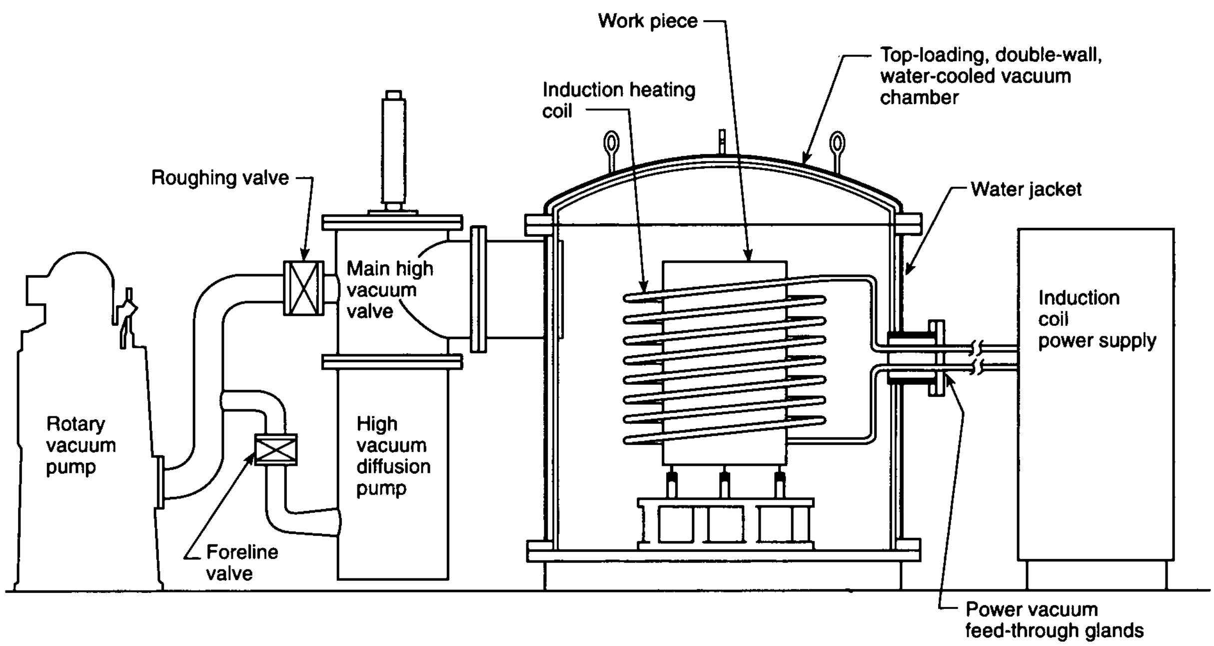

Figure A-1-1.2.1(b) Example of cold-wall, induction-heated vacuum furnace.

a small research unit to multiple torches of 1000 kW each for large production melters. The torches provide x, y, and z movements that are programmable or computer controlled. [*See Figure A-1-1.2.3(a).*]

(b) **Electron Beam (EB) Melter.**

1. Of all commercial melting techniques, electron-beam (EB) melting is capable of producing the highest refinement of end product. The beam of the electron gun can be focused to produce heat intense enough to vaporize even those metals with the highest melting points. Where combined with a vacuum atmosphere of approximately 10^{-4} torr (1.3×10^{-6} Pa), 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 has applications in melting alloy steels.

2. Commercial EB melters are available in a variety of sizes and configurations. Figure A-1-1.2.3(b) illustrates a

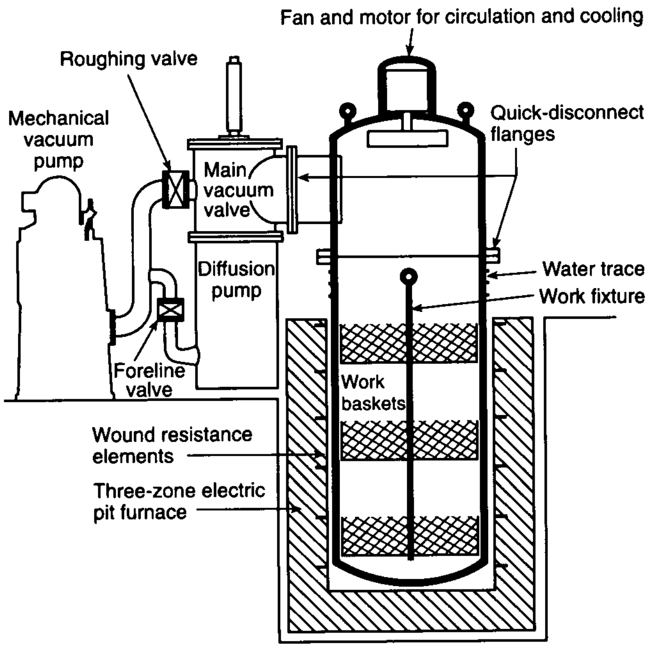

Figure A-1-1.2.2 Example of hot-wall, single-pumped, retort vacuum furnace.

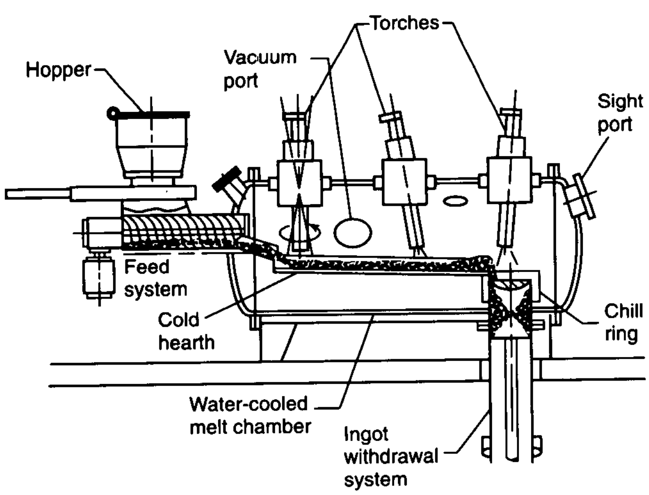

Figure A-1-1.2.3(a) Example of three-torch production plasma melter.

vertical feed system that allows the molten metal to drop from 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 needed 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.

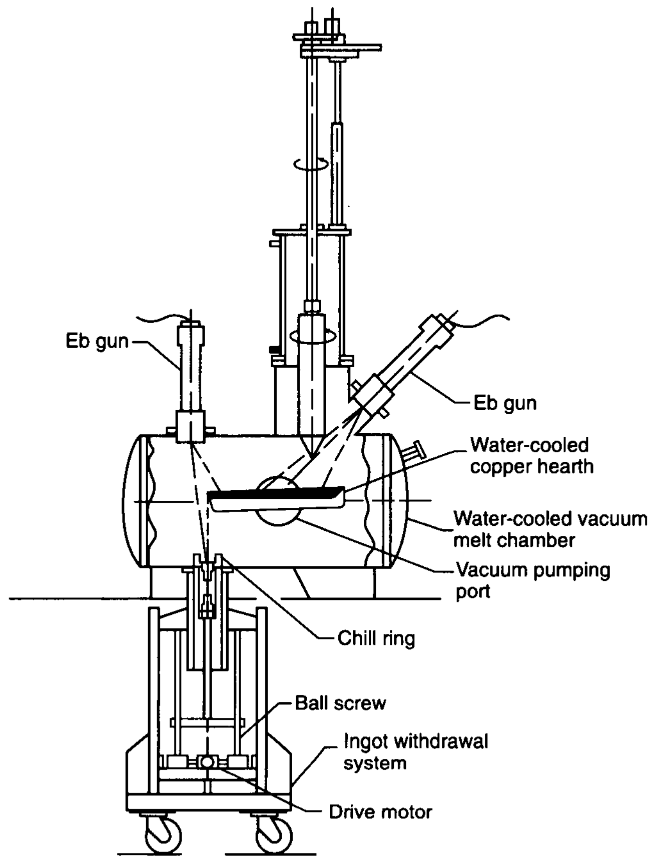

Figure A-1-1.2.3(b) Example of electron beam (EB) melter.

3. The following are some safety considerations applicable to this type of equipment. Water-cooling circuits should be constructed to be reliable to prevent steam pockets from forming in confined areas, which could result in an explosion. Beam gun controls should be designed so they do not 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 while viewing the melt process. Overpressure-relief systems should be incorporated where there is potential for adverse conditions. Installations should consider emergency alternative sources of cooling water for added protection of equipment and personnel. Since accelerating voltages might 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 refining metals. Alloys can be produced by sandwiching and welding strips of different metals together to produce an electrode that, after melting, results in the desired alloy. 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-1-1.2.3(c) illustrates the principal components of one type of consumable electrode arc melter.

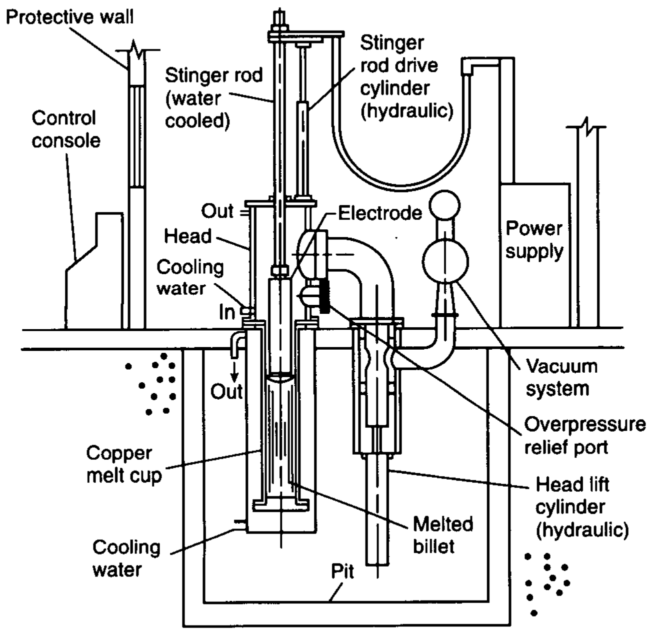

Figure A-1-1.2.3(c) Example of vacuum arc melter.

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 might 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 of approximately 10^{-2} torr (1.3×10^{-4} Pa). 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 that, instead of melting the electrode into a copper cup and allowing the molten metal to solidify, the electrode is melted into a cold-wall copper crucible. The crucible then is tilted, allowing the molten metal to pour into a casting mold, leaving a solidified metal lining or "skull" in the crucible.

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 overpressure-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.

A-1-4 Figures A-1-4(a) through (d) relate to Section 1-4.

A-2-1 Heating System, Direct-Fired.

