NFPA 8504
Standard on Atmospheric Fluidized-Bed Boiler Operation

1996 Edition

NFPA

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

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Standard on

Atmospheric Fluidized-Bed Boiler Operation

1996 Edition

This edition of NFPA 8504, *Standard on Atmospheric Fluidized-Bed Boiler Operation*, was prepared by the Technical Committee on Fluidized-Bed Boilers, released by the Technical Correlating Committee on Boiler Combustion System Hazards, and acted on by the National Fire Protection Association, Inc., at its Annual Meeting held May 20–23, 1996, in Boston, MA. It was issued by the Standards Council on July 18, 1996, with an effective date of August 9, 1996, and supersedes all previous editions.

Changes other than editorial are indicated by a vertical rule in the margin of the pages on which they appear. These lines are included as an aid to the user in identifying changes from the previous edition.

This edition of NFPA 8504 was approved as an American National Standard on July 26, 1996.

Origin and Development of NFPA 8504

In 1984, the Technical Committee on Boiler-Furnace Explosions began work on a document for the relatively new technology of fluidized-bed combustion system boilers. A new document, NFPA 85H, was issued in 1989. This was developed through numerous task force, subcommittee, and technical committee meetings. The document was written to provide user requirements in order to limit the hazards associated with these special systems and to broaden the NFPA 85 series of standards, which deal with safe boiler operation.

The second edition of the document constituted a major rewrite to address numerous technical issues. Foremost among the changes was the redesignation of the document from NFPA 85H, *Standard for the Prevention of Combustion Hazards in Atmospheric Fluidized Bed Combustion System Boilers*, to NFPA 8504, *Standard on Atmospheric Fluidized-Bed Boiler Operation*.

This edition of NFPA 8504 incorporates numerous changes, mostly for correlation with the other documents in the series. However, there were several technical changes made to this standard.

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Committee Scope: This Committee shall have primary responsibility for documents on the reduction of combustion system hazards in single- and multiple-burner boilers with a heat input rate of 12,500,000 Btu/hr and above. This includes all fuels. This Committee is also responsible for documents on the reduction of hazards in pulverized fuel systems, fluidized-bed boilers, heat recovery steam generators, and stoker-fired boilers, at any heat input rate.

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Committee Scope: This Committee shall have primary responsibility for documents on the operation and reduction of combustion system hazards and the prevention of boiler furnace explosions of fluidized-bed boilers. This includes all fuels at any heat input rate.

Contents

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

Information on referenced publications can be found in Chapter 11 and Appendix C.

Chapter 1 Introduction

1-1 Scope.

1-1.1 This standard shall apply to boilers with a fuel input rating of 12,500,000 Btu/hr (3663 kW) or greater. This standard applies only to boilers using atmospheric fluidized-bed combustion.

1-1.2 This standard covers firing of individual or blended fuels. Where multiple main fuels are fired, additional interlocks and other provisions shall be required but are not covered by this standard.

1-1.3 This standard covers burners and lances associated with fluidized-bed boilers.

1-1.4* This standard is not retroactive. This standard shall apply to new installations and to major alterations or extensions that are contracted subsequent to the effective date of this standard.

1-1.5 Furnaces such as those of process heaters used in metallurgical, chemical, and petroleum manufacture, wherein steam generation is incidental to the operation of a processing system, are not covered by this standard.

1-1.6 Since this standard is based upon the current state of the art, its application to existing installations is not mandatory. Nevertheless, operating companies are encouraged to adopt those features of this standard that are considered applicable and reasonable for existing installations.

1-1.7 Revisions to this standard reflect the current level of knowledge and do not imply that previous editions were inadequate.

1-1.8 The furnace pressure excursion prevention chapter of this standard (Chapter 5) provides methods of minimizing the risk of furnace pressure excursions in excess of the furnace structural capability.

1-2 Purpose.

1-2.1 The purpose of this standard is to contribute to operating safety and to prevent combustion hazards. It establishes minimum standards for the design, installation, operation, and maintenance of boilers and their fuel-burning, air supply, and combustion products removal systems. The standard requires the coordination operating procedures, control systems, and interlocks.

1-2.2 No standard can guarantee the elimination of boiler combustion hazards. Technology in this area is evolving constantly, and this is reflected in revisions to this standard. The user of this standard needs to recognize the complexity of firing fuel with regard to the type of equipment and the characteristics of the fuel. 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 is to be given latitude in the development of such designs. In such cases, the designer is responsible for demonstrating the validity of the proposed design.

1-2.3 Emphasis is placed on the importance of adequate strength of the structure, proper operation and maintenance procedures, operator training, combustion and draft control equipment, safety interlocks, alarms, trips, and other related controls that are essential to proper boiler operation.

1-2.4 The effect of gas cleanup systems located downstream of the post-combustion gas passes of the boiler is known to be significant. Coordination of the operating procedures and design of the boiler and the air quality control systems shall be required. Such coordination shall include requirements for ensuring a continuous flow path from the forced draft fan inlet through the stack. This standard provides only the general requirements for these systems because of the multiplicity of their designs.

Chapter 2 General

2-1 Furnace Explosions.

2-1.1 The basic cause of furnace explosions is the ignition of an accumulated combustible mixture within the confined space of the furnace or the associated boiler passes, ducts, and fans that convey the products of combustion to the stack.

2-1.2 A dangerous combustible mixture within the boiler enclosure consists of the accumulation of an excessive quantity of combustibles mixed with air in proportions that result in rapid or uncontrolled combustion where an ignition source is supplied. A furnace explosion can result from ignition of this accumulation if the quantity of combustible mixture and the proportion of air to fuel are such that an explosive force is created within the boiler enclosure. The magnitude and intensity of the explosion depends on both the relative quantity of combustibles that has accumulated and the proportion of air that is mixed with the combustibles at the moment of ignition. Explosions, including "furnace puffs," are the result of improper operating procedures by personnel, improper design of equipment or control systems, or malfunction of the equipment or control system.

2-1.3 Numerous conditions can arise in connection with the operation of a fluidized-bed system that can produce explosive conditions. The most common of these are as follows:

(a) An interruption of the fuel or air supply or ignition energy to burners, sufficient to result in momentary loss of flames, followed by restoration and delayed reignition of accumulated combustibles;

(b) Auxiliary fuel leakage into an idle furnace and the ignition of the accumulation by a spark or other source of ignition;

(c) Repeated unsuccessful attempts to light off auxiliary fuel without appropriate purging, resulting in the accumulation of an explosive mixture;

(d) The accumulation of an explosive mixture of fuel and air as a result of the main fuel entering a bed whose temperature is below the ignition temperature for the main fuel and the ignition of the accumulation by a spark or other source of ignition;

(e) Purging with an airflow that is too high, which stirs up combustibles smoldering in hoppers;

(f) Insufficient air to all or some bed compartments, causing incomplete combustion and accumulation of combustible material;

(g) The possible accumulation of combustibles in the windbox and ductwork under certain unusual operating, start-up, or shutdown conditions. Bed material retains heat long after a boiler shutdown and can be an ignition source even if its exposed surfaces have cooled.

2-1.4 The conditions favorable to a boiler explosion described in 2-1.3 are typical examples, and an examination of numerous reports of boiler explosions suggests that the occurrences of small explosions, furnace puffs, or near-misses have been far more frequent than usually is recognized.

2-1.5 By virtue of the more consistent ignition source available from the mass of high temperature bed material during normal operation, fluidized-bed combustion is less susceptible to furnace puffs and flameouts than burner combustion.

NOTE: During unit warm-up or operation using a slumped or semifluidized bed, the unit does not benefit from these mitigating factors.

2-1.6 Instrumentation, safety interlocks, protective devices, proper operating sequences, and a clearer understanding of the explosion problem by both designers and operators can further reduce the risks and incidence of furnace explosions, especially during start-up and light-off.

2-1.7 There can exist, in certain parts of the boiler enclosure or other parts of the unit, dead pockets that are susceptible to the accumulation of combustibles. These accumulations can ignite with explosive force in the presence of an ignition source.

2-2* Furnace Pressure Excursions.

2-2.1 Furnace structural damage can result from the occurrence of excessively high or low gas side pressure.

2-2.2 A condition that is likely to cause furnace pressure excursions in a fluidized-bed boiler is maloperation of the equipment regulating the boiler gas flow, including the air supply and flue gas removal systems. This can result in exposure of the furnace to excessive fan head capability.

NOTE: The rapid decrease in furnace gas temperatures and pressure resulting from either a rapid reduction in fuel input or a master fuel trip, which is a cause of implosions in nonfluidized-bed boilers, is not likely to occur in a fluidized-bed boiler because of the resistance to fast temperature changes provided by hot bed material and refractory.

2-2.3 On the basis of reported incidents and field tests, the maximum negative furnace pressure is determined primarily by the maximum head characteristic of the induced draft fan; a major objective of the final design shall be to limit the maximum head capacity of draft equipment to that necessary for satisfactory operation. Special consideration shall be given to fan selection and arrangement of ductwork to limit the effect of negative head.

2-2.4 With scrubbers or other high draft loss equipment for removing flue gas contaminants, a booster fan might be necessary. A bypass or other appropriate means shall be provided to counteract the potentially excessive negative pressure conditions that result from combining the suction heads of both the induced draft and booster fans.

2-3 Manufacture, Design, and Engineering.

2-3.1 The purchaser or the purchaser's agent shall, in cooperation with the manufacturer, ensure that the unit is not deficient in apparatus that is necessary for proper operation, so far as practical, with respect to pressure parts, fuel-burning equipment, air and fuel metering, and safe lighting and maintenance of stable fluidized-bed operation.

2-3.2 All fuel systems shall include provisions to prevent foreign substances from interfering with the fuel supply to the bed.

2-3.3 An evaluation shall be made to determine the optimum integration of manual and automatic safety features, with consideration of the advantages and disadvantages of each trip function.

NOTE: The maximum number of automatic trip features does not necessarily provide for maximum overall safety. Some trip functions result in additional operations that increase exposure to hazards.

2-3.4 This standard necessitates a minimum degree of automation. The trend toward more complex plants or increased automation shall require additional provisions for:

(a) Information regarding significant operating events that allow the operator to make a rapid evaluation of the operating situation. The operator shall be provided with continuous and usable displays of variables that allow the operator to avoid unsafe conditions. (*Also see Section 4-8.*)

(b) In-service maintenance and checking of system functions without impairment of the reliability of the overall control and safety systems.

(c) An environment conducive of proper decisions and actions.

2-3.5 Fuel feed piping and equipment shall be designed and constructed to prevent the formation of hazardous concentrations of combustible gases that exist under normal operating conditions.

2-4 Installation.

2-4.1 The boiler shall not be permitted to be operated before the installation and check of the required safeguards and instrumentation system.

2-4.2 The party responsible for the erection and installation of the equipment shall ensure that all apparatus is installed and connected properly.

2-4.3 The purchaser, the engineering consultant, the equipment manufacturer, and the operating company shall avoid boiler operation until the safeguards have been tested to verify their proper operation as a system. In some instances, it might be necessary to install temporary interlocks and instrumentation to meet these requirements. Any such temporary system shall be reviewed by the purchaser, the engineering consultant, the equipment manufacturer, and the operating company, and agreement shall be reached on its suitability in advance of start-up.

2-4.4 The safety interlock system and protective devices shall be tested jointly and checked by the organization responsible for the system design and those who operate and maintain such system and devices during the operating life of the plant. These tests shall be completed before initial operation.

2-5 Coordination of Design, Construction, and Operation.

2-5.1 Statistics indicate that human error is a contributing factor in the majority of furnace explosions. It is important to consider whether an error is the result of:

(a) Lack of proper understanding of, or failure to use, safe operating procedures;

(b) Lack of adequate operator training;

(c) Unfavorable operating characteristics of the equipment or its control;

(d) Lack of functional coordination of the various components of the steam-generating system and its controls.

2-5.2 Furnace explosions have occurred as a result of unfavorable functional design. Frequently, an investigation has revealed human error and has completely overlooked the chain of causes that triggered the operating error. Therefore, the design, installation, and functional objectives of the overall system of components and their controls shall be integrated. Consideration shall be given to the ergonomics that can affect operation of the system.

2-5.3 During the planning and engineering phases of plant construction, the design shall be coordinated with the operating personnel where possible.

2-5.4 The proper integration of the various components consisting of the boiler, fuel and air supply equipment, combustion products handling equipment, combustion controls, interlocks and safety devices, operator functions, and operator communication and training shall be the responsibility of the operating company and shall be accomplished by the following:

(a) Design and operating personnel who possess a high degree of competence in this field and who are mandated to achieve these objectives;

(b) Periodic analysis of the plant's status with respect to evolving technology so that improvements for greater safety and reliability can be implemented;

(c) Documentation of plant equipment, systems, and maintenance.

2-6 Maintenance Organization.

2-6.1* A program shall be provided for maintenance of equipment at intervals appropriate for the type of equipment, the service requirements, and the manufacturers' recommendations.

2-7 Basic Operating Objectives.

2-7.1 Basic operating objectives shall include the following:

(a) Establishment of operating procedures that result in the minimum number of manual operations.

(b) Standardization of all operating procedures. The use of interlocks is essential to minimize improper operating sequences and to interrupt sequences when conditions are not proper for continuation. It is particularly important that purge and start-up procedures with necessary interlocks be established and rigidly enforced. Chapters 5 and 6 describe operating sequences that have proved to be effective in unit operation.

2-7.2 Written operating procedures and detailed checklists for operator guidance shall be provided for achieving basic operating objectives. All manual and automatic functions shall be described.

2-8 Training.

2-8.1 Operator Training.

2-8.1.1 The owner or the owner's agent shall be responsible for establishing a formal and ongoing program for training operating personnel. This program shall prepare personnel to operate the equipment safely and effectively. The program shall consist of study or review of operating manuals, videotapes, programmed instruction, examinations, computer simulation (if available), and supervised hands-on field training. The training program shall be consistent with the type of equipment and the hazard involved.

2-8.1.2 The owner or the owner's agent shall certify that operators are trained and competent to operate the equipment under all conditions prior to their operation of such equipment.

2-8.1.3 The owner or the owner's agent shall be responsible for periodic retraining of operators, including review of their competence.

2-8.1.4 The training program and manuals shall be reviewed periodically and kept current with changes in equipment or operating procedures. The training program and manuals covering operating and maintenance procedures shall be readily available for reference and use at all times.

2-8.1.5 Operating procedures that cover both normal and emergency conditions shall be established. Start-up and shutdown procedures, normal operating conditions, and lockout procedures shall be covered in detail in operating manuals and the associated training program.

2-8.1.6 Operating procedures shall be directly applicable to the equipment involved and shall be consistent with safety requirements and the manufacturers' recommendations.

2-8.1.7 Operators shall be trained in the proper procedures for reducing load or tripping the system wherever there is a potential for an unsafe condition that could lead to personnel danger or property damage. Operators shall be authorized to call for outside assistance in case of emergency.

2-8.2 Maintenance Training.

2-8.2.1 The owner or the owner's agent shall be responsible for establishing a formal and ongoing program for training maintenance personnel. This program shall prepare personnel to perform any required maintenance tasks safely and effectively. The program shall consist of study or review of maintenance manuals, videotapes, programmed instruction, examinations, field training, training by the equipment manufacturers, and other modes of instruction. The training program shall be appropriate to the equipment and potential hazards involved.

2-8.2.2 Maintenance procedures and their associated training programs shall be established to cover routine and special techniques. Any possible environmental factors such as temperature, dust, contaminated or oxygen-deficient atmosphere, internal pressures, and limited access or confined space requirements shall be included.

2-8.2.3 Maintenance procedures shall be consistent with safety requirements and the manufacturers' recommendations. The procedures contained in the training programs shall be reviewed periodically and kept current with changes in equipment. They shall be used in the indoctrination and training of new maintenance personnel.

2-8.2.4 Maintenance personnel shall be trained to notify operating personnel in writing of any changes in safety and control devices.

2-8.2.5 Maintenance personnel shall be trained to be knowledgeable of and to adhere to all Occupational Safety and Health Act (OSHA) safety procedures.

2-9 Fluidized-Bed Combustion — Special Problems.

2-9.1 Heating the Bed. The bed material shall be heated to a temperature above the autoignition temperature of the main fuel prior to admitting the main fuel to the bed. This normally is accomplished using warm-up burners.