Heater: Direct-Fired, External, Nonrecirculating. A direct-fired, external heater arranged so that products of combustion are discharged into the oven chamber without any return or recirculation from the oven chamber. [*See Figure A-2-1(a).*]

Heater: Direct-Fired, External, Recirculating through. A direct-fired, external heater arranged so that oven atmosphere is recirculated to the oven heater and is in contact with the burner flame. [*See Figure A-2-1(b).*]

Heater: Direct-Fired, Internal, Nonrecirculating. A combustion chamber of a recirculating oven heater that may be permitted to be built within an oven chamber not substantially separated from the oven atmosphere by gastight construction.

Heater: Direct-Fired, External, Recirculating Not through. A heating system constructed so that the oven atmosphere circulates through a blower with products of combustion admitted to the recirculating ductwork, but without the oven atmosphere actually passing through the combustion chamber. [*See Figure A-2-1(c).*]

A-3-1.4.2 The following procedure should be followed if the furnace is located in contact with a wood floor or other combustible floor and the operating temperature is above 160°F (71°C):

Combustible floor members should be removed and replaced with a monolithic concrete slab that extends a minimum of 3 ft (1 m) beyond the outer extremities of the furnace.

Air channels, either naturally or mechanically ventilated, should be provided between the floor and the equipment (perpendicular to the axis of the equipment or noncombustible insulation, or both). This should be adequate to prevent surface temperatures of floor members from exceeding 160°F (71°C).

A-3-2.11 Fuel-fired or electric heaters should not be located directly under the product being heated where combustible materials might drop and accumulate. Neither should they be located directly over readily ignitible materials such as cotton unless for a controlled exposure period, as in continuous processes where additional automatic provisions or arrangements of guard baffles, or both, preclude the possibility of ignition.

A-4-2.1.1 Ignition temperature means the lowest temperature at which a gas-air mixture can ignite and continue to burn. This is also referred to as the autoignition temperature. Where burners supplied with a gas-air mixture in the flammable range are heated above the autoignition temperature, flashbacks can occur. In general, such temperatures range from 870°F to 130°F (465°C to 54°C). A much higher temperature is needed to ignite gas dependably.

Flame Propagation and Explosive Range. The term "rate of flame propagation" means the speed at which a flame progresses through a combustible gas-air mixture under the pressure, temperature, and mixture conditions existing in the combustion space, burner, or piping under consideration. (*See Figure A-4-2.1.1 and Table A-4-2.1.1.*)

A-4-2.4.3 Whenever the fuel train is opened for service, the risk of dirt entry exists. It is not required that existing piping be opened for the sole purpose of the addition of a filter or strainer.

A-4-2.6.3.1 Two basic methods generally are used. One uses a separate fire check at each burner, the other a fire check at each group of burners. The second method generally is more practical if a system consists of many closely spaced burners.

SHEET 1 OF 2

MFR'S. JOB OR CONTRACT NO.	DATE

PART A — PLANS

NAME OF CUSTOMER (name of owner)		
ADDRESS (St. & No.)	CITY	STATE
NAME OF MANUFACTURER		
ADDRESS (St. & No.)	CITY	STATE
DRAWINGS SUBMITTED, NOS.		NO. OF SETS

INSTALLA-TION	TYPE	BATCH ☐	CONTINUOUS ☐		
	CONSISTS OF				
RATED HEAT INPUT	BTU'S/HR	☐ GAS BTU'S/CU. FT	☐ FUEL OIL NO. GALS/HR	☐ ELECTRIC KW	
SIZE (EXTERNAL IN FT)	LENGTH	WIDTH	HEIGHT	OPERATING TEMP. °F	
LOCATION OF EQUIPMENT	BLDG. NO. OR NAME	NO. OF FLOOR OR STORY			
FUEL SHUT-OFF	ACCESSIBLE IN EVENT OF FIRE YES ☐ NO ☐	SEPARATE EXCESS TEMPERATURE LIMIT SWITCH SHUTS OFF HEAT YES ☐ NO ☐	SET FOR °F		
FIRE PROTECTION OF OIL QUENCH TANK	☐ NONE	☐ AUTOMATIC SPRINKLERS	☐ OPEN SPRINKLERS	☐ AUTOMATIC WATER SPRAY	☐ AUTOMATIC FIXED FOAM
	☐ IF OTHER, DESCRIBE				
TYPE OF WORK	HEAT TREATING METALS	☐ WITH SPECIAL FLAMMABLE ATMOSPHERE	☐ WITH SPECIAL INERT ATMOSPHERE		
	IF OTHER, DESCRIBE				
HEATING ARRANGE-MENT	☐ INTERNAL DIRECT FIRED NONRECIRCULATING	☐ INTERNAL DIRECT FIRED RECIRCULATING	☐ EXTERNAL DIRECT FIRED RECIRCULATING	☐ EXTERNAL INDIRECT FIRED	
	☐ IF OTHER, DESCRIBE	MUFFLE YES ☐ NO ☐	RADIANT TUBES YES ☐ NO ☐		
	TYPE OF ELECTRIC HEATING ELEMENTS AND LOCATION				
	NO. OF MAIN BURNERS	NO. OF PILOT BURNERS			
METHOD OF LIGHTING OFF	☐ PORTABLE TORCH	☐ FIXED	☐ PILOT	☐ OIL	☐ GAS ☐ SPARK IGNITOR
METHOD OF FIRING	☐ HI-LOW	☐ MODULATING	☐ ON-OFF	☐ CONTINUOUS	

MIXER TYPE	☐ GAS	NO. OF MAIN BURNER INSPIRATORS	☐ ZERO-GOVERNOR TYPE	☐ ATMOSPHERIC INSPIRATOR	☐ HIGH PRESSURE 1.0 PSIG OR OVER	☐ LOW PRESSURE	☐ OTHER
		NO. OF PILOT INSPIRATORS	☐ ZERO-GOVERNOR TYPE	☐ ATMOSPHERIC INSPIRATOR	☐ HIGH PRESSURE 1 0 PSIG OR OVER	☐ LOW PRESSURE	☐ OTHER
	☐ OIL	☐ AIR (16-32 OZ) ATOMIZING		☐ ROSS OR DRY SYSTEM AIR ATOMIZING			☐ OTHER
	IF OTHER, DESCRIBE (MFR. & TYPE)						

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Figure A-1-4(a) Sample furnace or oven manufacturer's application for acceptance.

SHEET 2 OF 2

PROTECTION AGAINST FUEL EXPLOSION

LIGHTING-OFF

OPENINGS INTO ROOM ☐ TOP ☐ BOTTOM

NO FUEL & IGNITION UNTIL. ☐ TIMED PREVENTILATION BY EXH. & RECIRCULATING FANS	TIMER SETTING MIN.	☐ DOORS WIDE OPEN	☐ BURNER (F.M.) COCKS CLOSED	☐ MEANS PROVIDED FOR CHECK OF MAIN SAFETY SHUT-OFF VALVE TIGHTNESS
PILOT-FLAME ESTABLISHING PERIOD AUTOMATICALLY LIMITED ☐ YES ☐ NO SEC.	TRIAL-FOR-IGNITION PERIOD AUTOMATICALLY LIMITED ☐ YES ☐ NO SEC.	OIL TEMP. INTERLOCK ☐ YES ☐ NO SET FOR °F	PROVED LOW-FIRE INTERLOCK ☐ YES ☐ NO	
MFR. & TYPE NO. OF F.M. COCKS AND TIMER	COMB. AIR BLOWER CANNOT BE ☐ STARTED UNTIL END OF PREVENT. (IF TIMER USED)	COMB. SAFEGUARD PROVES PILOT ☐ BEFORE MAIN SAFETY SHUT-OFF VALVE OPENS		

FIRING

HEAT CUTOFF AUTOMATICALLY, REQUIRING MANUAL OPERATION TO RESTORE, ON FAILURE OF ☐ COMBUSTION AIR ☐ RECIRCULATING FAN ☐ EXHAUST FAN ☐ FUEL PRESSURE ☐ FLAME (combustion safeguard)

☐ ROD OR SCANNER LOCATION ENSURES PILOT IGNITES MAIN FLAME	MANDATORY PURGE AFTER FLAME FAILURE ☐ YES ☐ NO

MFR. & TYPE NO.

MAIN SAFETY SHUT-OFF VALVE IPS. IN.	PILOT SAFETY SHUT-OFF VALVE IPS. IN.	
COMBUSTION SAFEGUARD	PRESSURE SWITCHES	AUTOMATIC FIRE CHECKS

PROTECTION AGAINST SPECIAL ATMOSPHERE EXPLOSION

ATMOSPHERE FIRST TURNED ON INTO: ☐ HEATED WORK SECTION ☐ COOLING SECTION

IF COOLING SECTION, EXPLAIN HOW HAZARD AVOIDED

TEMPERATURE OF THIS SECTION WHEN ATMOSPHERE TURNED ON °F	SHUT-OFF °F	☐ ATMOSPHERE INTERLOCKED WITH FURNACE TEMPERATURE CONTROLLER

PRECAUTIONS WHEN TURNING ON AND SHUTTING OFF ATMOSPHERE ☐ INERT GAS PURGE ☐ "BURN-OUT" ☐ NO IGNITION SOURCE WHILE FURNACE ATMOSPHERE EXPLOSIVE

IF LATTER CASE, CHECK FOR NONEXPLOSIVE ATMOSPHERE IS BY ☐ GAS ANALYZER ☐ BURNING TEST SAMPLE ☐ TIME-VOLUME MEASURE ☐ NONE

SPECIAL ATMOSPHERE GENERATOR

MANUFACTURER AND TYPE	☐ ATMOSPHERE GENERATOR OUTPUT VENTED TO OUTDOORS UNTIL GENERATOR BURNER STABLE

ALARM AND AUTOMATIC LOCKOUT OF FUEL & COMBUSTION AIR IF FAILURE OF: ☐ FUEL ☐ COMBUSTION AIR ☐ POWER ☐ FLAME ☐ ATMOSPHERE TEMPERATURE AT GENERATOR

MFR. & TYPE NO.

SAFETY SHUT-OFF VALVES	PRESSURE SWITCHES
TEMPERATURE SWITCHES	COMBUSTION SAFEGUARDS

PART A ACCEPTED BY ☐ AS SUBMITTED ☐ SUBJECT TO ANY CHANGES INDICATED DATE

PART B — MANUFACTURER'S INSPECTION & TEST (completed installation)

BURNERS	☐ LIGHTED ☐ MIXERS ADJUSTED ☐ TEMP. CONTROL SET ☐ ADJ. FOR STABLE LOW FLAME
SAFETY CONTROLS	☐ ADJUSTED ☐ TESTED FOR PROPER RESPONSE
INSTRUCTIONS	☐ CUSTOMER'S OPERATOR INSTRUCTED ☐ PRINTED OPERATING INSTRUCTIONS LEFT ☐ APPLICATION FOR ACCEPTANCE POSTED ON CONTROL PANEL
SIGNATURES	MFRS. FIELD REP. / TEST WITNESSED BY FOR CUSTOMER / DATE

PART B ACCEPTED BY ☐ AS SUBMITTED ☐ SUBJECT TO ANY CHANGES INDICATED DATE

PART C — FIELD EXAMINATION OF COMPLETED INSTALLATION

☐ PART A CHECKED ☐ PART B CHECKED ☐ SAFETY CONTROLS TESTED ☐ ROD OR SCANNER LOCATION ASSURES PILOT IGNITES MAIN FLAME

INSTALLATION ACCEPTABLE BY DATE

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Figure A-1-4(b) Sample furnace or oven manufacturer's application for acceptance.

SHEET 1 of 2

MFR'S. JOB OR CONTRACT NO.	DATE

PART A — PLANS

NAME & ADDRESS OF CUSTOMER (OWNER)			NAME & ADDRESS OF MANUFACTURER		
DRAWINGS SUBMITTED, NOS.					NO. OF SETS
INSTALLATION	ERECTION & ADJUSTMENTS (SEE PART B) BY: ☐ MANUFACTURER ☐ CUSTOMER		IF OTHER, DESCRIBE		
	SAFETY VENTILATION AIR FLOW TESTS (SEE PART B) TO BE MADE AFTER ERECTION BY: ☐ MANUFACTURER ☐ CUSTOMER		IF OTHER, DESCRIBE		
	TYPE ☐ BATCH ☐ CONTINUOUS	TYPE NO. OR OTHER INFORMATION			
CON-STRUCTION	☐ SHEET-STEEL ON STEEL FRAME NON-COMBUSTIBLE INSULATION	IF OTHER, DESCRIBE			
RATED HEAT INPUT	☐ GAS BTU'S/HR	☐ FUEL OIL NO. GALS/HR	☐ ELECTRIC KW	☐ STEAM PRESS, psig	
SIZE	LENGTH (External) FT	WIDTH (External) FT	HEIGHT (External) FT	VOLUME (Internal) CU. FT	OPERATING TEMP. °F
LOCATION OF EQUIPMENT	BLDG. NO. OR NAME		BUILDING FLOOR CONSTRUCTION AND NO. OF FLOOR OR STORY		
	AIR SPACE BETWEEN OVEN & WOOD FLOOR IN.	IF OTHER, DESCRIBE			
	AIR SPACE BETWEEN STACKS, DUCTS, & WOOD BLDG. CONST. IN.	IF OTHER, DESCRIBE			
	EXHAUST STACKS	DIAM. OR SIZE IN.	METAL GAUGE (USS)	☐ INSULATED	NO. OF CLEANOUT (ACCESS) DOORS
EXPLOSION VENTING AREA	OPEN ENDS SQ. FT	LOOSE ROOF PANELS SQ. FT	ACCESS DOORS WITH EXPLOSION LATCHES SQ. FT		
	MANUFACTURER AND TYPE LATCH	TOTAL AREA SQ. FT	VENT RATIO $\frac{\text{VENT AREA}}{\text{INTERNAL VOLUME}} =$		
FUEL SHUT-OFF	ACCESSIBLE IN EVENT OF FIRE ☐ YES ☐ NO				
FIRE PROTECTION IN OVEN	☐ NONE ☐ AUTOMATIC SPRINKLERS ☐ OPEN SPRINKLERS ☐ CO_2 ☐ STEAM			DRAWINGS SUBMITTED ☐ YES ☐ NO	
	☐ OTHER (DESCRIBE)		☐ SEPARATE EXCESS TEMPERATURE LIMIT SWITCH WITH MANUAL RESET	SET FOR °F	
FIRE PROTECTION FOR DIP TANK & DRAINBOARD	DRAWINGS SUBMITTED ☐ YES ☐ NO	FIXED AUTO. CO_2 ☐ YES ☐ NO	☐ OTHER (DESCRIBE)		
	OVERFLOW VALVES ☐ YES ☐ NO	DUMP VALVES ☐ YES ☐ NO	SALVAGE TANK ☐ YES ☐ NO	IS HEAT SHUT OFF AUTOMATICALLY ON FAILURE OF CONVEYOR ☐ YES ☐ NO	
TYPE OF WORK	IMPREGNATED-COATED ABSORBENT MATERIAL ☐ PAPER ☐ CLOTH	☐ LITHOGRAPH COATING ☐ VARNISH ELECT. COILS ☐ GRAVURE PRESS ☐ FOOD BAKING ☐ CORES OR MOLDS			
	METAL ☐ DIPPED ☐ FLOW-COATED ☐ SPRAYED		☐ OTHER (DESCRIBE)		
SOLVENTS EN-TERING OVEN	NAME OF SOLVENT USED	LENGTH OF BAKE MIN.	MAX. SOLVENT FOR WHICH OVEN DESIGNED CONTINUOUS GALS/HR BATCH GALS/BATCH		
DESIGNED SAFETY VENTILATION	ARRANGEMENT ☐ SEPARATE CENTRI-FUGAL EXHAUSTER ☐ RECIRCULATING FAN WITH SPILL ☐ NATURAL DRAFT STACK ☐ OPENINGS INTO ROOM		FILTERS ON FRESH AIR INTAKE ☐ YES ☐ NO		
	FRESH AIR ADMITTED INTO OVEN CFM REFERRED TO 70° F	OPENING WITH DAMPER CLOSED FRESH AIR INLET % EXHAUST OUTLET %	DOES CONVEYOR STOP AUTOMATICALLY ON FAILURE OF SAFETY EXHAUST FANS ☐ YES ☐ NO		
	FAN MFR. SIZE, TYPE	WHEEL DESIGN (BLADE TIP) ☐ RADIAL TIP ☐ BACKWARD INCLINED ☐ FORWARD CURVED	DIAM. IN.	TIP SPEED FT/MIN.	

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Figure A-1-4(c) Sample furnace or oven manufacturer's application for acceptance.

SHEET 2 OF 2

HEATING ARRANGEMENT	☐ INTERNAL DIRECT FIRED NONRECIRCULATING ☐ INTERNAL DIRECT FIRED RECIRCULATING ☐ EXTERNAL DIRECT FIRED RECIRCULATING ☐ EXTERNAL INDIRECT FIRED
	☐ OTHER (DESCRIBE)
	TYPE OF ELECTRIC HEATING ELEMENTS AND LOCATION
	NO. OF MAIN BURNERS / NO. OF PILOT BURNERS / CAN DRIPPINGS OFF WORK FALL ON HEATING ELEMENTS ☐ YES ☐ NO
METHOD OF LIGHTING OFF	☐ PORTABLE TORCH ☐ FIXED ☐ PILOT ☐ OIL ☐ GAS ☐ SPARK IGNITOR
METHOD OF FIRING	☐ HI-LOW ON-OFF ☐ ☐ MODULATING CONTINUOUS ☐ ☐ AUTOMATIC-LIGHTED MANUAL-LIGHTED ☐ ☐ SEMI-AUTOMATIC-LIGHTED
	TYPE OF PILOT ☐ CONTINUOUS ☐ INTERRUPTED ☐ INTERMITTENT ☐ OTHER (DESCRIBE)
MIXER TYPE	☐ GAS — NO. MAIN BURNER INSPIRATORS ☐ ZERO-GOVERNOR TYPE ☐ ATMOSPHERIC INSPIRATOR ☐ HIGH PRESSURE ☐ LOW PRESSURE
	NO. PILOT INSPIRATORS ☐ ZERO-GOVERNOR TYPE ☐ ATMOSPHERIC INSPIRATOR ☐ HIGH PRESSURE ☐ LOW PRESSURE
	☐ OIL ☐ AIR (16-32 OZ.) ATOMIZING
	☐ OTHER — OTHER TYPE MIXERS OR OIL BURNERS INCLUDING PILOTS (MFR. & TYPE)
PROTECTION AGAINST FUEL EXPLOSION — LIGHTING-OFF	NO FUEL AND IGNITION UNTIL: ☐ TIMED PREVENTILATION BY EXHAUST AND RECIRC. FANS / TIMER SETTING MIN. / ☐ DOORS WIDE OPEN / ☐ BURNER (F.M.) COCKS CLOSED / ☐ MEANS PROVIDED FOR CHECK OF MAIN SAFETY SHUT-OFF VALVE TIGHTNESS
	PILOT-FLAME-ESTABLISHING PERIOD AUTOMATICALLY LIMITED ☐ YES ☐ NO SEC. / TRIAL-FOR-IGNITION PERIOD AUTOMATICALLY LIMITED ☐ YES ☐ NO SEC. / OIL TEMP. INTERLOCK ☐ YES ☐ NO SET FOR °F / PROVED LOW-FIRE INTERLOCK ☐ YES ☐ NO
	MFR. AND TYPE NO. OF F.M. COCKS & TIMER / COMBUSTION AIR BLOWER CANNOT BE STARTED UNTIL END OF PREVENT. (IF TIMER USED) / COMBUSTION SAFEGUARD PROVES ☐ PILOT BEFORE MAIN SAFETY SHUT-OFF VALVE OPENS
FIRING	HEAT CUTOFF AUTOMATICALLY, REQUIRING MANUAL OPERATION TO RESTORE, ON FAILURE OF ☐ COMBUSTION AIR ☐ RECIRCULATING FAN ☐ SAFETY EXHAUST FAN ☐ HIGH AND LOW GAS PRESSURE ☐ LOW OIL PRESSURE ☐ FLAME (Combustion Safeguard)
	☐ ROD OR SCANNER LOCATION ENSURES PILOT IGNITES MAIN FLAME / MANDATORY PURGE AFTER FLAME FAILURE ☐ YES ☐ NO
MANUFACTURER & TYPE NO.	MAIN SAFETY SHUT-OFF VALVE IPS. IN. / PILOT SAFETY SHUT-OFF VALVE IPS. IN.
	COMBUSTION SAFEGUARD / PRESSURE SWITCHES / AIRFLOW SWITCHES
PART A ACCEPTED	☐ AS SUBMITTED ☐ SUBJECT TO ANY CHANGES INDICATED BY / DATE

PART B — MANUFACTURER'S INSPECTION & TEST

SAFETY VENTILATION	CFM REF. TO 70° F / MEASURED BY (SPECIFY) ☐ PITOT ☐ OTHER / MEASURED WITH FRESH AIR INLET & EXHAUST OUTLET DAMPERS IN MAXIMUM CLOSED POSITION ☐ YES ☐ NO
BURNERS	☐ LIGHTED ☐ MIXERS ADJUSTED ☐ TEMP. CONTROL SET ☐ ADJ. FOR STABLE LOW FLAME
SAFETY CONTROLS	☐ ADJUSTED ☐ TESTED FOR PROPER RESPONSE
INSTRUCTIONS	☐ CUSTOMER'S OPERATOR INSTRUCTED ☐ PRINTED OPERATING INSTRUCTIONS LEFT ☐ APPLICATION FOR ACCEPTANCE POSTED ON CONTROL PANEL
SIGNATURES	MFR'S. FIELD REP. / TEST WITNESSED BY FOR CUSTOMER / DATE
PART B ACCEPTED	☐ AS SUBMITTED ☐ SUBJECT TO ANY CHANGES INDICATED BY / DATE

PART C — FIELD EXAMINATION OF COMPLETED INSTALLATION

☐ PART A CHECKED ☐ PART B CHECKED ☐ SAFETY CONTROLS TESTED ☐ ROD OR SCANNER LOCATION ASSURES PILOT IGNITES MAIN FLAME	
ENGINEER'S SIGNATURE	DATE

Figure A-1-4(d) Sample furnace or oven manufacturer's application for acceptance.