2-9.2 Char Carryover. Elutriation of char from the bed is a characteristic of fluidized-bed combustion. Although most boiler designs provide for reinjection of elutriated char into the bed, a certain amount of unburned carbon is carried in the flue gas through the boiler's heat transfer surfaces and ductwork to the baghouse or other dust collection equipment. The system design shall include provisions to minimize accumulations in the flue gas ductwork and dust collection equipment.

2-9.3 Coal Firing. Common hazards are involved in the combustion of solid, liquid, and gaseous fuels. Each of these fuels has special hazards related to its physical characteristics. The following shall be considered in the design of the coal firing systems:

(a) Coal requires considerable processing in several independent subsystems that need to operate in harmony. Failure to process the fuel properly in each subsystem increases the potential explosion hazard.

(b) Methane gas released from freshly crushed or pulverized coal can accumulate in enclosed spaces.

(c) The raw coal delivered to the plant can contain foreign substances (e.g., scrap iron, wood shoring, rags, excelsior, rock). This foreign material can interrupt coal feed, damage or jam equipment, or become a source of ignition within the fuel-feeding equipment. The presence of foreign material can constitute a hazard by interrupting coal flow. Wet coal can cause a coal hang-up in the raw coal supply system. Wide variations in the size of raw coal can cause erratic or uncontrolled coal feeding or combustion.

(d) Explosions or fires can result from the back flow of hot flue gas or bed material into the fuel-feeding equipment. Provisions shall be made in the design to prevent back flow.

(e) Caution shall be exercised where interpreting the meter indication for combustibles. Most meters and associated sampling systems measure only gaseous combustibles. Therefore, the lack of a meter indication of combustibles does not prove that unburned coal particles or other combustibles are not present.

(f) Coal is subject to wide variations in analysis and characteristics. Changes in the percent of volatile matter and moisture affect the ignition characteristics of the coal and can affect the minimum required bed temperature prior to admission of coal into the bed. The amount of fines in the coal also can affect its ignition and burning characteristics. The minimum bed temperature that allows the admission of coal into the bed shall account for the range of ignition characteristics.

2-9.4 Waste Fuel Firing. Common hazards involved in the combustion of waste fuels should be recognized as follows:

(a) The considerations described in 2-9.3 also apply to waste fuels.

(b) Waste fuels can contain volatile solvents or liquids; therefore, special consideration shall be taken in the design of the fuel handling and storage system.

(c) Waste fuels are potentially more variable in analysis and burning characteristics than conventional fuels, and, therefore, an evaluation of special fuel handling and burning safeguards could be necessary.

2-9.5 Warm-up and Auxiliary Load-Carrying Burners. The operating systems and requirements for warm-up and load-carrying burners are covered in Section 4-6.

2-9.6 Hot Bed Material. Hot bed material can be removed from the bed to maintain the desired inventory of bed material. The temperature of the material is at or near the bed operating temperature [typically 1400°F to 1600°F (760°C to 870°C)] and shall be cooled prior to disposal.

2-9.7* Personnel Hazards. A number of personnel hazards are peculiar to fluidized-bed combustion. Safety precautions for dealing with such hazards shall be required for personnel safety. These hazards include:

(a) Hot solids;

(b) Lime;

(c) Hydrogen sulfide; and

(d) Calcium sulfide.

2-9.8 Additional Problems Requiring Consideration. The following additional problems shall be given consideration:

(a) Thermal inertia of the bed, causing steam generation to continue after fuel trip;

(b) Requirements for continuity of the feed water supply for extended periods following a fuel trip or the loss of all power supply to the plant;

(c) Potential for unintended accumulations of significant quantities of unburned fuel in the bed;

(d) Potential for generation of explosive gases if the air supply to a bed is terminated before the fuel in the bed is burned out;

(e) Potential risk of explosion when reestablishing the air supply to a hot bed;

(f) Bed solidification as a result of a tube leak; and

(g) Structural load requirements for abnormal accumulations of ash/bed material within the boiler furnace enclosure and the solids return path.

Chapter 3 Definitions

3-1 Definitions. The following definitions shall apply for the purposes of this standard.

Air, Infiltration. The leakage of air into a setting, furnace, boiler, or duct.

Air, Primary. In a bubbling bed, that portion of total air used to transport or inject fuel or sorbent and to recycle material to the bed. In a circulating bed, that portion of total air introduced at the base of the combustor through the air distributor.

Air, Secondary. Air for combustion supplied to the boiler to supplement the primary air. Typically, in a bubbling bed, that portion of the air introduced through the air distributor; and, in a circulating bed, that air that enters the combustor at levels above the air distributor.

Air/Fuel Ratio. A ratio of air to fuel supplied to a furnace.

Air-Rich. Indicates a ratio of air to fuel supplied to a furnace that provides more air than that needed for an optimum air/fuel ratio.

Excess Air. Air supplied for combustion in excess of theoretical air.

NOTE: This is not "air-rich" as previously defined.

Fuel-Rich. Indicates a ratio of air to fuel supplied to a furnace that provides less air than that needed for an optimum air/fuel ratio.

Theoretical Air (Stoichiometric Air). The chemically correct quantity of air needed for complete combustion of a given quantity of a specific fuel.

Alarm. An audible or visible signal indicating an off-standard or abnormal condition.

Alteration. A change or modification in a boiler system or subsystem that results in a deviation from the original design specifications or criteria.

Alternate Fuel. A fuel, other than the main fuel, also used to carry load.

Annunciator. A device that indicates an off-standard or abnormal condition by both visual and audible signals.

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.

As-Fired. Refers to fuel properties entering a boiler furnace enclosure.

Ash. As a constituent of fuel, noncombustible mineral matter that remains after the complete burning of a fuel sample. (*See also Char, Spent Bed Material.*)

Ash, Fly. The fine particles of material that are carried outside the boiler enclosure by the gaseous products of combustion.

Ash, Fusion Temperature. The temperature at which a cone of coal or coke ash exhibits certain melting characteristics. (*See ASTM D 1857, Standard Test Method for Fusibility of Coal and Coke Ash.*)

Atmospheric Fluidized-Bed Combustion. A fuel-firing technique using a fluidized bed operating at near-atmospheric pressure on the fire side.

Atomizer. A device in a burner that emits liquid fuel in a finely divided state.

Atomizer, Mechanical. A device in an oil burner that emits liquid fuel in a finely divided state without using an atomizing medium.

Atomizing Medium. A supplementary fluid, such as steam or air, that assists in breaking down liquid fuel into a finely divided state.

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.

Bed Compartment. Segments of a fluidized bed, which might be individually controlled with respect to combustion airflow and fuel feed.

Bed Drain. An opening provided in the enclosure of a fluidized bed for the removal of spent bed material and any tramp material.

Bed Material. Granular particles that compose the fluidized bed.

Bed Temperature. The average temperature of the fluidized bed.

Boiler. A closed vessel in which water is heated, steam is generated, or steam is superheated, or in which any combination thereof takes place by the application of heat from combustible fuels, in a self-contained or attached furnace.

Boiler Control System. The group of control systems that regulates the boiler process, including the combustion control but not the burner management.

Boiler Enclosure. The physical boundary for all boiler pressure parts and the combustion process.

Bubbling Fluidized Bed (BFB). A fluidized bed in which the fluidizing velocity is less than the terminal velocity of individual bed particles and in which part of the fluidizing gas passes through the bed as bubbles.

Burner. A device, or group of devices, for the introduction of fuel and air into a furnace at the velocities, turbulence, and concentration necessary to maintain ignition and combustion of the fuel in a defined flame envelope within the furnace.

Auxiliary Load-Carrying Burner. A burner whose primary purpose is load carrying, located over the bed and having its own air supply.

Duct Burner. A warm-up burner mounted in a duct used to heat air introduced directly into or through the bed.

Over Bed Burner. A warm-up burner located above the bed and firing over or into the bed.

Warm-up Burner. A burner having its own air supply used to warm up the bed to the ignition temperature of the main fuel. The warm-up burner also can be used for limited load carrying.

Burner Management System. The control system dedicated to boiler furnace safety, operator assistance in the starting and stopping of fuel preparation and burning equipment, and for preventing misoperation of and damage to fuel preparation and burning equipment. The burner management system includes the following functions specified in this standard: interlock system, fuel trip system, master fuel trip system, master fuel trip relay, flame monitoring and main fuel monitoring, main fuel combustion monitoring, bed temperature monitoring, and warm-up burner subsystems.

Calcination. The endothermic chemical reaction that takes place when converting calcium carbonate or calcium hydroxide to calcium oxide.

Calcium to Sulfur Molar Ratio (Ca/S). The ratio of the total moles of calcium in the sorbent fed to the boiler to the total moles of sulfur in the fuel fed to the boiler.

Capacity. The manufacturer's stated output rate over a period of time for which the boiler is designed to operate.

Capacity, Maximum. The highest rated capacity of a steam generator.

Char. The unburned combustibles in solid form combined with a portion of the fuel ash.

Circulating Fluidized Bed (CFB). A fluidized bed in which the fluidizing velocities exceed the terminal velocity of individual bed particles.

Coal. The general name for the natural, rock-like, brown-to-black derivative of forest-type plant material. By subsequent underground geological processes, this organic material is progressively compressed and indurated over time, ultimately becoming graphite and graphite-like material. Coal contains carbon, hydrogen, oxygen, nitrogen, and sulfur, as well as inorganic constituents that form ash after burning. There is no fixed standard for coal, but there is an almost endless variety with respect to character and composition. The basic classifications for coal are lignite, subbituminous, bituminous, and anthracite. (*See ASTM D 388, Standard Classification of Coals by Rank.*)

Combustion Chamber. The portion of the boiler enclosure into which the fuel is fed, ignited, and burned.

Combustion Control System. The control system that regulates the furnace fuel input, furnace air input, bed inventory, and other bed heater transfer mechanisms to maintain the bed temperature and the air/fuel ratio within the limits necessary for continuous combustion and stable bed operation throughout the operating range of the boiler in accordance with demand. This control system includes the furnace draft control where applicable.

Continuous Trend Display. A dedicated visual display of an operating trend(s) by any instrument such as a cathode ray tube (CRT), chart recorder, or other device to quantify changes in the measured variable(s).

Crusher. A device for reducing the size of solid fuels.

Directional Blocking. An interlock that, upon detection of significant error, acts to inhibit the movement of all appropriate final control elements in the direction that increases the error.

Drip Leg. A chamber of ample volume, with suitable cleanout and drain connections, into which gas is discharged so that liquids and solids are trapped.

Elutriation. The selective removal of fine solids from a fluidized bed by entrainment in the upward flowing products of combustion.

Extension. An addition to the boiler system or additional subsystems.

Fans.

Forced Draft (FD) Fan. A device used to pressurize and supply ambient air to the boiler mechanically to support combustion. In a fluidized-bed boiler, FD fans generally include both primary air and secondary air fans.

Induced Draft (ID) Fan. A device used to remove the products of combustion from the boiler mechanically by introducing a negative pressure differential.

Fan Test Block Capability. The point on the curve of the head versus the flow characteristics at which the fan is selected. This is the calculated operating point associated with the maximum continuous rating of the boiler furnace plus the head, flow, and temperature margins.

Flame Detector. A device that senses the presence or absence of flame and provides a usable signal.

Flame Detector, Self-Checking. A flame detector that automatically, and at regular intervals, tests the entire sensing and signal processing system of the flame detector. This ensures that the failure of any single component cannot result in a false indication of flame.

Flame Envelope. The confines (not necessarily visible) of an independent process that converts fuel and air into products of combustion.

Fluidize. To blow air or gas through a bed of finely divided solid particles at such a velocity that the particles separate and behave much like a fluid.

Fluidized Bed. A bed of granular particles maintained in a mobile suspension by the velocity of an upward flow of air or gas.

Freeboard. The space or volume above the upper surface of the bubbling bed and below the entrance to the convective pass.

Fuel, Auxiliary. Fuel, generally gaseous or liquid, used to warm the bed material sufficiently to allow ignition of the main fuel upon injection into the heated bed material; also can be used to carry partial or full load as an alternate to the main fuel. Auxiliary fuels are fired in burners.

Fuel, Main. Gaseous, liquid, or solid fuel introduced into the bed after the bed temperature has reached a value sufficient to support its combustion and that is used during the normal operation of the boiler. Main fuels necessitate the use of the fluidized hot bed as their ignition source.

Fuel Cutback. An action of the combustion control system that reduces fuel flow when the air/fuel ratio is less than that of a prescribed value.

Fuel Gas. See LP-Gas and Natural Gas.

Fuel Oil. Grades 2, 4, 5, and 6 fuel oils as defined in ASTM D 396, *Standard Specification for Fuel Oils*.

Fuel Trip. The automatic shutoff of a specific fuel as the result of an interlock or operator action.

Furnace. The combustion chamber of a boiler.

High Gas Pressure Switch. A pressure-actuated device arranged to effect a safety shutdown or prevent starting when the gas pressure exceeds the preset value.

High Oil Temperature Switch. A temperature-actuated device that initiates a signal when oil temperature rises above the limits necessary to maintain the viscosity range recommended by the burner manufacturer.

Igniter. A device that provides proven ignition energy to light off its associated burner immediately.

Igniter, Class 1 (Continuous Igniter). An igniter applied to ignite the fuel input through the burner and to support ignition under any burner light-off or operating conditions. Its location and capacity are such that it provides sufficient ignition energy (generally in excess of 10 percent of full-load burner input) at its associated burner to raise any credible combination of burner inputs of both fuel and air above the minimum ignition temperature.

Igniter, Class 2 (Intermittent Igniter). An igniter applied to ignite the fuel input through the burner under prescribed light-off conditions. It also is used to support ignition under low load or certain adverse operating conditions. The range of capacity of such igniters generally is 4 percent to 10 percent of the full-load burner fuel input. It shall not be used to ignite the main fuel under uncontrolled or abnormal conditions. The burner shall be operated under controlled conditions to limit the potential for abnormal operation, as well as to limit the charge of fuel to the furnace in the event that ignition does not occur during light-off. Class 2 igniters shall be permitted to be operated as Class 3 igniters.

Igniter, Class 3 (Interrupted Igniter). A small igniter applied particularly to gas and oil burners to ignite the fuel input to the burner under prescribed light-off conditions. The capacity of such igniters generally does not exceed 4 percent of the full-load burner fuel input. As part of the burner light-off procedure, the igniter is turned off when the timed trial for ignition of its associated burner has expired. This is to ensure that the main flame is self-supporting, is stable, and is not dependent upon ignition support from the igniter. The use of such igniters to support ignition or to extend the burner control range is prohibited.

Igniter, Class 3 Special (Direct Electric Igniter). A special Class 3 high-energy electrical igniter capable of directly igniting the burner fuel. This type of igniter shall not be used unless supervision of the individual burner flame is provided.

Exception: The igniter, Class 3 special, shall be permitted to be used without supervision of the individual burner flame while scavenging (clearing) the burner.

Interlock. A device or group of devices arranged to sense a limit or off-limit condition or improper sequence of events and to shut down the offending or related piece of equipment, or to prevent proceeding in an improper sequence in order to avoid a hazardous condition.

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.

Lance. A device, without its own air supply, that provides fuel input directly into the bed.

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

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.

Lock Hopper. A feeding device that incorporates a double pressure seal, thus enabling solids to be fed into a system with a higher pressure than that existing in the solids' storage area. Also, a letdown device that incorporates a double pressure seal that enables solids to be withdrawn from a system with a higher pressure than that existing downstream of the lock hopper.

Logic System. The decision-making and translation elements of the burner management system.

(a) *Hardwired System.* A logic system comprised of individual devices and interconnecting wiring.

(b) *Microprocessor-Based System.* A logic system comprised of the following:

1. Computer hardware, power supplies, input/output (I/O) devices, and interconnections between these systems; or

2. An operating system and logic software.

Low Gas Pressure Switch. A pressure-actuated device arranged to effect a safety shutdown or prevent starting when the gas pressure is below the preset value.

Low Oil Pressure Switch. A pressure-actuated device arranged to effect a safety shutdown or prevent starting when the oil pressure is below the preset value.

Low Oil Temperature Switch. A temperature-actuated device that initiates a signal when the oil temperature falls below the limits necessary to maintain the viscosity range recommended by the burner manufacturer.

Low Water Cutout. A device arranged to effect a master fuel trip when the water level in the steam drum falls to a predetermined low level.

LP-Gas. A material composed predominantly of any of the following hydrocarbons or their mixtures: propane, propylene, normal butane, isobutane, and butylenes.

Main Fuel Temperature Permit. The minimum bed temperature at which the main fuel can be introduced with resulting stable combustion.

Master Fuel Trip. An event resulting in the rapid shutoff of all fuel, including igniters.

Master Fuel Trip Relay. An electromechanical relay(s) utilized to trip all required equipment simultaneously when a master fuel trip is initiated.

Minimum Fluidization Velocity. The lowest velocity sufficient to cause fluidization (incipient fluidization).

Monitor. To sense and indicate a condition without initiating automatic corrective action.

Natural Gas. A gaseous fuel occurring in nature consisting mostly of a mixture of organic compounds (normally methane, ethane, propane, and butane). The heating value of natural gases varies from 700 Btu/ft^3 to 1500 Btu/ft^3 (26.1 MJ/m^3 to 55.9 MJ/m^3), with the majority averaging 1000 Btu/ft^3 (37.3 MJ/m^3).

Open Flow Path. A continuous path for movement of an airstream from the forced draft fan inlet to the stack.

Override Action, Fan. A control that, upon detection of significant error in furnace pressure, acts to reposition the induced draft fan control device(s) in a direction to reduce the error. (*See Directional Blocking.*)

Positive Means. The physical methods of satisfying a requirement.

Prove. To establish by measurement or test the existence of a specified condition, such as flame, level, flow, pressure, or position.

Purge. A flow of air through the boiler enclosure and associated flues and ducts that effectively removes any gaseous combustibles and replaces them with air. Purging also can be accomplished using an inert medium.

Purge Rate. A constant flow of not less than 25 percent of the full-load mass airflow with the bed in a semifluidized or fluidized condition.

Recirculation (Solids or Recycle). The reintroduction of solid material extracted from the products of combustion into a fluidized bed.

Recycle Rate. The rate at which a mass of material is reinjected into the fluidized bed. This value is often expressed as the ratio of the amount being reinjected to the total amount being elutriated from the fluidized bed.

Recycle Ratio. The mass of material being reinjected into the fluidized bed divided by the mass of fuel being fed into the bed.

Reinjection. Refers to the return or recycling of material removed or carried from the furnace back to the furnace. Also refers to fly ash collected and returned to the furnace or combustion chamber; sometimes expressed as a percent of the total collected.

Repair. A process that returns the boiler system or subsystem to its original design specifications or criteria.

Scavenging. The procedure by which liquid fuel left in a burner or igniter after a shutdown is cleared by admitting steam or air through the burner passages, typically through a dedicated scavenging medium valve.

Semifluidized. A state in which a uniform flow of air that is less than that necessary to fluidize the bed is admitted and is found to be sufficient to adequately remove gaseous combustibles as agreed between the manufacturer and the authority having jurisdiction.

Set Point. A predetermined value to which an instrument is adjusted and at which it shall perform its intended function.

Shall. Indicates a mandatory requirement.

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

Sorbent. A constituent in a fluidized bed that reacts with and captures a pollutant or, more generally, a constituent that reacts with and captures another constituent.

Spent Bed Material. Material removed from a fluidized bed generally comprised of reacted sorbent, calcined limestone, ash, and solid, unburned combustibles. For some applications, the spent bed material might also contain some inert material, such as sand.

Stable Bed. A fluidized bed of granular material that maintains sustained combustion at a desired temperature.

Stable Flame. A flame envelope that retains its continuity throughout the maximum rate of change within the operating range of the burner.

Standard. A document, the main text of which contains only mandatory provisions using the word "shall" to indicate requirements, which is in a form generally suitable for mandatory reference by another standard or code or for adoption into law. Nonmandatory provisions shall be located in an Appendix, footnote, or fine-print note and are not to be considered a part of the requirements of a standard.

Sulfation. The exothermic chemical reaction that takes place when calcium oxide unites with oxygen and sulfur dioxide to form calcium sulfate.

Sulfur Capture. The molar fraction of sulfur in the fuel input that is "captured" by calcium oxide to form calcium sulfate.

Sulfur Reacted. The fraction of the total sulfur in the fuel fed to the fluidized bed that is converted to sulfur dioxide or calcium sulfate.

Sulfur Retention. The molar ratio of the total sulfur in the fuel minus the sulfur leaving the unit as sulfur dioxide to the total sulfur in the fuel.

Supervise. To sense a condition needing attention and automatically initiate corrective action.

Supervised Manual System. A system in which a trained operator has primary responsibility for the proper start-up, operation, and normal shutdown of a boiler with interlocks to ensure that the operation follows established procedures.

Supplementary Fuel. Fuel burned to supply additional heat to the steam generator or to support combustion.

Transport Air. The air used to convey or inject solid fuel or sorbent or to recycle material. (*See also Air, Primary.*)

Unburned Combustible. Combustible matter leaving the boiler furnace enclosure, either as a gas or solid, without completing combustion.

Unit. The confined spaces of the furnace and the associated boiler passes, ducts, and fans that convey the gases of combustion to the stack.

Unit Purge. Air at purge rate that is flowed through the unit from the forced draft (FD) fan to the stack for either (1) a period of not less than 5 minutes, or (2) five changes in volume of the boiler enclosure, whichever is greater.

Valve, Charging. A small valve bypassing the main safety shutoff valve used for purging and charging the fuel headers and piping and for testing for leaks.

Valve, Flow Control. A valve capable of regulating quantity of throughput to a controlled range.

Valve, Safety Shutoff (Fuel Trip Valve). A fast-closing valve that automatically and completely shuts off the fuel supply to burners, lances, or igniters in response to a fuel trip or a master fuel trip.

Valve, Supervisory Shutoff. A manually operated shutoff valve with a means to provide a "valve closed" signal.

Valve, Vent. A valve used to allow venting of air or gas from the system to the atmosphere.

Volatile Matter. The portion of mass, except water vapor, that is driven off in a gaseous form when solid fuels are heated.

Chapter 4 Equipment Requirements

4-1 Structural Design.

4-1.1 Boiler Enclosure.

4-1.1.1* The boiler enclosure shall be capable of withstanding a transient pressure without permanent deformation due to yield or buckling of any support member. The minimum design pressure (*see Section 5-1*) shall be:

(a) Whichever is greater, 1.67 times the predicted operating pressure of the component or +35 in. (+8.7 kPa) of water, but shall not be in excess of the maximum head capability of the air supply fan at ambient temperature; and

(b) The maximum head capability of the induced draft fan at ambient temperature but not more negative than – 35 in. (– 8.7 kPa) of water.

4-1.1.2 The induced draft fan head capability increases due to significant draft losses beyond the boiler enclosure or for other reasons, such as excessive induced draft fan test block margins. Where the induced draft fan test block capability is more negative than – 35 in. (– 8.7 kPa) of water, consideration shall be given to an increased negative design pressure.

4-1.2 Combustion Products Removal Subsystem. The transient internal design pressure defined in 4-1.1.1 shall be taken into consideration in the design of the air and gas flow path from the forced draft fan discharge through the stack.

4-2 Fuel-Burning System.

4-2.1 Functional Requirements.

4-2.1.1 The fuel-burning system shall function to convert continuously any ignitible fuel input into unreactive products of combustion at the same rate that the fuel and air reactants enter the furnace.

4-2.1.2 The fuel-burning system shall be sized properly, adequate to meet the operating requirements of the unit, compatible with other boiler component systems, and capable of being controlled over the full operating range of the unit.

4-2.2 System Requirements.

4-2.2.1 The fuel-burning system shall provide means for proper start-up, operation, and shutdown of the combustion process. This shall include appropriate openings and configurations in the component assemblies to allow suitable observation, measurement, and control of the combustion process.

4-2.2.2 The fuel-burning system consists of the boiler enclosure and the following subsystems: air supply, coal or other solid fuel supply or both, crusher (where utilized), bed feed, liquid or gaseous fuel lances, burners, ash removal, ash reinjection, and combustion products removal. Each shall be sized and interconnected to satisfy the following requirements:

(a) *Boiler Enclosure.*

1. The boiler enclosure shall be sized and arranged so that stable bed operations and stable combustion can be maintained.

2. The boiler enclosure shall be free of dead pockets where prescribed purge procedures are followed.

3. Observation ports shall be provided to allow inspection of the duct and warm-up burners.

4. Means shall be provided for adequate monitoring of conditions at the bed and its ignition zone. Accessibility for maintenance shall be provided.

(b) *Air Supply Subsystem.*

1. The air supply equipment shall be sized and arranged to ensure a continuous airflow adequate for all operating conditions of the unit.

2. The arrangement of air inlets, ductwork, and air preheaters shall minimize contamination of the air supply by such materials as flue gas, water, fuel, and bed material. Appropriate drain and access openings shall be provided.

(c) *Bed Warm-up Burner Subsystem.* (*See Section 4-6 .*)

(d) *Solid Fuel Supply.*

1. The solid fuel supply subsystem shall be designed to ensure a steady fuel flow for all operating requirements of the unit.

2. The solid fuel unloading, storage, transfer, and preparation facilities shall be designed and arranged to size the fuel, to remove foreign material, and to minimize interruption of the fuel supply to the feeders. This design shall include the installation of breakers, cleaning screens, and magnetic separators where necessary. Means for detection of flow interruption and correction shall be provided to ensure a steady flow to the boiler.

3. Solid fuel feeders shall be designed with a capacity range to allow for variations in size, quality, and moisture content of the fuel as specified by the purchaser. Fuel piping to and from feeders shall be designed for free flow within the design range of solid fuel size, quality, and moisture content. Means shall be provided for proving solid fuel flow. Means shall be provided for clearing obstructions.

4. A bed feed that operates at a lower pressure than the boiler enclosure to which it is connected shall have a lock hopper or other suitable means to prevent back flow of combustion products.

5. If transport air is required, a means shall be provided to ensure a supply that is adequate for the required fuel input.

(e) *Crusher Subsystem* (where utilized in the fuel feed system).

1. Fuel crushing equipment shall produce satisfactory fuel sizing over a specified range of fuel analyses and characteristics. The crushing system shall be designed to minimize the possibility of fires starting in the system, and means shall be provided to extinguish fires. For further information, see NFPA 8503, *Standard for Pulverized Fuel Systems.*

2. The transport system shall be sized and arranged to transport the material properly throughout the crusher's operating range.

(f) *Fuel Oil or Fuel Gas Lances.* (*See Section 4-6.*)

(g) *Solids Removal Subsystems.*

1. The bed drain subsystem and flue gas cleaning subsystem shall be sized and arranged to remove the bed material, fly ash, and spent sorbent at a rate that is at least equal to the rate at which they are generated by the fuel-burning process during unit operation.

2. Convenient access and drain openings shall be provided.

3. The removal equipment handling hot ash from the boiler shall be designed to provide material cooling before discharging material into ash handling and storage equipment. Safety interlocks with a device to monitor cooling medium flow and material discharge temperature shall be provided to prevent fires or equipment damage.

(h) *Combustion Products Removal Subsystem.*

1. The flue gas ducts, fans, and stack shall be sized and arranged to remove the products of combustion at the same rate at which they are generated by the fuel-burning process during operation of the unit.

2. Convenient access and drain openings shall be provided.

3. The flue gas ducts shall be designed so that they do not contribute to furnace pulsations.

4. Components common to more than one boiler shall not limit the rate of removal of products of combustion generated during operation of any or all boilers.

5. Boilers that share a common component between the furnace outlet and the stack shall have provisions to bypass the common components for unit purge. Purge air shall not discharge into or through a common component if the other boiler(s) is in operation.

4-3 Burner Management System, Logic. The intent of this section is to provide guidance in the use of logic systems in burner management.

4-3.1 General Requirements. A logic system provides outputs in a particular sequence in response to external inputs and internal logic. The logic system for burner management shall be specifically designed so that a single failure in that system does not prevent an appropriate shutdown.

4-3.2 Specific Requirements. As a minimum, the requirements of 4-3.2.1 through 4-3.2.3.3 shall be included in the design to ensure that a logic system for burner management meets the intent of this standard.

NOTE: Some items are not applicable to specific types of logic systems (e.g., relay systems).

4-3.2.1 Failure Effects. The logic system designer shall evaluate the failure modes of components where considering the design application of the system. As a minimum, the following failures shall be evaluated and addressed:

(a) Interruptions, excursions, dips, recoveries, transients, and partial losses of power;

(b) Memory corruption and losses;

(c) Information transfer corruption and losses;

(d) Inputs and outputs (fail-on, fail-off);

(e) Signals that are unreadable or not being read;

(f) Failure to address errors;

(g) Processor faults;

(h) Relay coil failure;

(i) Relay contact failure; and

(j) Timer failure.

4-3.2.2 Design.

(a) Diagnostics shall be included in the design to monitor processor logic function.

(b) Logic system failure shall not preclude proper operator intervention.

(c) Logic shall be protected from unauthorized changes.

(d) Logic shall not be changed while the associated equipment is in operation.

(e) System response time (throughput) shall be sufficiently short to prevent negative effects on the application.

(f) Protection from the effects of noise immunity shall be adequate to prevent false operation.

(g) Any single component failure within the logic system shall not prevent a mandatory master fuel trip. (*See 6-2.5.*)

(h) The operator shall be provided with a dedicated manual switch(es) that shall actuate the master fuel trip relay independently and directly. (*See also 9-3.1.4.*)

4-3.2.3 Requirement for Independence. The logic system performing the safety functions for burner management shall not be combined with any other logic system. These burner management safety functions shall include, but shall not be limited to, proper purge interlocks and timing, bed temperature monitoring, mandatory safety shutdowns, and burner flame monitoring. [*See A-9-2.3(i).*]

4-3.2.3.1 The burner management system shall be provided with independent logic, independent input/output systems, and independent power supplies and shall be functionally and physically separate from other logic systems (e.g., boiler control system).

4-3.2.3.2 The same hardware type used for other logic systems shall be permitted to be used for burner management systems.

4-3.2.3.3 Data highway communications between the burner management system and other systems shall be permitted. However, signals that initiate mandatory master fuel trips shall be hardwired.

4-3.2.4 Logic sequences or devices intended to cause a safety shutdown, once initiated, shall cause a burner or master fuel trip, as applicable, and shall require operator action prior to resuming operation of the affected burner(s). No logic sequence or device shall be permitted that allows momentary closing and subsequent inadvertent reopening of main or ignition fuel valves.

4-4 Combustion Monitoring and Tripping Systems.

4-4.1 Functional Requirements. The basic requirements of the combustion monitoring and tripping system shall be as follows:

(a) Combustion instability situations shall be brought to the attention of the operator for remedial action.

(b) An emergency shutdown of the involved equipment shall be automatically initiated upon detection of serious combustion problems likely to lead to the accumulation of unburned fuel or other hazardous situations.

4-4.2* Bed Temperature Monitoring.

4-4.2.1 The bed temperature, monitored by taking a number of measurements physically located in the bed, shall provide a representative bed temperature profile under all operating conditions. If the bed is compartmented, the bed temperature of each individual compartment shall be monitored. The bed temperature(s) shall be available to the operator.

4-4.2.2 An indication of bed temperature outside the normal operating range shall be brought to the attention of the operator in order to permit remedial action.

4-4.2.3 Upon detection of a bed temperature that falls below the minimum value established for self-sustaining combustion of the fuel(s) being fired in the bed, that fuel supply shall be automatically shut down.

4-5 Combustion Control System.

4-5.1 Functional Requirements.

4-5.1.1 The combustion control system shall maintain furnace fuel and air input in accordance with demand.

4-5.1.2 The combustion control system shall maintain the bed temperature within the limits required for continuous stable combustion for the full operating range of the boiler.

4-5.1.3 Furnace inputs and their relative rates of change shall be controlled to maintain the air/fuel ratio within the limits required for continuous combustion and stable bed conditions for the full operating range of the boiler.

NOTE: To maintain a proper air/fuel ratio, the use of gravimetric-type or calibrated volumetric-type feeders with the use of combustion airflow measurement and monitoring of the flue gas percent oxygen and low range combustibles is an acceptable method of controlling the air/fuel ratio.

4-5.2 System Requirements.

4-5.2.1 Equipment shall be provided and operating procedures established to heat the bed material prior to admitting fuel to the bed. For bed start-up, the temperature of the bed material shall be raised to the minimum value established for self-sustaining combustion of the fuel, and the bed shall be fluidized before fuel is admitted. (*See Appendix B.*)

4-5.2.2 Provisions shall be made for setting minimum and maximum limits on the fuel and air control subsystems to ensure stable bed operation and to prevent fuel and airflows beyond the capacity of the furnace. These minimum and maximum limits shall be defined by the boiler manufacturer and verified by operating tests.