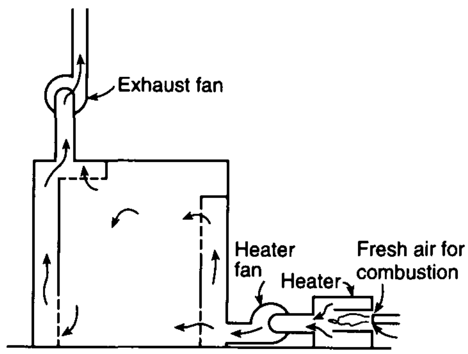


Figure A-2-1(a) Example of a direct-fired, external, nonrecirculating heater.

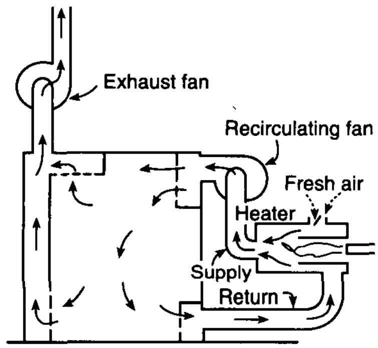


Figure A-2-1(b) Example of a direct-fired, external, recirculating through heater.

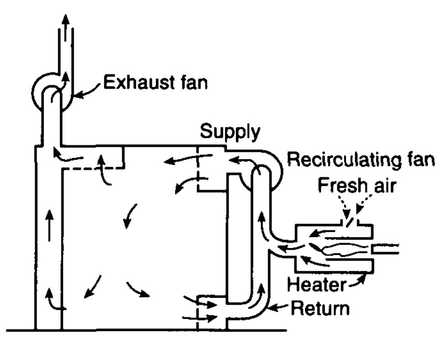


Figure A-2-1(c) Example of a direct-fired, external, recirculating not through heater.

A-4-2.6.3.3 Acceptable safety blowouts are available from some manufacturers of air-fuel mixing machines. They incorporate the following components and design features:

(a) A flame arrester;

(b) A blowout disk; and

(c) Provision for automatically shutting off the supply of air-gas mixture to the burners in the event of a flashback passing through an automatic fire check.

A-4-3.1.1 In the design and use of oil-fired units, the following should be considered:

(a) Unlike fuel gases, data on many important physical/chemical characteristics are not available for fuel oil, which, being a complex mixture of hydrocarbons, is relatively unpredictable.

(b) Fuel oil has to be vaporized prior to combustion. Heat generated by the combustion commonly is utilized for this purpose, and oil remains in the vapor phase as long as a sufficient temperature is present. Under these conditions, oil vapor can be treated as fuel gas.

(c) Unlike fuel gas, oil vapor condenses into liquid when the temperature falls too low and revaporizes whenever the temperature rises to an indeterminate point. Therefore, oil in a cold furnace can lead to a hazardous condition since, unlike fuel gas, it cannot be purged. Oil can vaporize (to become a gas) when, or because, the furnace operating temperature is reached.

(d) Unlike water, for example, there is no known established relationship between temperature and vapor pressure for fuel oil. For purposes of comparison, a gallon of fuel oil is equivalent to 140 ft^3 (4.0 m^3) of natural gas; therefore, 1 oz (0.03 kg) equals approximately 1 ft^3 (0.03 m^3).

A-4-3.3.6 The weight of fuel oil is always a consideration in vertical runs. When going up, pressure is lost. One hundred psig (689 kPa) with a 100-ft (30.5-m) lift nets only 63 psig (434 kPa). When going down, pressure increases. One hundred psig (689 kPa) with a 100-ft (30.5-m) drop nets 137 psig (945 kPa). This also occurs with fuel gas, but it usually is of no importance. However, it should never be overlooked when handling oil.

A-4-3.6.1 The atomizing medium might be steam, compressed air, low-pressure air, air-gas mixture, fuel gas, or other gases. Atomization might be mechanical (mechanical-atomizing tip or rotary cup).

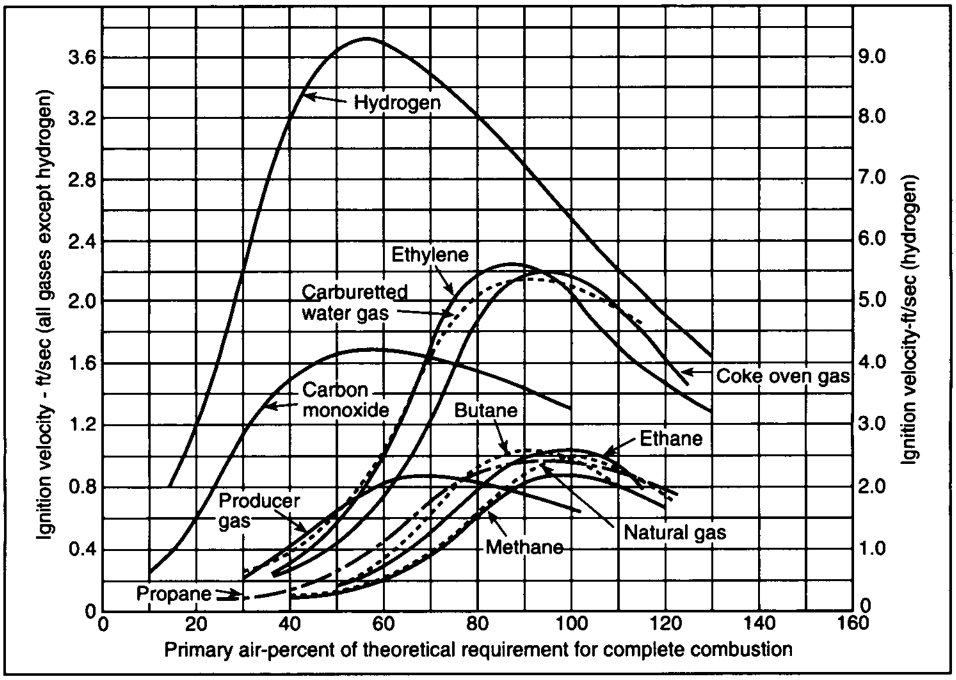
A-4-4.1 Oxy-fuel burners often are utilized in conjunction with arc melting furnaces to augment electric heating. Some of these burners utilize air as well. Stationary burners are attached to the furnace shell or cover, or both. Movable burners that normally are not attached to the furnace are suspended from structural members outside a furnace door. They are manipulated from the operating floor, and the oxygen and fuel are introduced into the furnace through long, concentric pipes.

Conventional flame safeguards are impractical in conjunction with oxy-fuel burners in arc furnaces because of the radio frequency noise associated with the arcs. The electric arc is a reliable means of ignition for the burners, once it has been established. After the arc has been established, the high temperatures inside an arc furnace cause the ignition of significant accumulations of oxygen and fuel.

Using oxygen to augment or to substitute for combustion air in industrial furnace heating systems presents new safety hazards for users acquainted only with air-fuel burners.

One group of hazards arises from the exceptional reactivity of oxygen. It is a potent oxidizer; therefore, it accelerates burning rates. It also increases the flammability of substances that generally are considered nonflammable in air. A fire fed by oxygen is difficult to extinguish.

Special precautions are needed to prevent oxygen pipeline fires, that is, fires in which the pipe itself becomes the fuel. Designers and installers of gaseous oxygen piping should familiarize themselves with standards and guidelines referenced in this standard on pipe sizing, materials of construction, and sealing methods. Gaseous oxygen should flow at relatively low velocity in pipelines built of ferrous materials, because friction created by particles swept through steel pipe at a high speed can ignite a pipeline. For this reason, copper or copper-based alloy con-



Ignition velocity curves for various gases

Figure A-4-2.1.1 Ignition velocity curves for typical flammable gases.

Table A-4-2.1.1 Properties of Typical Flammable Gases

Flammable Gas	Molecular Weight	Btu/CF	Autoignition (°F)	LEL % by Volume	UEL % by Volume	Vapor (Density Air = 1)	CF Air Req'd To Burn 1 CF of Gas
Butane	58	3200	550	1.9	8.5	2	31
CO	28	310	1128	12.5	74	0.97	2.5
Hydrogen	2	311	932	4	74.2	0.07	2.5
Natural gas (high Btu type)	18.6	1115	—	4.6	14.5	0.64	10.6
Natural gas (high methane type)	16.2	960	—	4	15	0.56	9
Natural gas (high inert type)	20.3	1000	—	3.9	14	0.70	9.4
Propane	44	2500	842	2.1	9.5	1.57	24

struction is customary where the oxygen velocity needs to be high, such as in valves, valve trim areas, and in orifices.

Oxygen pipelines should be cleaned scrupulously to rid them of oil, grease, or any hydrocarbon residues before oxygen is introduced. Valves, controls, and piping elements that come in contact with oxygen should be inspected and certified as "clean for oxygen service." Thread sealants, gaskets and seals, and valve trim should be oxygen-compatible; otherwise they could initiate or promote fires. Proven cleaning and inspection methods are described in Compressed Gas Association guidelines provided in Appendix G.

Furnace operators and others who install or service oxygen piping and controls should be indoctrinated in the precautions and safe practices for handling oxygen. For example, smoking or striking a welding arc in an oxygen-enriched atmosphere could start a fire. Gaseous oxygen has no odor and is invisible, so those locations in which there is a potential for leaks are off limits to smokers and persons doing hot work. The location of such areas should be posted. Persons who have been in contact with oxygen should be aware that their clothing is extremely flammable until it has been aired. Equipment or devices that contain oxygen should never be lubricated or cleaned with agents that are not approved for oxygen service.

Oxygen suppliers are sources of chemical material safety data sheets (MSDS) and other precautionary information for use in employee training. Users are urged to review the safety requirements in this standard and adopt the recommendations.

Another group of hazards is created by the nature of oxy-fuel and oxygen-enriched air flames. Because they are exceptionally hot, these flames can damage the burners, ruin work in process and furnace internals, and even destroy refractory insulation that was intended for air-fuel heating. Oxygen burner systems and heating controls should have quick-acting, reliable means for controlling heat generation.

Air that has been enriched with oxygen causes fuel to ignite very easily, because added oxygen increases the flammability range of air-fuel mixtures. Therefore, preignition purging is critical when oxygen is used.

Oxygen is also a hazard for persons entering furnaces to perform inspections or repairs. Strict entry procedures for confined spaces should be implemented. They should include analyses for excess oxygen (oxygen contents in

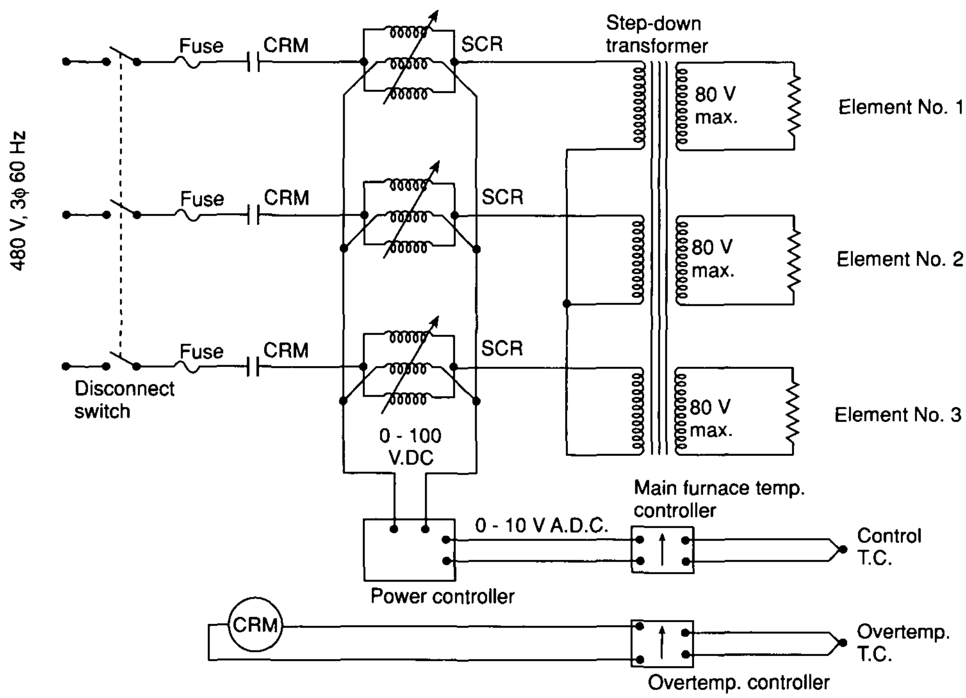


Figure A-4-8.1 Example of power supply.

excess of 20.9 percent) in addition to the usual atmosphere tests for oxygen deficiency and flammability.

A-4-4.3.11 Commercial grade carbon steel pipe exhibits a marked reduction in impact strength when cooled to subzero temperatures. Consequently, it is vulnerable to impact fracture if located downstream from a liquid oxygen vaporizer running beyond its rated vaporization capacity or at very low ambient temperatures.

A-4-8.1 Figure A-4-8.1 provides an example of a power supply.

A-4-9.3 Where dissimilar metals are heated in contact with each other, particularly where they are oxide-free and used within 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 a critical melting temperature. Operating temperatures near or above these points should be considered carefully.

Table A-4-9.3 Eutectic Melting Temperatures

Material	Temperature (°F)	(°C)
Moly/nickel	2310	1266
Moly/titanium	2210	1210
Moly/carbon	2700	1482
Nickel/carbon	2310	1166
Nickel/tantalum	2450	1343
Nickel/titanium	1730	943

A-4-10.4 Figure A-4-10.4 provides an example of some gas quenching methods.

A-5-2.9 This control circuit and its nonfurnace-mounted or furnace-mounted control and safety components should be housed in a dusttight panel or cabinet, protected by partitions or secondary barriers, or separated by sufficient spacing from electrical controls employed in the higher voltage furnace power system. Related instruments might or might not be installed in the same control cabinet.

The door providing access to this control enclosure might include means for mechanical interlock with the main disconnect device required in the furnace power supply circuit.

Temperatures within this control enclosure should be limited to 125°F (52°C) for suitable operation of plastic components, thermal elements, fuses, and various mechanisms that are employed in the control circuit.

A-5-7.2.3 An example of a leak test procedure for safety shutoff valves on direct gas-fired ovens with a self-piloted burner and intermittent pilot follows.

With the oven burner(s) shut off, the main shutoff valve open, and the manual shutoff valve closed:

(a) The tube should be placed in test connection 1 and immersed just below the surface of a container of water.

(b) The test connection valve should be opened. If bubbles appear, the valve is leaking and the manufacturer's instructions should be referenced for corrective action. The auxiliary power supply to safety shutoff valve No. 1 should be energized and the valve should be opened.

(c) The tube should be placed in test connection 2 and immersed just below the surface of a container of water.

(d) The test connection valve should be opened. If bubbles appear, the valve is leaking and the manufacturer's instructions should be referenced for corrective action.

This procedure is predicated on the piping diagram shown in Figure A-5-7.2.3(a) and the wiring diagram shown in Figure A-5-7.2.3(b).

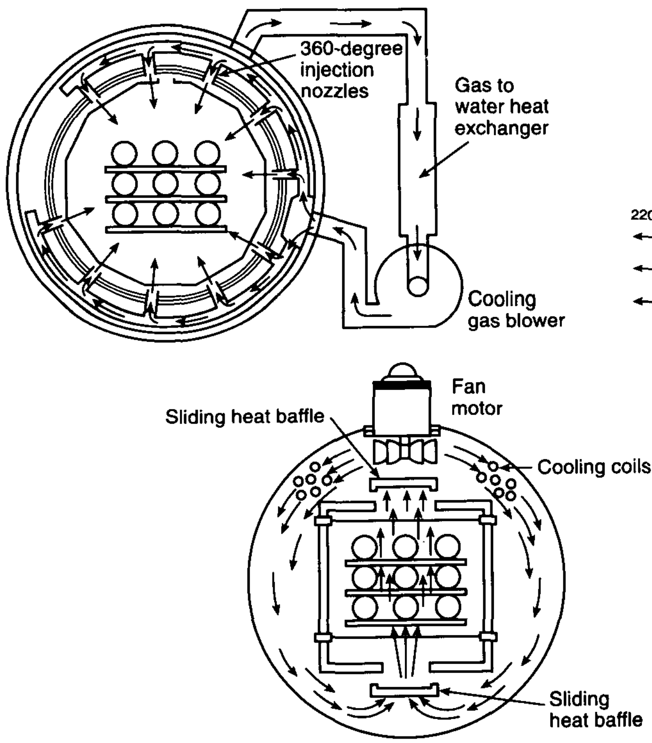


Figure A-4-10.4 Examples of some gas quenching methods.

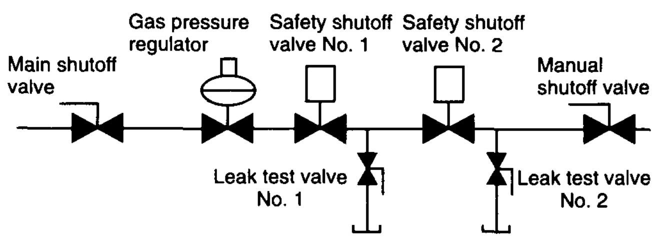


Figure A-5-7.2.3(a) Example of a gas piping diagram for leak test.

A-5-9.2.2 Figures A-5-9.2.2(a) and A-5-9.2.2(b) relate to 5-9.2.2.

A-5-11 Wherever the temperature of the fuel oil can drop below a safe level, the increased viscosity prevents proper atomization. No. 2 and No. 4 fuel oils can congeal if their temperature falls below their pour point, whether or not preheaters are used.

Wherever the temperature of the fuel oil can rise above a safe level, vaporization of the oil takes place before atomization and causes a reduction in fuel volume severe enough to create substantial quenching of the flame.

A-5-18.1.1 Abnormal conditions that could occur and require automatic or manual de-energization of affected circuits are as follows:

(a) A system fault (short circuit) not cleared by normally provided branch-circuit protection (*see NFPA 70, National Electrical Code*).

(b) The occurrence of excess temperature in a portion of the furnace that has not been abated by normal temperature-controlling devices.