4-5.2.3 Where changing the rate of furnace input, the airflow and fuel flow shall be changed simultaneously to maintain proper air/fuel ratio during and after the changes. This shall not eliminate the requirements for air lead and lag during changes in the fuel firing rate. Setting the fuel flow control on automatic without setting the airflow control set on automatic shall be prohibited, and this function shall be interlocked.

NOTE: Where fluidized-bed combustion boilers burn fuels of widely varying heat value and air demand per unit of fuel, the required air/fuel ratio limits should include provision for the calibration of the air/fuel ratio.

4-5.2.4 The control system shall prevent the demand for a fuel-rich mixture while in the automatic control mode.

4-5.2.5 Means shall be provided to limit fuel input to the air available while in the automatic control mode.

4-5.2.6 On balanced draft furnaces, furnace draft shall be maintained at the set point.

4-5.2.7 Equipment shall be designed and procedures established to allow as much on-line maintenance of combustion control equipment as practicable.

4-5.2.8 Provisions for calibration and testing of combustion control and associated interlock equipment shall be furnished.

4-5.2.9* Flue gas oxygen analyzers shall be provided for use as an operating guide. Consideration also shall be given to providing a combustibles analyzer for use as an operating guide.

4-5.2.10 Fuel gas flow meters shall be operated at constant pressure conditions or shall be pressure compensated where pressure variations introduce a significant error.

4-5.2.11 Fuel oil flow meters shall be compensated where variations in temperature or viscosity introduce a significant error.

4-5.2.12 Consideration shall be given to providing solid fuel flow measurement devices on each feeder as a part of the combustion control and solid fuel feed control systems in order to provide indexes of total fuel versus total airflow and for use as an operating guide.

4-5.2.13 Means shall be provided to maintain adequate transport/fluidizing air for transporting the required fuel, sorbent, and recycled ash material, as applicable.

4-6 Warm-up Burners and Lances.

4-6.1 Fuel Supply Subsystem, Gas.

4-6.1.1 The fuel supply equipment shall be sized and arranged to ensure a continuous fuel flow that is adequate for all operating requirements of the unit. These include coordination of the fuel control valve, burner safety shutoff valves, and associated piping volume to prevent fuel pressure transients that might result in exceeding burner limits for stable flame caused by placing burners in service or taking them out of service.

4-6.1.2 The portion of the fuel supply system located outside the boiler room shall be arranged to prevent excessive fuel gas pressure in the fuel-burning system, even in the event of a failure of the gas supply constant fuel pressure regulator(s). Usually this can be accomplished by providing full relieving capacity, vented to a safe location. Where full relieving capacity is not installed, a high gas supply pressure trip shall be provided. (*See also 7-5.3.*)

4-6.1.3 The fuel supply equipment shall be designed to inhibit contamination of the fuel. Convenient access to important fuel system components shall be provided. Drains shall be provided at low points in the piping.

4-6.1.4 The fuel supply equipment shall be capable of continuing the proper fuel flow during anticipated furnace pressure pulsations.

4-6.1.5 The fuel supply equipment shall be designed with careful consideration of the operating environment and ambient conditions, including severe external conditions such as fire or mechanical damage. Special attention shall be given to such factors as routes of piping and valve locations to minimize exposure to explosion hazard or high temperature sources.

4-6.1.6 As much of the fuel subsystem as is practicable shall be located outside the boiler house. A manual emergency shutoff valve shall be provided that is accessible in the event of fire in the boiler area.

4-6.1.7 A positive means to prevent leakage of gas into a furnace or duct shall be provided. Provisions shall be included to vent the piping upstream of the last shutoff valve in any line to a burner, igniter, or lance.

4-6.1.8 Provisions shall be made in the gas piping to allow testing for leakage and subsequent repair. Such provisions shall include a permanent and ready means for making easy, accurate, periodic tightness tests of the header safety shutoff valves and individual safety shutoff valves.

4-6.1.9* The discharge from atmospheric vents shall be located so that there is no possibility of the discharged gas being drawn into the air intake, ventilating system, or windows of the boiler room or adjacent buildings and shall be extended sufficiently above the boiler and adjacent structures so that gaseous discharge does not present a fire hazard.

Vents shall be sized according to Table 4-6.1.9

Table 4-6.1.9 Vent Line Sizes

Fuel Line Diameter		Vent Line Diameter	
(in.)	(mm)	(in.)	(mm)
≤1$^1/_2$	≤38	$^3/_4$	19
2	50.8	1	25.4
2$^1/_2$ to 3	64 to 76	1$^1/_4$	31.8
3$^1/_2$	89	1$^1/_2$	38
4 to 5	102 to 127	2	50.8
5$^1/_2$ to 6	140 to 152	2$^1/_2$	64
6$^1/_2$ to 7$^1/_2$	165 to 191	3	76
8	203	3$^1/_2$	89
>8	203	15% of the cross-sectional area of the pipe	

4-6.1.10 The vent lines from the individual burners shall be permitted to be manifolded together. The vent lines from the individual igniters shall be permitted to be manifolded together. The cross-sectional area of the manifolded line shall not be less than the largest vent line plus 50 percent of the sum of the cross-sectional areas of the additional vent lines.

Exception No. 1: Burner vents shall not be manifolded with igniter vents or lance vents in any combination.

Exception No. 2: Header vents shall be permitted to be manifolded with other header vents only where they are operated and tripped in parallel.

Exception No. 3: Vents of headers served from different pressure reducing stations shall not be manifolded.

Exception No. 4: Vent systems of different boilers shall not be manifolded.

Exception No. 5: Vents of systems operating at different pressures shall not be manifolded.

Exception No. 6: Vents of systems using different fuel sources shall not be manifolded.

4-6.1.11 Shutoff valves shall be located as close as practicable to the igniters, burners, or lances to minimize the volume of fuel downstream of the valve.

4-6.1.12 Gas piping materials and system design shall be in accordance with ANSI B31.1, *Power Piping*.

4-6.2 Fuel Supply Subsystem, Fuel Oil.

4-6.2.1 The fuel supply equipment shall be sized and arranged to ensure a continuous fuel flow that is adequate for all operating requirements of the unit. These include coordination of the fuel control valve, burner safety shutoff valves, and associated piping volume to prevent fuel pressure transients that might result in exceeding burner limits for stable flame caused by placing burners in service or taking them out of service.

4-6.2.2 Unloading, storage, pumping, heating, and piping facilities shall be designed and arranged to inhibit contamination of the fuel. Where necessary, cleaning devices shall be provided to ensure a clean fuel to valves and burners. Convenient access to important fuel system components shall be provided. Adequate drains shall be provided.

4-6.2.3 Fill and recirculation lines to storage tanks shall discharge below the liquid level to avoid free fall, which might generate static electrical charges as well as increased vaporization.

4-6.2.4 Adequate strainers, filters, traps, sumps, and similar components shall be provided to remove harmful contaminants where practicable; materials not removed shall be accommodated by special operating and maintenance procedures. Contaminants in fuel include salt, sand, sludge, water, and other abrasive or corrosive constituents. Some fuels contain waxy materials that precipitate, clogging filters and other elements of the fuel system.

4-6.2.5 The fuel supply equipment shall be designed with careful consideration of the operating environment and ambient conditions, including severe external conditions such as fire or mechanical damage. Special attention shall be given to such factors as routes of piping and valve locations to minimize exposure to explosion hazard or to high temperature or low temperature sources. Low temperatures can increase viscosity, inhibit flow, or precipitate waxy materials. High temperatures can cause carbonization or excessive pressures and leakage due to fluid expansion in "trapped" sections of the system.

4-6.2.6 As much of the fuel supply subsystem as is practicable shall be located outside the boiler house. A manual emergency shutoff valve shall be provided that is accessible in the event of fire in the boiler area.

4-6.2.7 A means shall be provided to prevent or relieve excess pressure from expansion of entrapped oil in the fuel system. This is especially important in the case of crude oil.

4-6.2.8 Relief valve discharge passages, vents, and telltales shall be provided with suitable piping to allow the safe discharge of oil or vapors. This piping might need to be heat traced.

4-6.2.9 Shutoff valves shall be located as close as practicable to the igniters, burners, or lances to minimize the volume of fuel downstream of the valve.

4-6.2.10 Oil piping materials and system design shall be in accordance with NFPA 31, *Standard for the Installation of Oil-Burning Equipment*, and ANSI B31.1, *Power Piping*.

4-6.2.11 All instrument and control piping and other small lines containing oil shall be rugged, capable of withstanding the expected range of external temperatures, suitably protected against damage, and maintained at the proper temperature. The use of interface fluids or sealing diaphragms might be necessary with this instrumentation.

4-6.2.12 A positive means to prevent leakage of oil into a furnace or duct shall be provided.

4-6.2.13 Provisions shall be made in the oil supply system to allow testing for leakage and subsequent repair. Such provisions shall include a permanent and ready means for making easy, accurate, periodic tightness tests of all safety shutoff valves.

4-6.2.14 Fuel oil shall be delivered to the burners at the proper temperature and pressure as recommended by the burner manufacturer to ensure proper atomization.

4-6.2.15 Where heating of oil is necessary, it shall be accomplished without contamination or coking.

4-6.2.16 Adequate recirculation provisions shall be incorporated for controlling the viscosity of the oil to the burners for initial light-off and for subsequent operation. Recirculation systems shall be designed and operated to prevent excessively hot oil from entering fuel oil pumps that could cause them to vapor-bind, and subsequently interrupt the fuel oil supply.

4-6.2.17 A positive means shall be provided to prevent fuel oil from entering the burner header system through recirculating valves, particularly from the fuel supply system of another boiler.

NOTE: Check valves for this function have not proven dependable in heavy oil service.

4-6.2.18 Provisions, including an ignition source, shall be provided for clearing (scavenging) the passages of an atomizer that lead into the furnace or duct.

4-6.3 Warm-up Burner Subsystem.

4-6.3.1 General.

4-6.3.1.1 The warm-up burner subsystem shall function to supply sufficient heat energy to bring the bed to the fuel ignition temperature.

4-6.3.1.2 The warm-up burner shall meet the requirements of 4-2.1.

4-6.3.1.3 Provision shall be made for visual observation of conditions at the burner ignition zone. Additional provisions shall be made for flame detection equipment. The burner equipment shall be located in an appropriate environment with convenient access for maintenance. Special attention shall be given to fire hazards imposed by leakage or rupture of piping near the burner. The requirements of good housekeeping shall be practiced.

4-6.3.2 Subsystem Requirements.

4-6.3.2.1 Air Supply. A portion of the total air supply sufficient for light-off and flame stabilization shall be supplied to the warm-up burner(s).

4-6.3.2.2 Ignition.

(a) The ignition subsystem shall be sized and arranged to ignite the warm-up burner fuel input within the limits of the igniter classification. The subsystem shall be tested to verify that the igniters furnished meet the requirements of the class specified for the subsystem design. Igniters are designated according to use as Class 1, Class 2, or Class 3 as defined in Chapter 3 and verified by test. Many factors affect the classification of igniters, including the characteristics of the warm-up fuel, the furnace and burner design, and the igniter capacity and location relative to the warm-up fuel burner.

(b) Where Class 1 and Class 2 igniters are used, the tests described in 4-6.5 also shall be performed with the ignition subsystem in service to verify that the igniters furnished meet the requirements of the class specified in the design. The resulting extended turndown range shall be available where Class 1 igniters are in service and flame is proven.

(c) Tests shall be performed to determine transient limits in the igniter air and fuel supplies, or the warm-up burner air and fuel supplies, that do not extinguish the igniter flame or reduce the igniter's ability to perform its intended function or adversely affect other burners or igniters in operation. (*See also 4-6.5.*)

(d) Permanently installed igniters shall be required. They shall be individually supervised to verify that the requirements of 4-6.3.2.2(a), (b), and (c) have been met. This shall include supervision of the igniter flame and capacity.

(e) The ignition equipment shall be located in an appropriate environment with convenient access for maintenance.

4-6.3.2.3 Flame Monitoring and Tripping, Functional Requirements. The basic requirements of any flame monitoring and tripping system shall be as follows:

(a) The warm-up burners shall meet the requirements of 4-4.1.

(b) Each burner shall provide enough system resistance or dampening to the fuel and airflow to override anticipated furnace pulsations and maintain stable combustion.

(c) Each burner shall be individually supervised. Upon detection of loss of burner flame, the safety shutoff valve for the burner experiencing the loss shall automatically close.

(d) It is recognized that any fuel input that does not ignite and burn on a continuous basis creates a hazard. Regardless of the number or pattern of flame loss indications used for tripping, loss of flame indication on an operating burner or flame envelope shall initiate an alarm to warn the operator of potential hazard.

(e) Field testing shall be required to validate basic flame tripping concepts. These tests shall be performed on representative units. The results of these tests shall be permitted to be applied to other units of similar size and arrangement, including burners/nozzles of substantially the same capacity that use similar fuels. These tests shall not replace acceptance tests relating to proof of design, function, and components.

(f) Oil-fired warm-up burners, firing into the bed, shall be permitted to be scavenged immediately after shutdown or trip if the bed is fluidized and the bed temperature is greater than 1400°F (760°C) or if associated igniters are in service.

4-6.3.2.4 Flame Detection.

(a) *Flame Detector Sighting.* The use of flame detector sighting shall be considered in the initial burner design. Field tests shall be required to establish optimum sighting angles of burners or nozzles and also to check the effective angular range of flame detectors in relation to burners or nozzles. Methods and equipment used to reduce the emission of air pollutants can affect the burner flame, selection of the flame detector, and location/sighting of the flame detector.

(b) *Clean Air Supply.* Clean air, where necessary, shall be supplied in order to minimize problems with dirty detector lenses.

(c) *Self-Checking of Flame Detectors.* Where flame-sensing detectors can fail in the flame-proven mode, self-checking features shall be provided.

(d) *System Objectives.* System objectives shall be developed with due consideration given to those requirements that are specifically related to the combustion conditions that are typical for particular furnace configurations, burner systems, and fuel characteristics. Such objectives shall be consistent with the particular manufacturer's design philosophy.

4-6.3.2.5 Combustion Control System.

(a) The combustion control system shall be in accordance with Section 4-5.

(b) Equipment shall be provided and operating procedures established to ensure a stable flame condition at each burner and to preclude the possibility of an air/fuel ratio condition that could result in a fuel-rich condition within the furnace.

(c) Provision shall be made for setting minimum and maximum limits on the warm-up burner fuel and air control subsystems to prevent fuel flow and airflow beyond the stable flame limits of the burner(s). These minimum and maximum limits shall be specified by the burner manufacturer and verified by operating tests. (*See 7-3.2.*)

(d) The control system shall prevent the demand for a fuel-rich mixture while in the automatic control mode.

4-6.4 Lance Subsystem.

4-6.4.1 Functional Requirements.

4-6.4.1.1 The lance subsystem shall function to provide alternate or supplemental fuel input to the bed.

4-6.4.1.2 The lances shall meet the requirements of 4-2.1.

4-6.4.2 Subsystem Requirements.

4-6.4.2.1 Fuel Supply System.

(a) The liquid or gaseous fuel lance subsystem shall be designed so that the fuel is supplied in a continuous manner and within the confines of stable combustion limits. Minimum bed temperature interlocks shall be furnished to ensure the combustion of fuel in the bed at all times.

(b) Provision shall be made for protecting the lance nozzles and tips.

(c) The lance equipment shall be located in an appropriate environment with access for maintenance. Special attention shall be given to fire hazards posed by leakage or rupture of piping near the lance. Good housekeeping practices shall be enforced.

4-6.4.2.2 Multiple Lances Under Common Control.

(a) A group of lances shall be permitted to be supplied from a common header whose input is controlled by a single set of fuel safety shutoff and control valves.

(b) Flow to a group of lances that is controlled from a common source shall be treated as an individual lance.

4-6.5 Burner Testing. The turn-down limits of stable flame for each burner subsystem producing a separate flame envelope shall be determined by tests without the ignition system in service. These tests shall verify that transients generated in the fuel and air subsystems do not adversely affect the burners in operation. Such transients are generated by components such as burner shutoff valves or dampers that operate at speeds faster than the speed of response of other components in the system. These tests shall include the use of those fuels expected to be used.

4-7 Power Supplies. All reasonable precautions shall be taken to ensure the availability of a failure-free power supply (electric or pneumatic) to all devices.

4-8 Operating Information. As a minimum, continuous, simultaneous trend displays of boiler steam flow, feed-water flow, total fuel flow, and total airflow as a percentage of the maximum unit load shall be provided at the operating location. Continuous, simultaneous trend displays also shall be provided at the operating location for drum level, bed temperature(s), final steam temperature, main steam pressure, and furnace draft.

Chapter 5 Furnace Pressure Excursion Prevention

5-1 General. This chapter provides methods for minimizing the risks of furnace pressure excursions in excess of furnace structural capability. This shall be accomplished by one of the following methods:

(a) The boiler enclosure, the air supply system, and the flue gas removal system shall be designed so that the maximum head capability of the forced draft and induced draft fans within these systems, with ambient air, does not exceed the design pressure of the boiler enclosure, associated ducts, and equipment. This design pressure is defined the same as, and shall be in accordance with, the wind and seismic stresses of subsection 1-5.6 of Section 5 of AISC M016, *Manual of Steel Construction Allowable Stress Design.*

(b) A furnace pressure control system shall be provided in accordance with Section 5-2 and a furnace design as specified in 4-1.1.

NOTE: For the purpose of discussion within Chapter 5, the generic term "forced draft fan" is used to refer to a number of combustion air sources commonly found on fluidized-bed boilers. Due to the diverse nature of the air supply systems provided on fluidized-bed boilers, a careful study of the specific design is recommended in order to apply the provisions of this chapter properly to a specific unit. Some special considerations include:

(a) Multiple air sources at different locations (e.g., primary air fans, secondary air fans).

(b) The isolating effect of a slumped bed.

(c) High-pressure blowers.

5-2 Furnace Pressure Control Systems.

5-2.1 Functional Requirements. The furnace pressure control system shall control the furnace pressure at the desired set point in the combustion chamber.

5-2.2 System Requirements. See Figure 5-2.2.

5-2.2.1 The furnace pressure control subsystem (A), as shown in Figure 5-2.2, shall position the draft regulating equipment to maintain furnace pressure at the desired set point.

5-2.2.2 The control system, as shown in Figure 5-2.2, shall include:

(a) Three furnace pressure transmitters (B), each on a separate pressure-sensing tap and suitably monitored (C) to minimize the possibility of operating with a faulty furnace pressure measurement;

(b) A feed-forward signal (D) to indicate boiler airflow demand. This shall be permitted to be a fuel flow signal, a boiler-master signal, or other suitable index of demand but shall not be a measured airflow signal;

(c) Override action or directional blocking (E) for large furnace draft errors introduced after the auto/manual transfer station (P); and

(d) The prevention of uncontrolled changes in air or flue gas flow caused by axial fans, where used, achieved by operating the fans in such a manner as to avoid a stall condition.

NOTE: Purge air might be necessary to keep the sensing lines open.

5-2.3 Component Requirements.

5-2.3.1 Power Supplies. All reasonable precautions shall be taken to ensure the availability of a failure-free power source (electric or pneumatic) to all devices associated with the furnace pressure control protection systems.

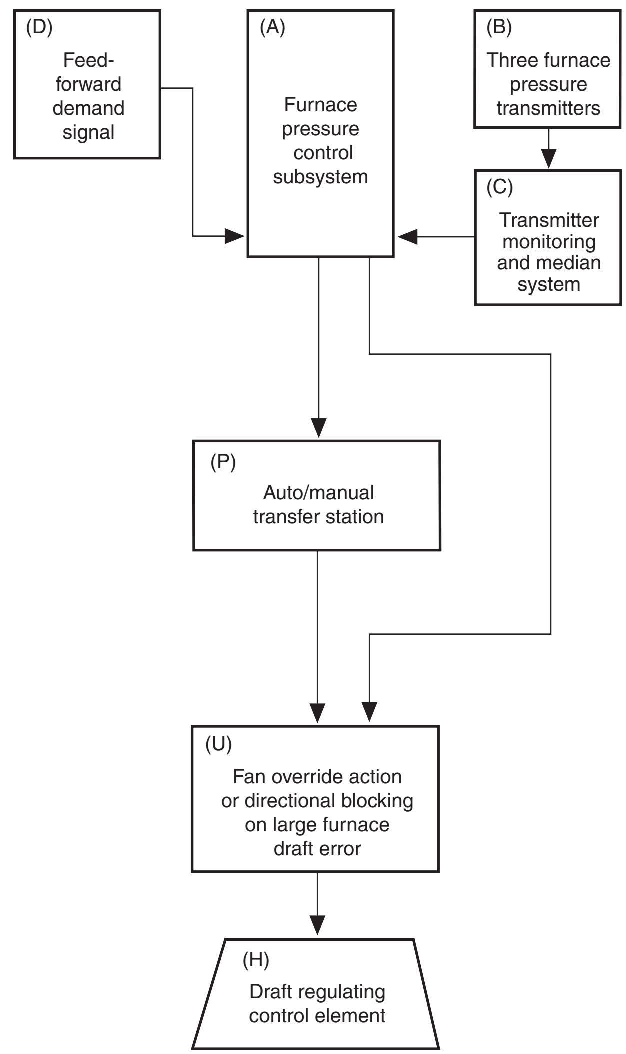


Figure 5-2.2 System requirements.

5-2.3.2 Furnace Pressure Control Final Control Elements. The furnace pressure control element(s) [i.e., draft fan inlet damper, drive blade pitch control, speed control (*see H in Figure 5-2.2*)] shall meet the following criteria:

(a) The operating speed shall not exceed the control system's sensing and positioning capabilities in order to avoid undesirable hunting and overshooting of automatic control. Excessive speed can create damaging negative pressure transients. Excessive speed also can be unsuitable for manual control.

(b) The operating speed of the draft control equipment shall not be less than that of the airflow control equipment.

(c) To ensure a satisfactory rate of response with variable speed and axial fans, special consideration shall be given to the design of the furnace draft control system.

5-3 Sequence of Operations.

5-3.1 Functional Requirements.

5-3.1.1 The purpose of sequencing requirements is to ensure that operating events occur in the proper order and is not to provide fan operating procedures. The proper fan start-up and shutdown procedures shall be specified by manufacturers, engineering consultants, and operating companies. These procedures shall be integrated with the operating procedures specified in this chapter and in Chapter 6.

5-3.1.2 An open flow path from the inlet of the forced draft fans through the stack shall be ensured under all operating conditions. Where the system design does not allow the use of fully open air paths, the minimum width of open area air paths shall not be less than that required for purge airflow with fans in operation. Those principles to be observed shall include the following:

(a) On installations with multiple induced draft or forced draft fans, all fan flow control devices and shutoff dampers shall be opened in preparation for starting the first induced draft fan. In addition, sufficient isolating dampers, windbox dampers, air registers, and other control dampers shall be opened to ensure an open flow path from the forced draft fan inlet through the furnace, the induced draft fans, and the stack. Unless an open flow path is provided by other means, the open path shall be ensured while starting the first induced draft and forced draft fan.

NOTE: On installations with multiple induced draft and forced draft fans, during any individual fan's starting sequence, its associated flow control devices and shutoff dampers may be permitted to be closed.

(b) On installations with a single induced or forced draft fan, the induced draft fan's associated control devices and shutoff dampers shall be permitted to be closed as required during the fan's start-up. Once the induced draft fan is operating and has stabilized, the forced draft fan's associated flow control devices and shutoff dampers shall be brought to the position that ensures acceptable starting current for that fan's start-up and then brought to the position for purge airflow during fan operation.

(c) Within the limitations of the fan manufacturer's recommendations, all flow control devices and shutoff dampers on idle fans shall remain open until the first induced draft and first forced draft fans are in operation while maintaining furnace pressure conditions and indication of an open flow path. After the first induced draft and forced draft fans are started and are delivering air through the furnace, the shutoff damper(s) of the remaining idle fan(s) shall be permitted to be closed.

(d) The practice of operating with excess induced draft fan capability in relation to either forced draft fan capability or boiler load shall be discouraged.

5-3.1.3 The sequence for starting and stopping fans under all conditions shall be as follows:

(a) An induced draft fan is started, and then a forced draft fan is started. Subsequent induced draft and forced draft fans shall be started in accordance with 5-3.1.4.

(b) Shutdown procedures shall be the reverse of those required in 5-3.1.3(a).

5-3.1.4 Where starting and stopping fans, the methods employed and the manipulation of the associated control elements shall minimize furnace pressure excursions. The furnace pressure control subsystem shall be placed on and maintained on automatic control as soon as practicable.

5-3.1.5 Following shutdown of the last fan due to any cause, the opening of fan dampers shall be delayed or controlled to avoid excessive positive or negative furnace pressure transients during fan coast-down.

5-4 Interlock System.

5-4.1 Functional Requirements. The functional requirements for interlock systems specified in Chapter 9 shall be followed.

5-4.2 System Requirements.

5-4.2.1 It is possible to achieve conditions conducive to a furnace pressure excursion that cannot be detected by any of the mandatory automatic-trip devices, even though such devices are properly adjusted and maintained; therefore, operating personnel shall be made aware of the limitations of the automatic protection system.

5-4.2.2 The following interlocks shall be provided:

(a) *High Furnace Pressure.*

1. A master fuel trip shall be initiated when the furnace pressure exceeds the normal operating pressure by a value specified by the manufacturer. If fans are operating after the trip, they shall be continued in service. The airflow shall not be increased by deliberate manual or automatic control action.

2. Before the main fuel firing and following a master fuel trip, forced draft fans shall be tripped if the furnace positive pressure exceeds the normal operating pressure by a value specified by the manufacturer. The value of the positive pressure at which this trip is activated shall be greater than that specified in 5-4.2.2(a)1.

(b) *High Furnace Draft (Balanced-Draft Units).*

1. A master fuel trip (not necessarily automatic) shall be initiated when the furnace negative pressure exceeds the normal operating pressure by a value specified by the manufacturer. If fans are operating after the trip, they shall be continued in service. The airflow shall not be increased by deliberate manual or automatic control action.

NOTE: For the trips specified in 5-4.2.2(a)1, (a)2, and (b)1, a short time delay might be necessary to prevent tripping on rapid transients that do not present a hazard.

2. Before the main fuel firing and following a master fuel trip, all induced draft fans shall be tripped if furnace negative pressure exceeds the normal operating pressure by a value specified by the manufacturer. The value of the negative pressure at which this trip is activated shall be greater than that specified in 5-4.2.2(b)1.

(c) *Loss of Forced Draft Fans.*

1. An interlock to prove each forced draft fan is running and capable of providing the required flow shall be provided. Loss of such proofs shall initiate appropriate loss of forced draft fan interlocks. Variable speed and axial flow fans might necessitate special provisions.

2. Damper(s) shall be closed on loss of an individual forced draft fan, unless it is the last forced draft fan in service.

3. Where an interlock system is provided to start, stop, and trip induced draft fans and forced draft fans in pairs, the associated induced draft fan shall be tripped on loss of an individual forced draft fan, and the dampers associated with both fans shall be closed, provided they are not the last fans in service. If they are the last fans in service, the forced draft fan dampers shall remain open, and the induced draft fan

shall remain in operation with the control damper positioned or the speed controlled to avoid excessive negative draft.

4. A master fuel trip shall be initiated on loss of all forced draft fans. All forced draft fan dampers shall be opened after a time delay to avoid high duct pressure during fan coast-down. Dampers shall remain open. Gas recirculation fan system dampers shall be closed.

(d) *Loss of Induced Draft Fans.*

1. An interlock to prove each induced draft fan is running and capable of providing the required flow shall be provided. Loss of such proofs shall initiate appropriate loss of induced draft fan interlocks. Variable speed and axial flow fans might necessitate special provisions.

2. Damper(s) shall be closed on loss of an individual induced draft fan, provided it is not the last induced draft fan in service.

3. Where an interlock system is provided to start, stop, and trip induced draft fans and forced draft fans in pairs, the associated forced draft fan shall be tripped on loss of an individual induced draft fan. The dampers associated with both fans shall be closed, provided they are not the last fans in service.

4. A master fuel trip shall be initiated on loss of all induced draft fans. All forced draft fans shall be tripped. All induced draft fan dampers shall be opened after a time delay to avoid high draft during fan coast-down. Dampers shall remain open and fans shall be started in accordance with 5-3.1.2 through 5-3.1.4. Gas recirculation fan system dampers shall be closed.

(e) *Multiple and Variable Speed Fans.* After the start of the first induced draft and forced draft fans, any subsequent fan(s), whether of the forced draft or induced draft type, shall be capable of delivering airflow before opening its damper(s).

5-5 Alarm System.

5-5.1 Functional Requirements. The functional requirements for alarm systems specified in Chapter 10 shall be followed.

5-5.2 System Requirements. In addition to the alarms required in 5-5.1, the following separately annunciated alarms shall be provided:

(a) Initiation of directional blocking or runback action;

(b) Redundant transmitter deviations within the furnace pressure control system;

(c) Axial flow fan (if used) nearing stall line;

(d) Fan override action.

Chapter 6 Sequence of Operations

6-1 General.

6-1.1 The purpose of sequencing requirements is to ensure that operating events occur in the proper order. This allows properly prepared fuel to be admitted to the fluidized-bed combustion zone only when sufficient bed mass and temperature exist, and when there is proper airflow to ignite the fuel as it enters the furnace and to burn it continuously and as completely as possible within the confines of the combustion area.

6-1.2 Sequence of operations is based on the typical safety interlock system shown in Figure 9-3.1 (b). These sequences shall be followed where the unit is operated manually or where certain functions are accomplished by interlocks or automatic controls. Different arrangements shall be permitted where equivalent protection is provided and the intent of the operating sequences specified in this chapter is met.

6-1.3 The starting and shutdown sequences for fluidized-bed boilers are designed to preserve the temperature of the bed material and refractory while providing proper operating conditions. As a result, the warm-up cycle for cold start-up and hot restart, as well as the shutdown sequence, is different from other coal, oil, or gas-fired boilers. For example, on a cold start-up, after the normal purge period, airflow through the bed (depending on the process design) shall be permitted to be reduced below the purge value to provide for the proper warm-up rate. However, under no circumstances shall the total airflow through the unit be less than the unit purge rate. Another difference occurs during a hot restart. If the bed material is above a predetermined minimum ignition temperature, fuel shall be permitted to be admitted to the boiler, or warm-up burners shall be permitted to be started to preserve bed temperature without the normal purge. A third difference is that tripping the fans or diverting airflow from previously active bed sections shall be permitted shortly after a master fuel trip without the normal post purge. Again, the objective is to maintain bed temperature and protect the refractory against sudden temperature change by reducing the cooling effect from high volumes of air. Provided that the average bed temperature remains above the ignition point, sufficient ignition energy remains in the bed material and refractory to ensure total burnout of combustible volatile matter after the master fuel trip.

NOTE: The bed temperature measurement is not valid unless the bed is fluidized.

6-1.4 Fluidized-bed boilers that have multiple beds (sometimes called zones, sections, or compartments) might necessitate a restrictive pattern of bed start-up and shutdown and prohibit random bed operation. In such cases, bed sequencing shall be specified by the manufacturer's operating instructions and verified by actual experience with the unit.

6-1.4.1 The first bed section shall have reached a predetermined ignition temperature before fuel is introduced.

6-1.4.2 Beds adjacent to an active bed shall have reached a predetermined ignition temperature before fuel is introduced.

6-1.5 Purge and light-off shall be performed under the following basic operating conditions, which significantly improve the margin of operating safety, particularly during start-up:

(a) The number of equipment manipulations necessary shall be minimized, thereby minimizing exposure to operating errors or equipment malfunction.

(b) The hazard of dead pockets in the gas passes and the accumulation of combustibles shall be minimized by continuously diluting the contents of the furnace with large quantities of air.

6-1.5.1 The basic start-up procedure shall incorporate the following requirements:

(a) All dampers and burner air registers shall be placed in a predetermined open position.

(b) A unit purge with the air registers and dampers in the position specified in 6-1.5.1(a) shall be completed. The bed shall be purged while in the fluidized or semifluidized condition.

(c) Components (e.g., precipitators, fired reheaters) containing sources of ignition energy shall be purged for not less than 5 minutes or five volume changes of that component prior to being placed into operation, whichever is greater. This purge can be done concurrently with the unit purge.