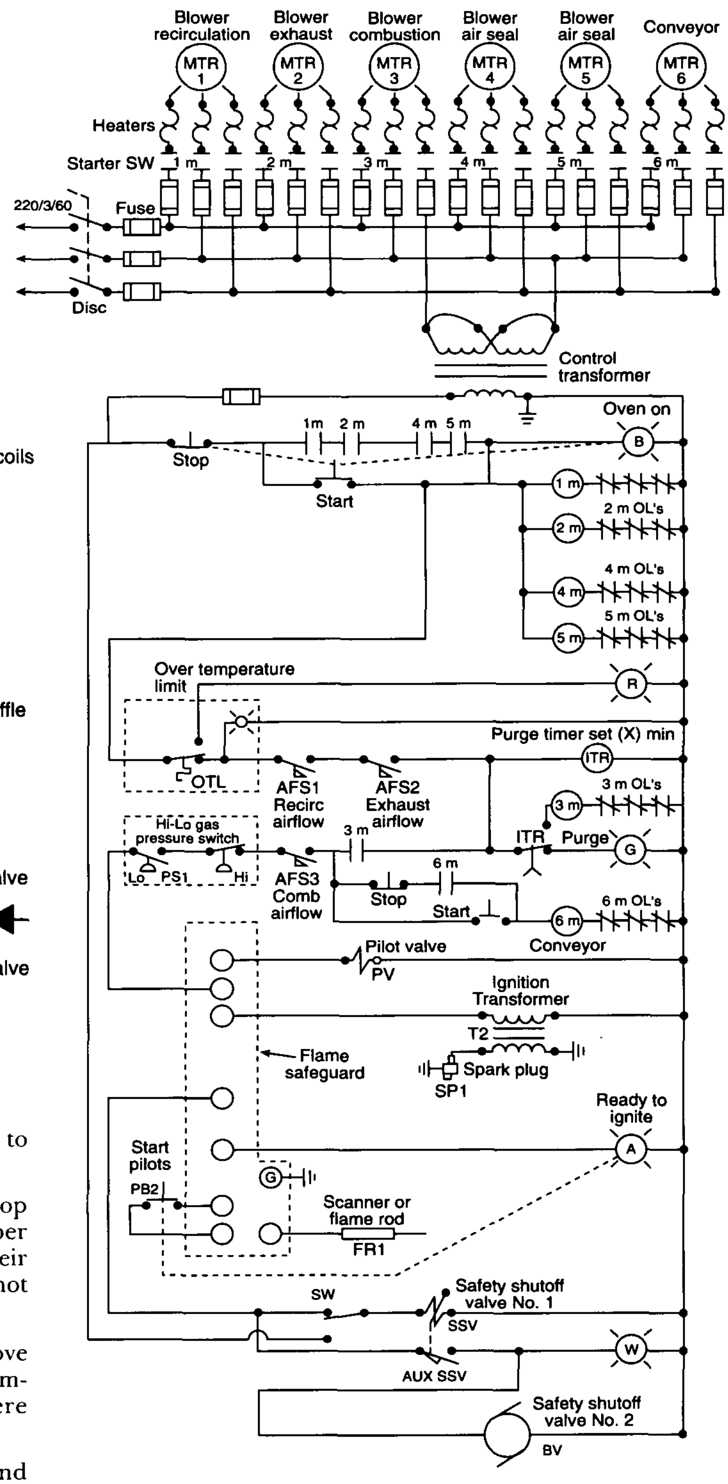


Figure A-5-7.2.3(b) Example of a wiring diagram for leak test.

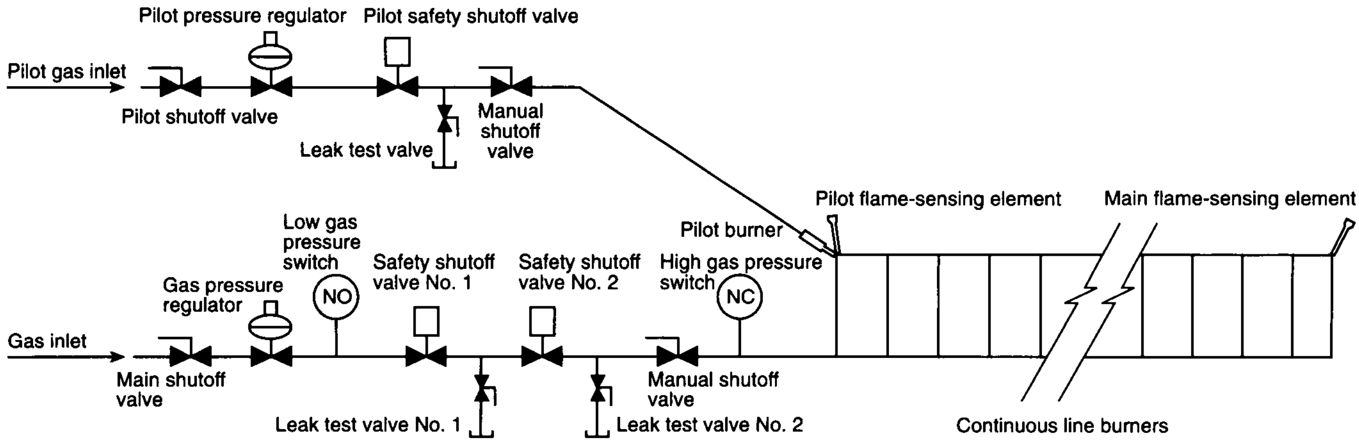


Figure A-5-9.2.2(a) Example of an approved combustion safeguard supervising a pilot for a continuous line burner during light-off and the main flame alone during firing.

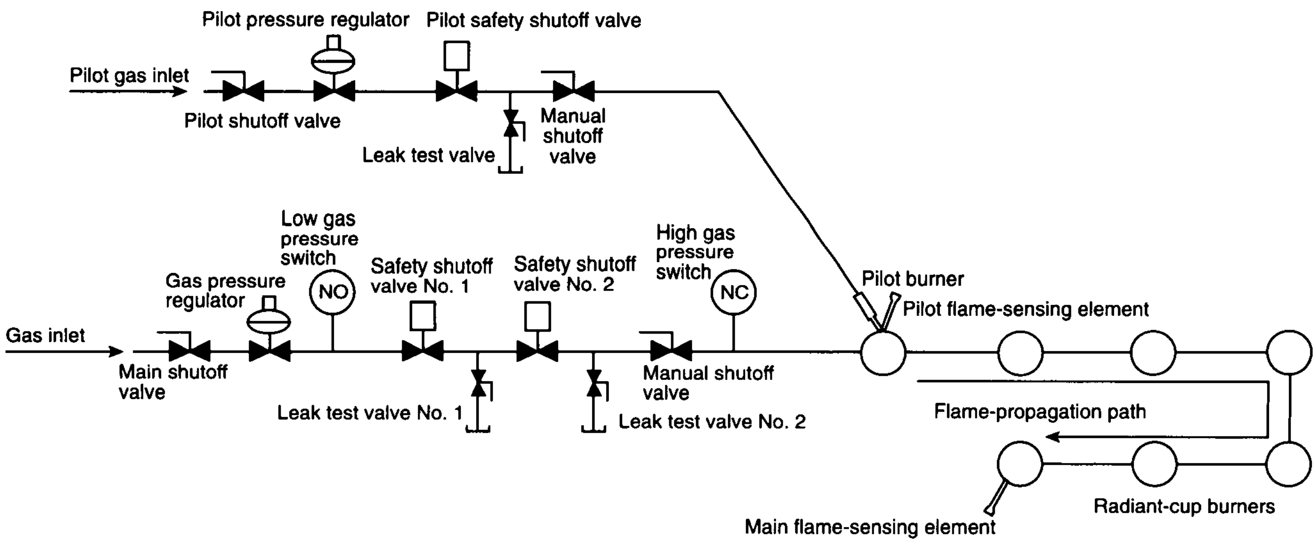


Figure A-5-9.2.2(b) Example of an approved combustion safeguard supervising a group of radiant-cup burners having reliable flame-propagation characteristics from one to the other by means of flame-propagation devices.

(c) A failure of any normal operating controls where such failure can contribute to unsafe conditions.

(d) A loss of electric power that can contribute to unsafe conditions.

A-5-18.1.4 This could require derating some components as listed by manufacturers for uses such as for other types of industrial service, motor control, and as shown in Table A-5-18.1.4.

A-5-19.2 Types of Indicating and Recording Vacuum Gauges.

(a) **Mechanical Gauges.** The bellows and diaphragm mechanical gauges 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 Gauge.** For high vacuum work, the McLeod gauge is often used as a primary standard for the calibration of other, more easily used instruments. The gauge 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). As derived from Boyle's Law, at constant temperature, P_1 equals P_2V_2/V_1. The gauge then is calibrated to read P_1.

(c) **Thermal Gauges.** The operation of a thermal gauge is based on the theory that energy dissipated from a hot surface is proportional to the pressure of the surrounding gas. Some manufacturer's produce thermal gauges that are subject to contamination by vaporized materials, and this issue should be discussed with the gauge manufacturer.

1. *Thermocouple Gauge.* The thermocouple gauge 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. Therefore, the thermocouple electromagnetic field (emf) can be used to indicate pressure. In order to compensate for ambient temperature, an identical second unit is sealed in an evacuated

Table A-5-18.1.4 Heater Ratings

	Resistance-Type Heating Devices		Infrared Lamp and Quartz Tube Heaters	
Control Device	**Rating in % of Actual Load**	**Permitted Current in % of Rating**	**Rating in % of Actual Load**	**Permitted Current in % of Rating**
Fusible safety switch (% rating of fuse employed)	125	80	133	75
Individually enclosed circuit breaker	125	80	125	80
Circuit breakers in enclosed panelboards	133	75	133	75
Magnetic contactors				
0–30 amperes	111	90	200	50
30–100 amperes	111	90	167	60
150–600 amperes	111	90	125	80

NOTE: The above applies to "maximum load" or open ratings for safety switches, circuit breakers, and industrial controls approved under current NEMA standards.

tube. The differential output of the two thermocouples is proportional to the pressure.

2. *Pirani Gauge.* The Pirani gauge 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 to the gas being measured by means of conduction. In the Pirani gauge, the resistance of the filament, rather than its temperature, is used as an indication of pressure.

3. *Bimetal Gauge.* A bimetallic spiral is heated by a stabilized power source. Any change of pressure causes a change of temperature and, therefore, a deflection of the spiral, which is linked to a pointer on a scale that indicates pressure.

(d) **Ionization Gauges.** The two types of ionization gauges are the hot filament (hot cathode) gauge and the cold cathode (Phillips or discharge) gauge. Their principle of operation is based on the fact that collisions between molecules and electrons result in the 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 Gauge.* This gauge 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 the heated filament are accelerated toward the positively charged coil grid. The accelerated electrons pass through the coil grid into the space between the grid 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, therefore, is a measure of the pressure of the system.

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

2. *Cold Cathode Gauge.* A cold cathode gauge employs the principle of the measurement of an ion current produced by a discharge of high voltage. 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 the 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-6-1.1 Direct Thermal Oxidation Incinerators. Fume incinerators should operate at the temperature necessary for the oxidation process and in accordance with local, state, and federal regulations. Fume incinerators or afterburners should control atmospheric hydrocarbon emissions by direct thermal oxidation, generally in the range of 1200°F to 2000°F (650°C to 1100°C). Figure A-6-1.1(a) shows a solvent fume incinerator with heat recovery.

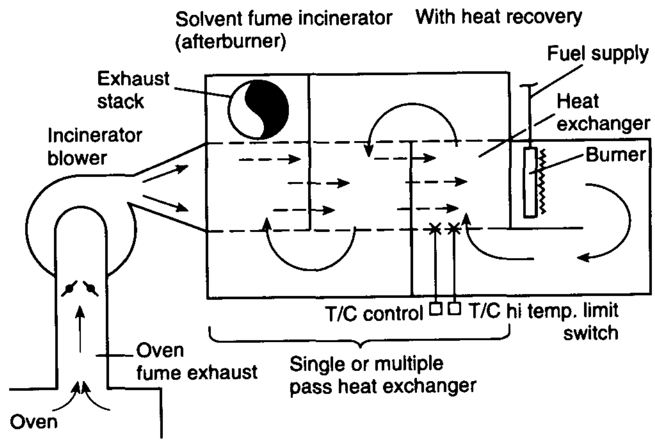


Figure A-6-1.1(a) Example of direct thermal oxidation incinerator (afterburner) with primary heat recovery.