(d) The bed warm-up cycle shall start after the purge is complete. Airflow through the bed shall be permitted to be reduced below the purge requirements depending on the process constraints. Multizone fluidized beds might necessitate slumping those beds that are not being heated for start-up. Fluidized beds shall be permitted to be warmed up with the bed in a slumped or fluidized mode.

(e) Fluidized-bed boilers shall be warmed following the procedures and the warm-up rates specified by the manufacturer.

(f) Fuel input that necessitates ignition by the bed material shall not be fed into the bed until the average bed temperature has reached 1400°F (760°C).

Exception: A lower fuel input temperature limit shall be permitted, provided the temperature has been verified through test or actual experience as being capable of safely igniting the fuel (see Appendix B). However, in no case shall the temperature be lower than 900°F (480°C) for coal or 1100°F (590°C) for oil and natural gas.

6-1.5.2 Each boiler shall be tested during initial start-up to determine whether any modifications to the procedures specified in 6-1.5.1 are necessary in order to obtain satisfactory ignition or to satisfy other design limitations during light-off and warm-up. However, unnecessary modifications in the basic procedures shall be avoided, thereby satisfying the requirements of 6-1.5, particularly the requirement of 6-1.5(a).

6-2 Operational Requirements.

6-2.1 Cold Start.

6-2.1.1 Preparation for starting shall include a thorough inspection and shall verify the following:

(a) The furnace and gas passages are in good repair and free of foreign material.

(b) All personnel are evacuated from the unit and associated equipment; all access and inspection doors are closed; and all equipment and instrumentation are in proper operating condition.

(c) All airflow and flue gas flow control dampers have been operated through their full range to check the operating mechanism.

(d) All normally adjustable individual burner dampers or registers have been operated through their full range to check the operating mechanism.

(e) All safety shutoff valves are operational and closed and ignition sparks are de-energized.

(f) The feeder equipment is effectively isolated to prevent the leakage of fuel or sorbent into the furnace and to prevent hot air or flue gas from the fluidized bed from leaking back into the feed system.

(g) The proper drum water level is established; circulating flow is established in forced circulation boilers.

(h) The feeders and associated equipment are in good condition and properly adjusted for service.

(i) Energy is supplied to the control system and to the safety interlocks.

(j) The oxygen analyzer and carbon monoxide or combustibles analyzer, if provided, are operating satisfactorily; the carbon monoxide or combustibles indication is at zero and oxygen indication is at maximum.

(k) A complete functional check of the safety interlocks has been made, at minimum, after overhaul or other significant maintenance.

(l) A complete periodic operational test of each igniter has been made; frequency of testing is dependent on the design and operating history of each individual unit and ignition system; as a minimum, a test shall be performed during every start-up following overhaul or other significant maintenance; a test shall be integrated into the starting sequence and shall follow the purge of and precede the admission of any warm-up burner fuel.

(m) The furnace contains the proper bed inventory and the bed is charged if necessary.

NOTE: If no bed inventory material is available at start-up, consideration should be given to the use of an inert material such as sand to reduce the hazard of calcium oxide to maintenance personnel if it becomes necessary to reenter the unit shortly after start-up. [*See A-2-9.7(b).*]

6-2.1.2 Starting Sequence. The starting sequence shall be performed in the following order:

Exception: The starting sequence order shall be permitted to be varied where specified by the boiler manufacturer.

(a) The unit shall be prepared for operation. Adequate cooling water flow to critical components shall be ensured. Verification that the plant air, instrument air, and service steam systems are operational shall be made.

(b) Verification of the existence of an open flow path from the inlet(s) of the forced draft fans through the furnace space and into the stack shall be made.

(c) The flue gas cleanup system, ash transportation system, and gas recirculation fans shall be started as specified by the equipment manufacturers. Where provided, regenerative-type air heaters shall be started as specified by the manufacturer. The air heater soot blower shall be operated as specified by the air heater manufacturer.

(d) An induced draft fan shall be started, then a forced draft fan(s) shall be started in accordance with the manufacturer's instructions. Some systems might necessitate starting additional equipment prior to starting the fans. (The manufacturer's fan-start procedure shall be followed.) Additional induced draft or forced draft fans shall be started in accordance with Chapter 5.

(e) Dampers and air registers shall be opened to the purge position. For duct burners with an inlet damper or blower (if provided), the inlet damper shall be opened to the purge position and the blower shall be running to allow boiler airflow purge through the duct burner.

(f) The bed and boiler enclosure shall be purged with not less than five volumetric changes but, in any event, for a continuous period of not less than 5 minutes. A freeboard purge without air specifically passing through the bed material shall not be considered sufficient. The purge shall include the air and flue gas ducts, air heater(s), warm-up burners(s), windbox(es), and bed(s).

(g) Gas recirculation systems present special problems with respect to ensuring a complete unit purge. The boiler manufacturer's specifications on gas recirculation fan operation during purge and light-off shall be followed.

(h) Proper bed height shall be established at this time, if necessary, by adding sorbent or inert solids or by draining excess bed material. Forced draft and induced draft fans shall remain in operation; solid fuel feeders shall remain off, and all fuel valves shall be proved to be closed.

NOTE: At this point, the bubbling fluidized-bed and circulating fluidized-bed processes have different start-up procedures. [*See also 6-2.1.2(j).*]

(i) The bubbling fluidized-bed starting procedure is as follows:

1. The bubbling fluidized-bed process might necessitate two types of devices for warming the bed. One type is a duct burner that heats the combustion air, and the other type heats the bed or portions of the bed. The bed warm-up rate shall not exceed the manufacturer's specifications.

2. Combustion airflow through the bed can be reduced to the level necessary for warming up the bed sections. However, in no event shall total air through the unit be reduced below purge rate.

3. Dampers shall be permitted to be closed on bed sections that are not to be fired.

4. Burners shall be started in accordance with Chapters 7 and 8, as applicable.

NOTE: If the first burner fails to light within the established trial for ignition period after admission of fuel, the unit should be repurged before a second trial.

5. The bed shall continue to be heated at a rate specified by the manufacturer. Proper bed level shall be maintained by adding sorbent or inert solids as needed.

6. Fuel input that necessitates ignition by the bed material shall not be fed into the bed until the average bed temperature for the section being started has reached 1400°F (760°C). Warm-up burners shall remain in service until the stable ignition of this fuel has been established.

Exception: A lower fuel input temperature limit shall be permitted, provided the temperature has been verified through test or actual experience as being capable of safely igniting the fuel (see Appendix B). However, in no case shall the temperature be lower than 900°F (480°C) for coal or 1100°F (590°C) for oil and natural gas.

7. The duct temperature shall be maintained within the manufacturer's specified limits.

8. Verification that the fuel is igniting shall be made by watching for a steady increase in bed temperature and a decreasing oxygen level. Fuel flow shall be increased to maintain bed temperature as necessary. Airflow shall be increased as necessary to maintain the desired oxygen level. In the case of solid fuel, if the main fuel has been fed for more than 90 seconds or a period established by the manufacturer without an increase in bed temperature, solid fuel feeding shall be discontinued until the reason for ignition failure is determined.

9. The active bed area shall be expanded by activating idle bed sections according to steam load demands by following the manufacturer's recommended sequence.

(j) The circulating fluidized-bed starting procedure is as follows:

1. The circulating fluidized-bed process initiates its warm-up cycle with the purge complete permissive. In general, the light-off and warm-up specifications of the manufacturer shall be followed.

2. After placing the first bed warm-up burner in service, the bed material and refractory shall be heated at the manufacturer's specified rate.

3. Warm-up burners shall be added, if necessary, to maintain the required bed heat-up rate. Any fans and blowers that might have been shut down for the warm-up cycle shall be placed back in service when the bed temperature reaches the required temperature. Preparation to admit the main fuel shall be made.

4. Fuel input that necessitates ignition by the bed material shall not be fed into the bed until the average bed temperature has reached 1400°F (760°C). Warm-up burners shall remain in service until the stable ignition of this fuel has been established.

Exception: A lower fuel input temperature limit shall be permitted, provided the temperature has been verified through test or actual experience as being capable of safely igniting the fuel (see Appendix B). However, in no case shall the temperature be lower than 900°F (480°C) for coal or 1100°F (590°C) for oil and natural gas.

5. Verification that the fuel is igniting shall be made by watching for a steady increase in bed temperature and a decrease in oxygen. Warm-up burners shall be removed and fuel flow shall be increased to maintain bed temperature at the recommended level. Airflow shall be increased as necessary to maintain the desired oxygen level. In the case of solid fuel, if fuel has been fed for more than 90 seconds or a period established by the manufacturer without an increase in bed temperature, solid fuel feeding shall be discontinued until the reason for ignition failure is determined.

(k) The normal on-line metering combustion control (unless designed specifically for start-up procedures) shall not be placed in automatic service until:

1. A predetermined minimum main fuel input has been exceeded.

2. Stable bed temperature conditions have been established.

3. All manual control loops are operating without a significant error signal between their set point and process feedback.

4. Airflow control is on automatic.

6-2.2 Normal Operation.

6-2.2.1 The firing rate shall be regulated by increasing or decreasing the fuel and air supply simultaneously to all fuel ports or bed sections, maintaining normal air/fuel ratio continuously at all firing rates. This shall not eliminate the requirements for air lead and lag during changes in the fuel firing rate.

6-2.2.2 For those applications where gas or oil is fired, the firing rate shall be regulated by flow control or pressure control valves or by similar devices and shall not be regulated by modulating the shutoff valves. Shutoff valves shall be fully open or completely closed.

6-2.2.3 Fuel feed rates and transport airflow shall be maintained between the maximum and minimum limits specified by the boiler manufacturer or, preferably, as determined by trial. These trials shall test for minimum load under stable bed temperature, fluidization, and proper combustion conditions as follows:

(a) With all feeders in service and combustion controls on automatic; and

(b) With different combinations of feeders in service and combustion controls on automatic.

(c) Where changes occur to the manufacturer's maximum and minimum limits because of various feeder combinations and different fuel conditions, additional testing shall be required to establish the new limits.

6-2.2.4 If lower minimum loads are required than can be obtained with all feeders at minimum speed, the feeder(s) (and associated bed sections if applicable) shall be removed from service. The remaining feeder(s) shall be operated at a fuel rate above the minimum required for stable operation. The minimum fuel rate shall be determined by tests with various combinations of fuel distribution and excess air. These tests shall reflect the most restrictive conditions.

6-2.2.5* The stable operating philosophy of a fluidized bed shall be to maintain a bed temperature greater than 1400°F (760°C) and to initiate a main fuel trip below this temperature if the required warm-up burner(s) is not in service.

Exception: A lower trip temperature for fuels other than natural gas shall be permitted [but not lower than 1200°F (650°C) for coal and fuel oil], provided the temperature has been verified through test or actual experience to maintain stable combustion of the fuel.

6-2.2.6 Total airflow shall not be reduced below 25 percent of full-load airflow. Airflow shall not be reduced below that required to maintain stable fluidization conditions within active beds or bed compartments.

6-2.3 Normal Shutdown.

6-2.3.1 When taking the unit out of service, the boiler load shall be brought down to a minimum.

6-2.3.2 After the boiler load is reduced, there are two options for normal shutdown as follows:

(a) If the unit is scheduled to be out of operation for a significant period of time, the main fuel shall be tripped and the forced draft and induced draft fans shall be allowed to remain in operation. Following a 5-min post-purge, fans shall be allowed to operate until the unit is sufficiently cooled for maintenance.

(b) If the unit is scheduled to be restarted soon, the fans shall be permitted to be tripped after the minimum period needed to remove volatiles and burn the fuel remaining in the bed from the furnace after the main fuel has been tripped. This typically is indicated by a drop in bed temperature and an increase in oxygen reading. The fans shall not be tripped until there is positive indication of fuel burnout. Fan tripping effectively reduces start-up time by conserving the temperature of the bed and the refractory.

6-2.4 Normal Hot Restart.

6-2.4.1 When restarting a unit after it has been tripped or after the furnace has been bottled up, the purge cycle outlined in 6-1.5.1(a) through (f) shall not be required prior to introduction of main fuel, provided the bed temperature is above the main fuel temperature specified in 6-1.5.1(f).

NOTE: The bed temperature measurement is only valid where the bed is fluidized.

6-2.4.2 If the bed temperature has dropped below the main fuel temperature permissive during the shutdown, a unit purge shall be required as outlined in 6-1.5.1.

CAUTION: Under certain unusual operating, start-up, or shutdown conditions, it is possible to accumulate combustibles in the windbox and ductwork.

6-2.5* Emergency Shutdown — Master Fuel Trip.

6-2.5.1 With the initiation of a master fuel trip (MFT), all fuel shall be stopped from entering the boiler. Oil and gas safety shutoff valves shall be tripped and igniter sparks de-energized. The fuel, sorbent, and bed feed system and the bed drain system shall be tripped. Electrostatic precipitators, fired reheaters, or other ignition sources shall be tripped. Master fuel trips shall operate in a manner to stop all fuel flow into the furnace within a period that does not allow a dangerous accumulation of fuel in the furnace. The owner shall have the option of allowing a master fuel trip to initiate a time delay forced draft fan and induced draft fan trip [*see 6-2.3.2(b)*]. Where the design allows, char recirculation shall be stopped.

Table 6-2.5.1(a) Mandatory Automatic Master Fuel Trips
(*See Chapter 9 for more details.*)

A master fuel trip shall result from any of the following conditions:
(a) Loss of any induced draft or forced draft fan required to sustain safe combustion *(see Chapter 5);*
(b) Furnace pressure exceeds the normal operating pressure by a value recommended by the manufacturer *(see Chapter 5);*
(c) Insufficient drum level (a short time delay as established by the manufacturer shall be permitted);
(d) Loss of boiler circulation pumps or flow, if applicable;
(e) Total airflow drops below the purge rate by 5 percent of the full-load airflow;
(f) Bed temperature falls below the value specified in 6-2.2.5 when the main fuel is being admitted to bed and no warm-up burner is established;
(g) Sustained loss of energy supply to interlock systems.

Table 6-2.5.1(b) Mandatory Master Fuel Trips with Alarms — Not Necessarily Automatically Initiated

A master fuel trip shall result from any of the following conditions:
(a) Sustained loss of energy supply for combustion control;
(b) Cooling water flow for fluidized-bed system components less than minimum;
(c) Plant air or instrument air pressure low (process requirement only);
(d) Bed temperature high — trip to prevent unit damage resulting from excessive temperature;
(e) Furnace pressure falls below the normal operating pressure by a value recommended by the manufacturer.

6-2.5.2 The sorbent, bed material feed, and bed material drain system shall be permitted to be restarted as necessary.

6-2.5.3 The owner shall have the option under conditions where there is low-low drum water level and furnace outlet temperature is above 900°F (482°C) to stop the flow of fluidizing air immediately. This might necessitate tripping a forced draft fan. The induced draft fan, however, shall not be tripped.

6-2.5.4 If the option for tripping fans on a master fuel trip is not exercised, the fans that are operating after the master fuel trip shall be continued in service. The airflow shall not be increased immediately by deliberate manual or automatic control action.

6-2.6 Emergency Shutdown — Main Fuel Trip. With the initiation of a main fuel trip due to any of the emergency conditions listed in Table 6-2.6(a) or 6-2.6(b), all main fuel shall be stopped from entering the boiler.

Table 6-2.6(a) Mandatory Automatic Main Fuel Trips
(see Chapter 9 for more details.)

A main fuel trip shall result from any of the following conditions:
(a) Master fuel trip;
(b) Inadequate bed temperature *[see 6-2.1.2(i)4, 6-2.1.2(j)4, and 6-2.2.5]*;
(c) Inadequate airflow to fluidize the bed.

Table 6-2.6(b) Mandatory Main Fuel Trips — Not Necessarily Automatically Initiated

A main fuel trip shall result from inadequate solids inventory.

6-3 Emergency Conditions Not Requiring Shutdown or Trip.

6-3.1 Many unit installations include multiple induced draft fans or forced draft fans, or both. In the event of a loss of a fan or fans, the control system shall be capable of reducing the fuel flow to match the available airflow; otherwise, tripping of the unit is mandatory.

6-3.2 If an air deficiency develops while firing the main fuel, the fuel shall be reduced until the proper air/fuel ratio has been restored.

6-3.3 Momentary interruptions in the main fuel supply or changes in fuel quality shall not require a unit trip, provided the bed temperature remains above the limits for safe operation (*see 6-2.2.5*). Use of warm-up burners shall be permitted to maintain bed material temperature. Use of lances also shall be permitted, provided the bed temperature is above the minimum safe value for that fuel. Where fuel feed to a malfunctioning feeder subsystem can be restored before the bed temperature falls below the main fuel temperature trip limit, the subsystem shall be permitted to be returned to service.

6-4 General Operating Requirements — All Conditions.

6-4.1 Prior to allowing personnel to enter a unit, positive action shall be taken to prevent fuel from entering the furnace.

6-4.2 Burners shall not be lighted one from another or from the hot refractory. The igniter for the burner shall always be used.

6-4.3 When feeder or fuel transport line maintenance is being performed with the boiler in service, positive means to isolate the feeder or fuel transport line from the boiler shall be used.

Chapter 7 Sequence of Operations for Gas-Fired Warm-up Burners

7-1 General. This chapter contains additional mandatory requirements for burning fuel gas in warm-up burners.

7-2 Gas Firing — Special Problems. Common hazards are involved in the combustion of solid, liquid, and gaseous fuels. Each of these fuels has special hazards related to its physical characteristics. The following shall be considered in the design of the firing systems:

(a) Gas is colorless; therefore, a leak usually cannot be visually detected. Also, reliance cannot be placed on detection of a gas leak by means of its odor.

(b) Potentially hazardous conditions are most likely to occur within buildings, particularly where the gas piping is routed through confined areas. In the latter instance, adequate ventilation shall be provided. Outdoor boilers tend to minimize confined area problems.

(c) The nature of gas fuel creates the possibility of severe departures from proper air/fuel ratios that can progress to a hazardous condition without any visible evidence at the burners, furnace, or stack. Therefore, combustion control systems that respond to reduced boiler steam pressure or steam flow with an impulse for more fuel, unless protected or interlocked to prevent a fuel-rich mixture, shall be considered potentially hazardous. This also shall apply to manual firing without the above-mentioned interlocks or alarms. See Sections 7-3, 7-4, and 7-5 for requirements to avoid such hazards.

(d) Natural gas can be either "wet" or "dry." A wet gas usually implies the presence of distillate, which might be characteristic of a particular source. In the case of such a wet gas, the carryover of distillate into the burners can result in a momentary flameout and possible reignition. Reignition can result in a furnace explosion. Therefore, special precautions shall be taken with wet gas supply systems.

(e) Widely different characteristics of gas from either single or multiple sources can result in a significant change in Btu input rate to the burners without an equivalent change in airflow.

(f) Discharges from relief valves or from any other form of atmospheric vents can become hazardous unless special precautions are taken.

(g) Maintenance and repair of gas piping can be hazardous unless proper methods are used for purging and recharging the line before and after making the repairs.

7-3 Warm-up Burner Subsystem Requirements.

7-3.1 The warm-up burner subsystem shall be designed so that the burner inputs are supplied to the furnace continuously and within their stable flame limits. Variations in the burning characteristics of the fuel, and in the normal variations in fuel handling equipment and fuel-burning equipment, introduce an uncertainty to the lower operating limits of the warm-up fuel subsystem in any given furnace design. Under these circumstances, Class 1 or Class 2 igniters, as demonstrated by test, shall be permitted to be used to maintain stable flame. (*See 4-6.5 and 7-3.2.*)

7-3.2 The limits of stable flame for each burner subsystem producing a separate flame envelope shall be determined by tests without the ignition subsystem in service. These tests shall verify that transients generated in the fluidized bed and the fuel and air subsystems do not adversely affect the burners in operation. Such transients are generated by components such as burner shutoff valves or dampers that operate at speeds faster than the speed of response of other components in the system. These tests shall include the expected range of available fuels.

7-3.3 Provision shall be made for visual observation of conditions at the burner ignition zone. Additional provisions shall be made for flame detection equipment.

7-3.4 Where Class 1 and Class 2 igniters are used, the tests required in 4-6.3.2.2(b), 4-6.3.2.2(c), and 7-3.2 also shall be performed with the igniter subsystem in service to verify that the igniters furnished meet the requirements of the class specified in the design. The resulting extended turn-down range shall be available where Class 1 igniters are in service and flame is proven.

7-3.5 The burner equipment shall be located in an appropriate environment with convenient access for maintenance. Special attention shall be given to fire hazards imposed by leakage or rupture of piping near the burner. The requirements of good housekeeping shall be practiced.

7-3.6 All burner safety shutoff valves shall be located as close as practicable to the burner to minimize the volume of fuel left in the burner lines downstream of the valves.

7-4 Flame Monitoring and Tripping System.

7-4.1 Each burner shall be supervised individually. Upon detection of loss of burner flame, the safety shutoff valve for the burner experiencing the loss shall automatically close.

7-4.2 Upon detection of loss of all warm-up burner flame or partial loss of flame to the extent that hazardous conditions could develop, a trip of the warm-up burner system shall be automatically initiated.

7-5 Sequence of Operations.

7-5.1 General.

7-5.1.1* The sequence of operations is based on the typical fuel supply system shown in Figures A-7-5.1.1(a) through (i). Different arrangements shall be permitted where equivalent protection is provided and the intent of the operating sequences specified in this chapter is met.

7-5.1.2 Burners shall be placed in service in a sequence specified by operating instructions and verified by actual experience. Burners shall be placed in service as necessary, with fuel flows and individual register or damper settings that ensure proper light-off.

7-5.1.3 The fuel pressure at the burner header for all burners served by a single control valve shall be permitted to be used as a guide in maintaining the necessary fuel flow for each burner and shall be maintained automatically within prescribed limits as additional burners are placed in service. The total number of burners placed in service shall be the number necessary to accomplish the following within the rate of rise limits specified by the boiler manufacturer:

(a) Raise boiler pressure or temperature; and

(b) Raise bed temperature.

7-5.1.4 Each burner shall be tested during initial start-up to determine whether any modifications to the procedures specified in 7-5.2 are needed in order to obtain satisfactory ignition or to satisfy other design limitations during light-off and warm-up. For example, some boilers are purged with the registers in the normal operating position. In this case, it might be necessary to momentarily close the registers of the burner being lighted to establish ignition. However, unnecessary modifications in the basic procedures shall be avoided, thereby satisfying the requirements of Section 6-1, particularly the requirement of 6-1.5(a).

7-5.2 Functional Requirements.

7-5.2.1 Cold Start.

7-5.2.1.1 Preparation for starting shall include a thorough inspection and shall verify the following:

(a) All safety shutoff valves are closed; all sparks are deenergized.

(b) Chapter 8 shall be referenced for oil ignition systems requirements.

(c) Fuel system vents are open and venting to atmosphere outside the boiler room; lines are drained and cleared of condensate and similar materials.

(d) The proper drum water level is established in drum-type boilers, and circulating flow is established in forced circulation boilers or minimum water flow is established in once-through boilers.

(e) Burner elements and igniters are positioned in accordance with the manufacturer's specification.

(f) Energy is supplied to the control systems and to the safety interlocks.

(g) Meters or gauges are indicating fuel header pressure to the unit.

7-5.2.1.2 Starting Sequence. The starting sequence shall be performed in the following order:

(a) *An operational leak test of the fuel header piping system shall be performed in accordance with established procedures while maintaining purge rate airflow. Successful completion of the leak test shall be part of a completed unit purge.

(b) All fuel valve(s) shall be closed and the safety shutoff valve(s) shall be opened. The permissive conditions in the furnace purge system specified in 9-3.2 shall be satisfied before this can be accomplished.

(c) Verification that the burner fuel control valve(s) is set for light-off shall be made. Depending on the system design, this shall be accomplished by closing the burner control valve and opening a bypass valve to a light-off setting or setting the burner control valve to a light-off position. The burner headers shall be vented to fill with gas and to provide a flow (if necessary), so that the fuel control valve(s) regulates and maintains the correct fuel pressure or flow for burner light-off.

(d) The igniter header safety shutoff valve shall be opened, and verification that the igniter fuel control valve is holding the recommended fuel pressure for proper igniter capacity shall be made. The igniter headers shall be vented to fill with gas and to provide a flow (if necessary), so that the igniter fuel control valve(s) regulates and maintains the correct fuel pressure for igniter light-off.

(e) The air register or damper on the burner selected for light-off shall be adjusted to the position recommended by the manufacturer.

(f) The spark or other source of ignition for the igniter(s) on the burner(s) to be lit shall be initiated. The individual igniter safety shutoff valve(s) shall be opened, and all igniter system atmospheric vent valves shall be closed. If flame on the first igniter(s) is not established within 10 seconds, the individual igniter safety shutoff valve(s) shall be closed and the cause of failure to ignite shall be determined and corrected.

With airflow maintained at purge rate, repurge shall not be required, but at least 1 minute shall elapse before attempting a retrial of any igniter. Repeated retrials of igniters without investigating and correcting the cause of the malfunction shall be prohibited.

(g) Where Class 3 special electric igniters are used, the procedures described in 7-5-2.1.2(a) through (c), (e), and (h) through (k) shall be used, recognizing the requirements for individual burner flame supervision.

(h) After making certain that the igniter(s) is established and is providing appropriate ignition energy for the warm-up burner(s), the individual burner safety shutoff valve(s) shall be opened, and the individual burner atmospheric vent valves shall be closed. A master fuel trip shall be initiated when the bed temperature falls below the main fuel ignition temperature as specified in 6-1.5.1(f) and when satisfactory ignition has not been obtained within 5 seconds following the actual entry of fuel into the burner. Purging shall be repeated, and the condition that caused the failure to ignite shall be corrected before another light-off attempt is made. For the following burner and all subsequent burners placed in operation, failure to ignite or loss of ignition for any reason on any burner(s) shall cause the fuel flow to that burner(s) to stop. All conditions for proper light-off shall exist before restarting a burner.

(i) After stable flame is established, the air register(s) or damper(s) shall be returned to normal operation, making certain that ignition is not lost in the process.

(j) Class 3 igniters shall be shut off at the end of the time trial for proving the main flame. Verification that the stable flame continues on the main burners after the igniters are shut off shall be made. Systems that allow the igniters to remain in service on either an intermittent or continuous basis shall have been tested to meet all the requirements of Class 1 igniters or Class 2 igniters with the proper associated interlocks.

(k) After the burner flame is established, the burner header atmospheric vent valve shall be closed if open. The main fuel bypass control valve shall automatically control burner header gas pressure.

(l) The procedures of 7-5.2.1.2(e) through (j) for placing additional burners in service shall be followed, as necessary, to increase bed temperature, raise steam pressure, or carry additional load. Automatic control of burner fuel flow and burner airflow during the lighting and start-up sequence is recommended. The fuel flow to each burner (as measured by burner fuel header pressure, individual burner flows, or other equivalent means) shall be maintained at a controlled value that is compatible with the established airflow through the corresponding burner.

CAUTION: Total furnace airflow shall not be reduced below purge rate airflow and shall be at least that which is necessary for complete combustion in the furnace.

(m) The normal on-line burner combustion control shall not be placed in service until:

1. A predetermined minimum warm-up burner fuel input has been attained.

2. The burner fuel and airflow are adjusted as necessary.

3. Stable flame has been established.

NOTE: Paragraph 7-5.2.1.2(m) does not apply to burner fuel systems as shown in Figure A-7-5.1.1(e). Each individual flow control burner should have an individual combustion control system that maintains the correct air/fuel ratio, a stable flame, and a fire rate in accordance with the demand for the full operating range of the burner.

Exception: Where on-line burner combustion control is designed specifically for start-up procedures.

(n) It shall be permitted to place a multiple number of igniters in service simultaneously from a single igniter safety shutoff valve, provided that the igniters are supervised, so that failure of one of the group to light causes the fuel to all igniters of the group to be shut off.

(o) It shall be permitted to place in service, simultaneously, a multiple number of burners served by their corresponding multiple igniters from a single burner safety shutoff valve, provided that the burners are supervised, so that failure of one of the group to light causes the fuel to all burners of the group to be shut off.

7-5.2.2 Normal Operation.

7-5.2.2.1 The firing rate shall be regulated by increasing or decreasing the fuel and air supply to all operating burners, maintaining normal air/fuel ratio continuously at all firing rates. This shall not eliminate the requirements for air lead and lag during changes in the fuel firing rate.

Exception No. 1: This requirement shall not apply to systems provided with metering of air and fuel to each burner and designed specifically for individual burner modulating control.

Exception No. 2: In the case of a duct burner, the firing rate shall be regulated by increasing or decreasing the fuel flow. An interlock shall be provided to prevent airflow to the duct burner from falling below the minimum required for combustion as recommended by the manufacturer.

7-5.2.2.2 The firing rate shall not be regulated by varying the fuel to individual burners by means of the individual burner safety shutoff valve(s). The individual burner safety shutoff valve(s) shall be fully open or completely closed. Intermediate settings shall not be used.

7-5.2.2.3 Air registers shall be set at firing positions determined by tests.

Exception: This shall not apply to systems provided with metering of air and fuel to each burner and designed specifically for individual burner modulating control.

7-5.2.2.4 The burner fuel and airflow shall be maintained within a range between the maximum and minimum limits specified by the boiler manufacturer or, preferably, as determined by trial. These trials shall test for minimum load and for stable flame as follows:

(a) With all burners in service and combustion control on automatic; and

(b) With different combinations of burners in service and combustion control on automatic.

Where changes occur to the minimum and maximum limits because of various burner combinations and fuel conditions, retesting shall be required.

7-5.2.2.5 On loss of an individual burner flame, that individual burner's safety shutoff valve shall be automatically closed and its vent opened immediately. The burner register shall be closed where it interferes with the air/fuel ratio supplied to any other individual burner flame.

7-5.2.3 Normal Shutdown.

7-5.2.3.1 The reverse procedure of that used during start-up shall be followed during shutdown. Burners shall be shutdown sequentially, as load is reduced by closing the individual burner safety shutoff valves, leaving the registers on these burners in firing position.

7-5.2.3.2 Venting Procedure.

(a) The last burner or group of burners shall be taken out of service by tripping the main safety shutoff valves.

(b) The individual burner safety shutoff valves shall be closed.

(c) All atmospheric vent valves shall be opened to minimize the possibility of gas leaking into the boiler-furnace enclosure.

7-5.3 Mandatory Automatic Fuel Trip for Gas-Fired Warm-up Burners. A fuel trip shall result from any of the following conditions:

(a) Fuel pressure at the burner below the minimum established by the burner manufacturer or by trial;

(b) Loss of air supply fan or inadequate airflow to the burner;

(c) Loss of all flame;

(d) Last individual burner safety shutoff valve closed;

(e) High fuel gas pressure at the burner;

(f) Master fuel trip; or

(g) High burner discharge temperature (for duct burner only).

7-5.4 Emergency Conditions Not Requiring Shutdown or Trip. If an air deficiency develops while flame is maintained at the burners, the fuel shall be reduced until the proper air/fuel ratio has been restored. Where fuel flow cannot be reduced, airflow shall be increased slowly until the proper air/fuel ratio has been restored.

7-5.5 General Operating Requirements — All Conditions.

7-5.5.1 The igniter for the burner always shall be used. Burners shall not be lighted one from another, from hot refractory, or from bed material.

7-5.5.2 Where operating at low capacity with multiple burners controlled by one master flow control valve, the burner fuel pressure shall be maintained above minimum by reducing the number of burners in service as necessary.

7-5.5.3 Before maintenance is performed on the gas header, the header shall be purged.

7-6 Interlock System. See Chapter 9.

7-7 Alarm System.

7-7.1 Functional Requirements. See Chapter 10.

7-7.2* Required Alarms. In addition to the alarms in the interlock system specified in Chapter 9, the separately annunciated alarms in 7-7.2(a) through (g) shall be provided.

(a) *Fuel Gas Supply Pressure (High and Low).* The gas pressure supplied to the plant shall be monitored at a point as far upstream of the final constant fuel pressure regulator(s) as practicable. This warns the operator of unusual pressure conditions that might result in damage to equipment or indicates a complete loss of gas supply.

(b) *Fuel Gas Burner Header Pressure (High and Low).* Each burner header served by a single flow control valve shall monitor gas pressure as close to the burners as practicable in order to warn the operator, in advance of trip conditions, of abnormal fuel pressures. Furnace pressure fluctuations at the burner throat shall be considered in determining the location of and the setting for low burner header pressure trip functions.

(c) *Fuel Gas Meter Pressure (High and Low).* The pressure at the fuel gas meter shall be monitored at the upstream tap if the fuel gas flow meter is part of the combustion control system and is not pressure compensated. This shall warn the operator that a significant error exists in the flow signal to the control system.