Catalytic Fume Incinerators. Catalytic fume incinerators should operate at the temperature necessary for the catalytic oxidation process in accordance with local, state, and federal regulations.

Catalytic fume incinerators control atmospheric hydrocarbon emissions by thermal oxidation, using a catalyst element. Oxidation occurs at or near the autoignition temperature of the contaminants, which ranges from 450°F to 950°F (232°C to 510°C).

Catalyst elements use various types and forms of substrates, such as:

(a) Metal shavings;

(b) Small, irregular, metal castings;

(c) Formed or stamped light gauge sheet metal;

(d) Ceramic- or porcelain-formed structures, pellets, or granules.

Most substrates are restricted to fixed bed applications, although pellets and granules have application in fluidized beds as well. Various catalyst materials are available and include "rare earth" elements, precious metals such as platinum and palladium, or a few metallic salts. For commercial use, the catalyst material is bonded to the substrates specified in (a) through (d) above.

For atmospheric pollution control, catalyst materials frequently are installed in oven exhaust streams, and the increased energy level resulting from hydrocarbon oxidation is either discharged to the outside atmosphere or recycled to the process oven, directly or by means of a heat exchange system.

The application of catalysts should recognize the inherent limitations associated with these materials, such as the inability to oxidize silicone and chlorinated compounds as well as metallic vapors such as tin, lead, and zinc. These materials can destroy catalyst activity, whereas various inorganic particulates (dust) might mask the catalyst elements and retard activity, thus requiring specific maintenance procedures. Consultation with qualified suppliers and equipment manufacturers is recommended prior to installation.

Where applicable, catalyst afterburner exhaust gases may be permitted to be utilized as a heat source for the process oven generating the vapors or some other unrelated process. Heat recovery can be indirect by the use of heat exchange devices, or direct, by the introduction of the exhaust gases into the process oven.

Alternately, catalytic heaters may be permitted to be installed in the oven exhaust stream to release heat from evaporated oven by-products with available energy being returned by means of heat exchange and recirculation to the oven processing zone. [*See Figures A-6-1.1(b) and (c).*]

A-6-2.1 The temperature differential (ΔT) across the catalyst should be monitored to ensure that catalytic oxidation is occurring. Separate temperature-indicating instruments or controllers can be used to determine the ΔT arithmetically. Control of fuel or electrical energy for preheating the fume stream entering the catalyst can utilize temperature-measuring instruments at the catalyst inlet or discharge or at a juncture between instruments in each location. Maximum permitted afterburner temperature should be monitored only at the catalyst bed exit. The ΔT across the catalyst bed indicates the energy release and should be limited to values nondestructive to the catalyst material.

A-8-1.1 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 by-products that might 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 1832°F (1000°C). Heating is by an external electric furnace capable of uniform reproducible temperature control. Quartz muffles are employed where demanded by corrosion conditions and where the scale of the operation is sufficiently small to enable the degree of care and delicate handling necessary to avoid breakage.

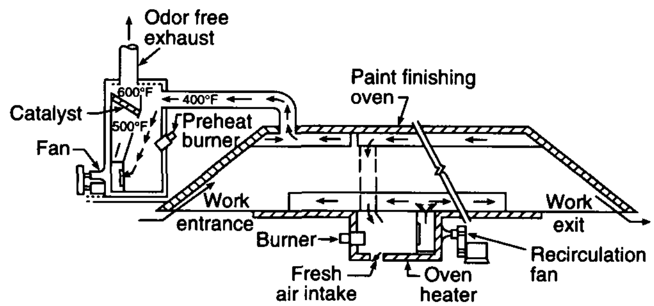


Figure A-6-1.1(b) Example of catalyst system independent of oven heater for air pollution control.

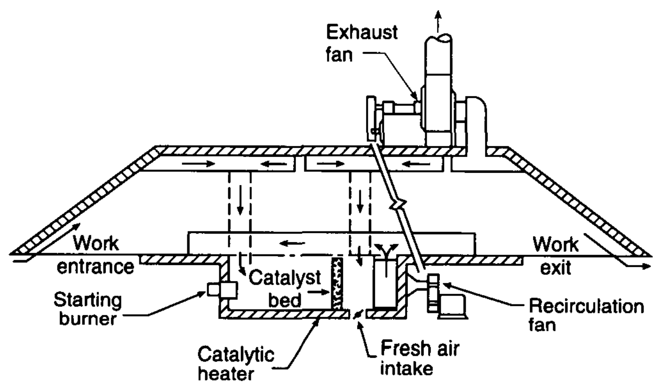


Figure A-6-1.1(c) Example of indirect-type catalytic oven heater for full air pollution control.

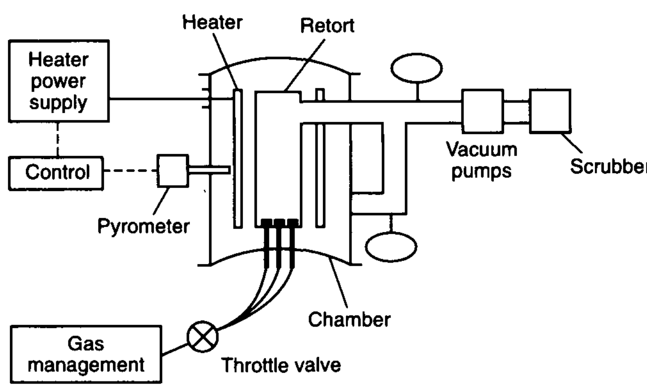


Figure A-8-1.1 Example of high-temperature CVD system.

Reaction temperatures above 1832°F (1000°C) necessitate cold-wall furnace technology, with most furnaces utilizing graphite hot zones. If the CVD reaction involves a product that can damage the heating element or impair the efficiency of the insulation, or both, a graphite muffle with inert pump-out and gas injection provisions is used in conjunction with gas blanketing outside to ensure that the reactants are confined. (*See Figure A-8-1.1.*)

(c) **Vacuum System.** CVD reaction pressures that range from 0.5 torr to 500 torr (66.66 kPa to 66.661 kPa) employ rotary mechanical oil-sealed pumps, often in series with a mechanical blower. A throttle valve controlled by a vacuum gauge that should be corrosion resistant and capable of measuring total absolute pressure regardless of composition maintains the desired pressure in the reaction chamber.

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

1. Oil sludging and loss of lubricity;
2. Corrosive attack, usually with hydrochloric acid; or
3. Abrasion from tramp deposition product.

Several means of combating these rigorous conditions are available, depending on the specifics of the materials involved.

(d) **Gas Management.** Gases in controlled quantity may be permitted to 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, three gas components are involved:

1. The precursor, which contains the element or compound to be deposited;
2. The reducer, such as hydrogen or ammonia; and
3. A diluent, such as argon or nitrogen, to influence structure, density, or other characteristics of the deposit.

Particular care should be exercised to ensure that the reactor is in the proper 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.

(e) **Handling By-Product.** A common reaction by-product is hydrogen chloride (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 for the furnace design for CVD service should include:

1. Use of austenitic stainless steel interior surfaces of the chamber.
2. Avoidance of nonferrous metals in valves and piping that might be exposed to reactants and by-products.
3. Provision of adequate clamping of access closures to avoid leakage where operating near atmospheric pressure.
4. Provision of pressure-relief devices such as corrosion-resistant relief valves or properly vented rupture discs.
5. Provision of NFPA-approved auxiliaries where operating with flammable mixtures.

A-11 Before entering any equipment or confined space, all applicable regulations should be referenced. In particular, reference should be made to ANSI Z117.1, *Safety Requirements for Confined Spaces.*

Authoritative references include NIOSH *Pocket Guide to Chemical Hazards* and the annual TLVs—*Threshold Limit Values for Chemical Substances in the Work Environment.*

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 needed, they should be supplied by the furnace manufacturer.

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

Drive belts are not worn.

Drive belt tension is proper.

No oil leaks are at the shaft seals.

Oil level is correct.

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 necessary. A partial list follows:

Waterflow for cooling is correct.

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 is drained and operating.

Air supply oiler is filled to correct level and operating.

Pilot valves are not leaking excess air.

Moving O-ring seals are cleaned or changed where excess wear is indicated.

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 are tight and free from overheating.

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

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

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

NOTE: Undervoltage 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: The effective life of thermocouples varies depending on the environment and process, the temperature, and the vacuum, and these factors should 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 are required to be water-cooled. 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, the motor and bearings greased, and the 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, and 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 for 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, 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.

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. Make each interlock fail manually, verifying that related equipment shuts down or stops as required.

(ii) Inspect all electrical switches and contacts, and 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 turndown equipment.

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

(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: The frequency of the following maintenance procedures depends on the equipment manufacturer's recommendations.

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

(ii) Review the vacuum chamber vessel for evidence of hot spots that indicate 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 springs and O-rings in the gas ballast valves.

(viii) Run a blank-off test for the mechanical vacuum pump to ensure process parameters are met.

Appendix B Pump Data

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

Figures B-1 through B-4 show approximate minimum commercial absolute pressure capabilities of the principal types of vacuum pumps.

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	0.300 torr to 10^{-7} torr (40 Pa to 1.3 × 10^{-5} Pa)
*Cryogenic devices (i.e., liquid nitrogen cold traps)	0.001 torr (1.3 × 10^{-1} Pa)
*Getter	0.001 torr (1.3 × 10^{-1} Pa)
*Ion molecular	0.001 torr (1.3 × 10^{-1} Pa)

*Generally associated with small specialized systems.

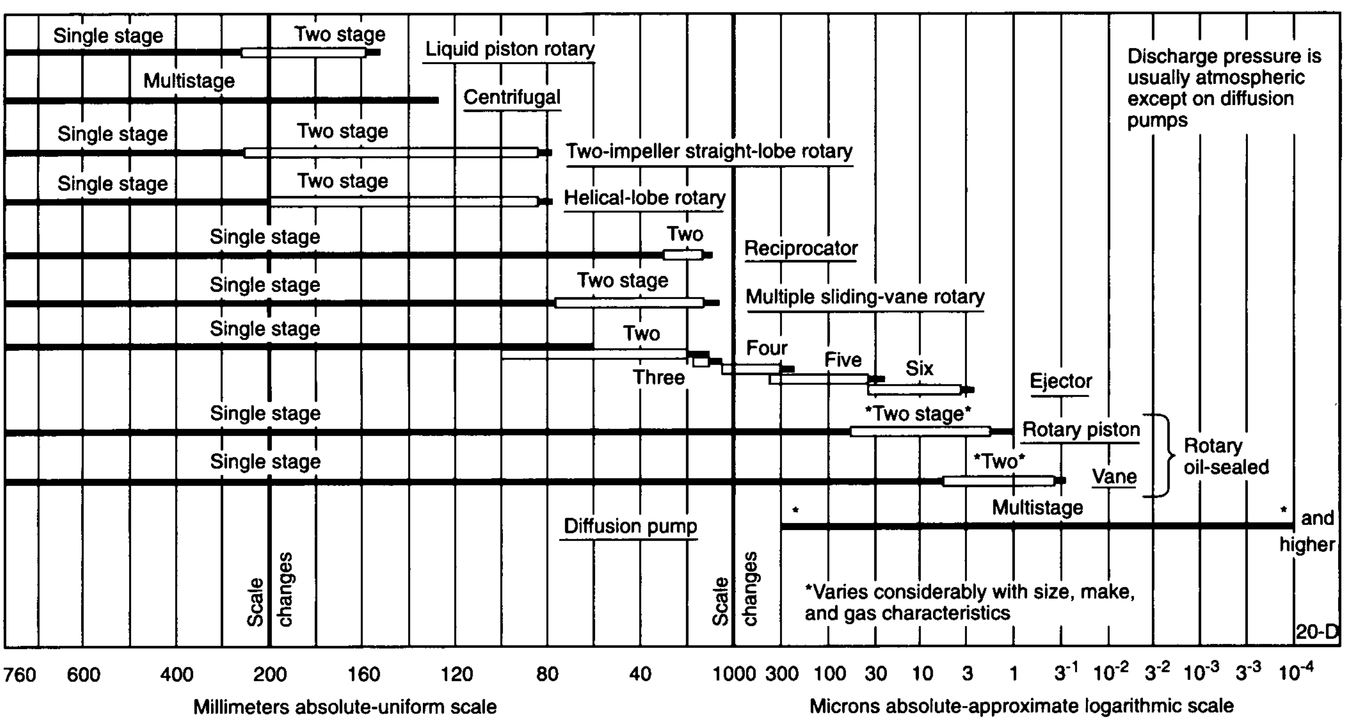


Figure B-1 Pump ranges.

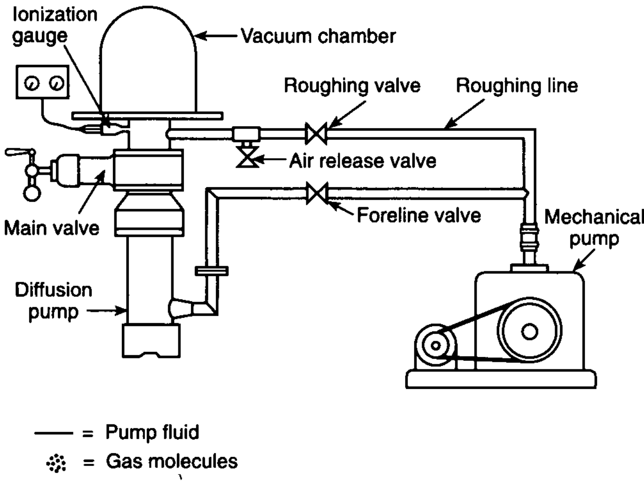


Figure B-2 Typical vacuum system.

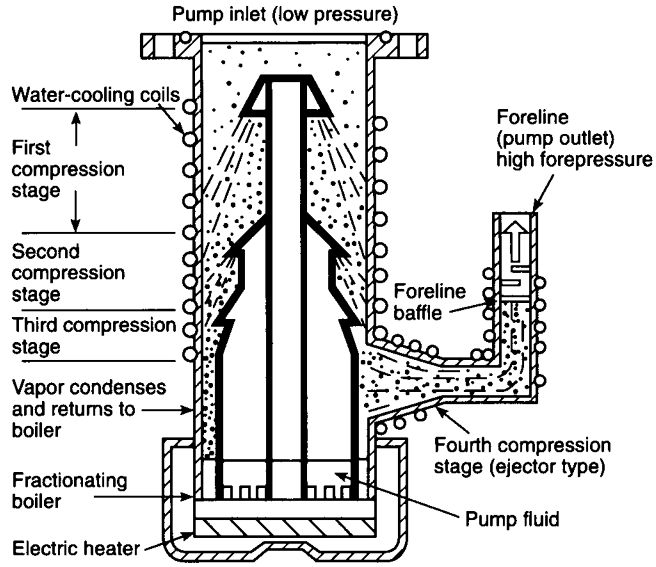


Figure B-3 How a diffusion pump works.

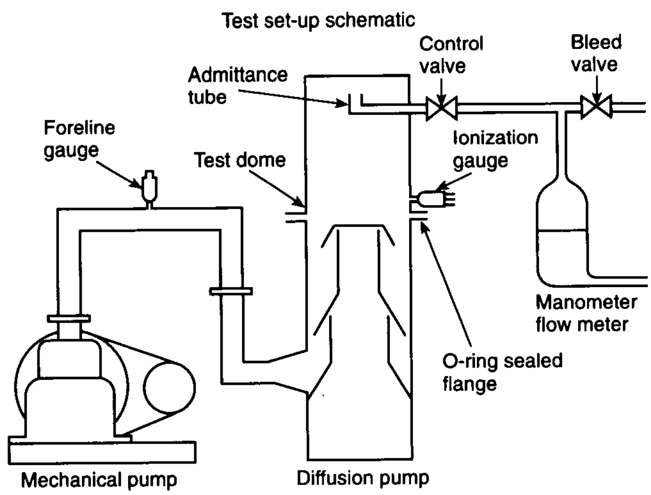


Figure B-4 Typical test set-up used to determine effective pumping speeds with variables indicated in the speed curve graph.

Appendix C Engineering Data

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

Table C-1 Conversion of Gas Flows*

Unit	Torr · l · s^{-1}	Micron · cu ft · min^{-1}	atm · cm^3 · h^{-1}	Micron · l · s^{-1}
Torr · l · 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 · l · s^{-1}	10^{-3}	2.120	4.738	1

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

Table C-2 Conversion of Pumping Speeds*

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

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

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 liter 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]

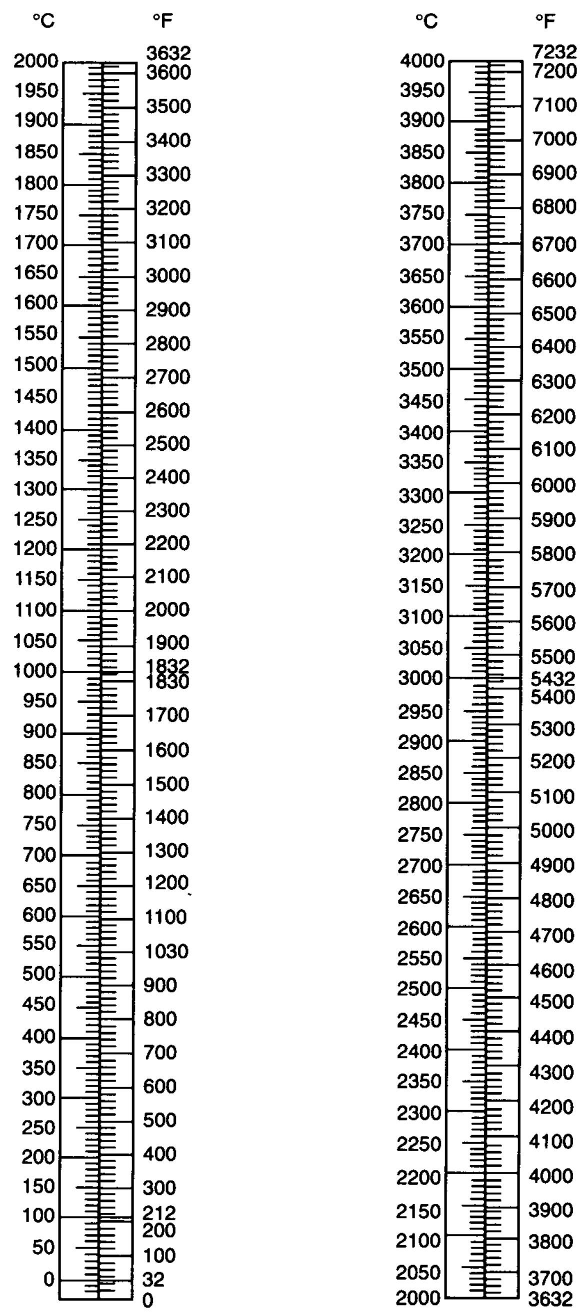


Figure C-1 Conversion from °C to °F.

Table C-4 Conversion of Units of Pressure

Unit	Torr mm Hg	Micron μ	Pa	atm	Microbar μ b	Millibar mb	Bar b	in. 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	$9.8698 \cdot 10^4$	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 centimeter	1 cm	393.7 mil
1 inch	in.	2.54 cm	1 centimeter	1 cm	0.3937 in.
1 foot	ft	30.48 cm	1 centimeter	1 cm	0.0328 ft
1 yard	yd	0.914 m	1 meter	1 m	1.094 yd
1 square inch	sq in.	6.452 cm^2	1 square centimeter	1 cm^2	0.155 sq in.
1 square foot	sq ft	929.0 cm^2	1 square meter	1 m^2	10.76 sq ft
1 square yard	sq yd	0.836 m^2	1 square meter	1 m^2	1.196 sq yd
1 cubic inch	cu in.	16.39 cm^3	1 cubic centimeter	1 cm^3	0.061 cu in.
1 US gallon	gal	3.785	1 liter	1 l	0.264 US gal
1 British gallon	gal	4.546	1 liter	1 l	0.2201 Brit. gal
1 cubic foot	cu ft.	28.32	1 liter	1 l	0.035 cu ft
1 cubic yard	cu yd	0.765 m^3	1 cubic meter	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 millimeter	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 millimeter	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 millimeter	1 kg mm^2	0.635 l tn·(sq in.)[1] (Brit.)
1 micron·cubic foot	" cu ft	0.0283 torr · l	1 torr·liter	1 torr·l	35.31 micron · cu ft
1 micron liter	" l	10^3 torr · l	1 torr · liter	1 torr · l	10^3 micron · l
1 torr ·liter	torr l	1.316 atm cm^3	1 atmosphere cubic centimeter	1 atm · cm^3	0.759 torr · l

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

Table C-6 Physical Properties of Metals

Metal	Symbol	Density at 20°C [g·cm^3]	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]	
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°)