(d) *Ignition Fuel Header Pressure (High and Low).* Each ignition fuel header served by a single control valve shall monitor gas pressure as close to the igniters as practicable in order to warn the operator of high or low pressure in advance of conditions that lead to a trip.

(e) *Burner Valves Not Closed.* The closed position of individual burner safety shutoff valves shall be monitored, and failure of any valve to close following a trip shall be alarmed.

(f) *Loss of Combustion Air to Burners.* For individually controlled burners, the combustion air to each burner shall be monitored and alarmed if the burner register is closed, the air supply fan is tripped, or the airflow is low.

(g) *Burner Discharge Temperature (High).* The discharge temperature from a burner, such as a duct burner, that is designed to maintain a desired discharge temperature shall be monitored and shall alarm when the temperature exceeds the maximum operating temperature to warn the operator in advance of the temperature that leads to a trip.

7-8 Boiler Front Control (Supervised Manual).

7-8.1 General.

7-8.1.1* System Requirements. This section provides minimum requirements for the design, installation, and operation of individually controlled warm-up burners operated from the burner location and specifies functional requirements for proper operation. No specific degree of automation beyond the minimum specified safeguards is defined or shall be required, as this is subject to many factors, such as the physical size of units, use of central control rooms, degree of reliability required, and availability of experienced operating personnel.

This section defines and specifies the requirements of the operating system that shall be used under the following conditions:

(a) A trained operator shall be in constant attendance.

(b) The start-up or normal shutdown of any burner shall be performed by an operator at the burner locations.

(c) The operator shall have direct visual access to view the burner flame.

(d) Suitable equipment shall be provided to control burner inputs and their relative rates of change to maintain an air/fuel mixture within the limits necessary for continuous combustion and stable flame throughout the controllable operating range of the burner. [*See Figures A-7-5.1.1(a) through (i) for minimum recommended equipment.*]

7-8.1.2 System Description. This operating system is defined as a "supervised manual system." A supervised manual system is one in which a trained operator has primary responsibility for the proper start-up, operation, and normal shutdown of a burner with interlocks to ensure that the operation follows proper established procedures. This system includes certain interlocks for preventing improper operator action, certain safety trips and flame supervisions, and an indication of the status of the start-up sequence. The operator(s) of this type of system shall be provided with and shall operate the system in accordance with a written set of operating instructions for each burner.

7-8.1.3 Fundamental Principles. The written instructions shall include, but shall not be limited to, the following:

(a) The unit shall be purged in accordance with 6-2.1.2(f).

(b) The burner, air damper, or register shall be adjusted to the light-off position. The total airflow through the unit shall not be reduced below purge rate.

(c) If flame on the igniter is not established within 10 seconds, the individual igniter safety shutoff valve shall be closed and the cause of failure to ignite shall be determined and corrected. With airflow maintained at purge rate, repurge shall not be required, but at least 1 minute shall elapse before attempting a retrial.

Exception: For direct electric (Class 3 Special) igniters, 7-8.1.3(c) shall not apply.

(d) The operator shall observe the igniter operation continuously while opening the individual burner supervisory shutoff valve. If the burner flame is not proven within 10 seconds after the individual burner shutoff valve leaves the closed position, a burner fuel trip shall occur. If no other fuel is being fired, a master fuel trip shall occur.

(e) After each stable burner flame is established, the igniter shall be shut off unless classified as Class 1 or Class 2. The stability of the burner flame shall be verified.

(f) The burner(s) shall be lighted only from its associated igniter(s).

(g) The operator shall observe flame stability while making any register or burner damper adjustments.

(h) After each successive burner light-off, the operator shall verify the flame stability of all operating burners.

(i) If the second or succeeding burner flame is not established, the operator shall close the individual burner supervisory shutoff valve immediately, open the burner register or damper to the firing position, and determine and correct the cause for failure to ignite. At least 1 minute shall elapse before attempting to light this burner or any other igniter.

7-8.1.4 Interlocks, Warm-up Burner Fuel Trip. A burner fuel trip shall result from any of the following conditions (*see also Section 9-3*):

(a) High fuel supply pressure;

(b) Fuel pressure at the burner below the minimum established by the burner manufacturer or by trial;

(c) Loss of all flame;

(d) Loss of control energy where fuel flow to burners is affected by such loss;

(e) Master fuel trip;

(f) Loss of or inadequate burner combustion air supply; or

(g) High burner discharge temperature (for duct burner only).

7-8.1.5 Loss of Individual Burner or Igniter Flame.

7-8.1.5.1 Loss of flame at an individual igniter shall cause the igniter individual safety shutoff valve to close and the associated sparks to de-energize.

7-8.1.5.2 Loss of flame at an individual burner shall cause the burner individual safety shutoff valve to close.

7-8.1.5.3 The conditions of 7-8.1.5.1 and 7-8.1.5.2 shall be indicated. (*See A-7-7.2 for recommended alarms in addition to those that are required.*)

7-8.2 Operating Cycle. The following operating sequences are based on a typical system. Certain provisions and sequences shall not apply where other systems are used, and the sequence order might vary, depending on the system installed. However, the principles outlined in these sequences shall be followed, and all applicable interlocks, trips, alarms, or their equivalents shall be provided.

7-8.2.1 Prefiring Cycle. The following steps shall be taken by the operator when starting a supervised manual burner, and the required interlocks shall be satisfied at each step.

	Operator Actions		Interlock Functions
(a)	Confirm individual burner safety shutoff valves closed.	(a)	Proved closed
(b)	Confirm individual burner supervisory shutoff valves closed.	(b)	Proved closed
(c)	Confirm burner header safety shutoff valve closed.	(c)	Proved closed
(d)	Confirm burner header fuel control valve in light-off position.	(d)	Proved
(e)	Open all burner registers to purge position.	(e)	None
(f)	Complete unit purge in accordance with 6-2.1.2(f).	(f)	Prove purge airflow rate *[see 7-8.1.3(a) and (b)]*.
(g)	Immediately proceed with light-off cycle after completion of purge.	(g)	None
(h)	Repurge required if airflow rate drops below purge rate.	(h)	Prove purge airflow rate.

7-8.2.2 Light-Off Cycle — First Burner. All required interlocks shall be satisfied. (*See 7-8.1.4 and 7-8.1.5.*)

	Operator Actions		Interlock Functions
(a)	Maintain purge airflow rate.	(a)	Prove that airflow has not dropped below purge rate.
(b)	Adjust register of burner to be lighted to light-off position, if necessary.	(b)	Prove purge airflow rate.
(c)	Confirm manual main atmospheric vent valve is open.	(c)	None
(d)	Energize igniter for first burner. For direct electric ignition, omit 7-8.2.2(e).	(d)	Prove flame within 10 seconds. If flame is not proved, safety shutoff valves for this igniter shall close and spark shall be de-energized.
(e)	If ignition flame is not established, determine cause and make necessary corrections. Burner register shall be opened to purge position for at least 1 minute before repeating light-off cycle.	(e)	None
(f)	Open burner shutoff valve if igniter flame is proven.	(f)	Igniter flame proven
(g)	If main burner flame is not established within main flame trial for ignition period (Class 2 and Class 3 igniters), a master fuel trip shall be initiated.	(g)	None

7-8.2.3 Light-Off Cycle — Subsequent Burners.

	Operator Actions		Interlock Functions
(a)	Adjust register of burner to be lighted to light-off position, if necessary.	(a)	Prove that airflow has not dropped below purge rate.
(b)	Energize igniter. For direct electric igniters, omit 7-8.2.3(c).	(b)	Prove flame within 10 seconds. If flame is not proven, safety shutoff valves for this igniter shall close and spark shall be de-energized.
(c)	If ignition flame is not established, determine cause and make necessary corrections. Burner register shall be opened to purge position for at least 1 minute before repea ting light-off cycle.	(c)	None
(d)	Open burner shutoff valves if igniter flame is proven.	(d)	Igniter flame proven
(e)	If main burner flame is not established within main flame trial for ignition period, trip the safety shutoff valves for that burner and its igniter. Determine and correct cause of failure. Wait at least 1 minute before attempting to relight this burner or any other burner.	(e)	None

7-8.2.4 Normal Shutdown Cycle.

	Operator Actions		Interlock Functions
(a)	Reduce burner load to minimum. Do not reduce airflow through burner below its minimum operating rate.	(a)	None
(b)	Close individual supervisory shutoff valve at burner and associated igniter valve if in operation. Leave burner airflow at firing rate.	(b)	As each burner supervisory shutoff valve is closed, loss of flame shall cause its associated shutoff valve to close. After last burner supervisory shutoff valve is closed, loss of all burner flame shall cause header or supply safety shutoff valve to close.
(c)	Purge burner for at least 1 minute. Adjust burner airflow per manufacturer's instructions.	(c)	None
(d)	Repeat 7-8.2.4(a) through (c) for subsequent burners.	(d)	None

7-8.2.5 Emergency Shutdown.

(a) An emergency shutdown shall initiate a burner fuel trip.

(b) For the conditions that shall initiate an emergency shutdown, see 7-8.1.4.

7-8.2.6 Operator Actions Following an Emergency Shutdown.

(a) All individual burner supervisory shutoff valves shall be closed. Burner register positions shall remain unchanged.

(b) The burners shall be purged in accordance with the following procedure:

1. Fans that are operating after the burner fuel trip shall be continued in service.

2. Airflow shall not be increased immediately by deliberate manual or automatic control action.

3. If the airflow is above purge rate, it shall be permitted to be decreased gradually to this value and a post-firing burner purge shall be performed.

4. If the airflow is below purge rate at the time of the trip, it shall be continued at the existing rate for 5 minutes and then increased gradually to purge rate and held at this value for a post-firing unit purge.

(c) Where the burner fuel trip is caused by loss of draft fans, or draft fans also have tripped, all dampers in the air and flue gas passages of the unit shall be slowly opened to the fully open position in order to create as much natural draft as possible to ventilate the unit. Opening fan dampers shall be timed or controlled to avoid excessive positive or negative furnace pressure transients during fan coast-down. This condition shall be maintained for not less than 15 minutes. At the end of this period, the flow control dampers shall be closed and the fan(s) shall be started immediately. Airflow shall be increased gradually to at least purge rate.

(d) The cause of emergency shutdown shall be determined and corrected.

(e) The first burner light-off cycle (*see 7-8.2.2*) shall be performed if restart of unit is required.

(f) If it is desired to remove the boiler from service for a period of time, fans shall be shut down on completion of unit purge and manual shutoff valves shall be closed.

Chapter 8 Sequence of Operations for Oil-Fired Warm-up Burners

8-1 General. This chapter contains additional mandatory requirements for burning fuel oil in warm-up burners.

8-2 Oil Firing — Special Problems. Common hazards are involved in the combustion of solid, liquid, and gaseous fuels. Each of these fuels has special hazards related to its physical characteristics. The following items shall be considered in the design of the firing systems:

(a) Fuel oils have high volumetric heats of combustion; therefore, even small leaks can create potential fire hazards.

(b) Where firing oils that need preheating, the viscosity of oil flowing to the burners shall be held within limits to maintain proper atomization.

(c) Water or sludge in fuel oil storage tanks or improperly located suction takeoffs from the storage tank can result in hazardous interruptions or pulsations of the fuel supply to the burners. A flameout can result because of plugged strainers or burner tips.

(d) Widely different characteristics of fuel oil from either a single source or multiple sources can result in a significant change in Btu input rate to the burner(s) without an equivalent change in airflow or without an appropriate change in fuel oil temperature to restore the flowing viscosity to the proper value. Different shipments of fuel oil with dissimilar characteristics can cause a precipitation of sludge that can lead to hazards as described in 8-2(c).

(e) On installations designed to fire both heated and unheated fuel oils, consideration shall be given to the design of the burner control system to ensure proper interlocks are activated for the selected fuel oil. Similar consideration shall be given to the fuel oil piping supply to the burner as well as the oil recirculating piping to the fuel storage tanks, depending on the arrangement of the equipment provided.

(f) There is an ever-present hazard when inserting an oil gun in a burner assembly without a tip, new gaskets, or sprayer plate. This results in an unsafe operating condition.

(g) Proper pumping and atomization of fuel oils are dependent upon control of viscosity. Changes in viscosity in relation to temperature vary for different oils and blends of oils. Close attention shall be given to the design and operation of viscosity control systems for each fuel where its source or properties are variable.

(h) Clear distillate fuels have low conductivities and generate static electrical charges in the fuel stream that can be dangerous unless flowing velocities are limited. (*See NFPA 77, Recommended Practice on Static Electricity, and API RP 2003, Recommended Practice for Protection Against Ignitions Arising Out of Static, Lightning, and Stray Currents.*)

(i) The incompressibility of fuel oil can create very rapid transients in oil flow through operating burners under the following conditions:

1. The rapid operation of the oil supply valve;

2. The rapid operation of individual burner shutoff valves;

3. The rapid operation of the regulating valve in the return oil line from the burner header (on systems using this type of control).

(j) The operation of air heater sootblowers shall be in accordance with the recommendations of the air heater manufacturer. Initial firing of oil fuel in a cold boiler can create a special hazard by causing fires in air heaters.

8-3 Warm-up Burner Subsystem Requirements.

8-3.1 The warm-up burner subsystem shall be designed so that the burner inputs are supplied to the furnace continuously and within their stable flame limits. Variations in burning characteristics of the fuel, and in the normal variations in fuel handling equipment and fuel-burning equipment, introduce an uncertainty to the lower operating limits of the warm-up burner fuel subsystem in any given furnace design. Under these circumstances, Class 1 or Class 2 igniters, as demonstrated by test, shall be permitted to be used to maintain stable flame. (*See 4-6.5 and 8-3.2.*)

8-3.2 The limits of stable flame for each burner subsystem producing a separate flame envelope shall be determined by tests without the ignition subsystem in service. These tests shall verify that transients generated in the fluidized bed and the fuel and air subsystems do not affect the burners adversely during operation. Such transients are generated by means such as burner shutoff valves or dampers that operate at speeds faster than the speed of response of other components in the system. These tests shall include the expected range of available fuels.

8-3.3 Where Class 1 and Class 2 igniters are used, the tests described in 4-6.3.2.2(b), 4-6.3.2.2(c), and 8-3.2 also shall be performed with the ignition subsystem in service to verify that the igniters furnished meet the requirements of the class specified in the design. The resulting extended turndown range shall be available where Class 1 igniters are in service and flame is proven.

8-3.4 Provisions shall be made for visual observation of conditions at the burner ignition zone. Additional provisions shall be made for flame detection equipment.

8-3.5 Provisions shall be made for cleaning of the burner nozzle and tip.

8-3.6 The burner equipment shall be located in an appropriate environment with convenient access for maintenance. Special attention shall be given to the fire hazards imposed by leakage or rupture of piping near the burner. Particular attention shall be given to the integrity of flexible hoses or swivel joints. The requirements of good housekeeping shall be practiced.

8-3.7 All burner safety shutoff valves shall be located as close to the burner as practicable to minimize the volume of oil left downstream of the burner valves in the burner lines or that flows by gravity into the furnace on an emergency trip or burner shutdown.

8-3.8 Atomizing Subsystem.

8-3.8.1 Where the fuel is to be atomized with the assistance of another medium, the atomizing medium shall be free of contaminants that could cause an interruption of service. For steam atomizing, adequate insulation and traps shall be included to ensure dry atomizing steam to the burners.

8-3.8.2 The atomizing medium shall be provided and maintained at the pressure necessary for proper operation.

8-3.8.3 Provisions shall be made to ensure that fuel cannot enter the atomizing medium line during or after operation. Check valves for this function have not proven dependable in heavy oil service.

8-3.8.4 The atomizing subsystem shall be designed for convenient cleaning and maintenance.

8-4 Flame Monitoring and Tripping System.

8-4.1 Each burner shall be supervised individually. Upon detection of loss of burner flame, the safety shutoff valve for the burner experiencing the loss shall automatically close.

8-4.2 Upon detection of loss of all warm-up burner flame or partial loss of flame to the extent that hazardous conditions could develop, a trip of the warm-up burner system shall be automatically initiated.

8-5 Sequence of Operations.

8-5.1 General.

8-5.1.1* The sequence of operations is based on the typical fuel supply system shown in Figures A-8-5.1.1(a) through (p). Different arrangements shall be permitted where equivalent protection is provided and the intent of the operating sequences specified in this chapter is met.

8-5.1.2 Burners shall be placed in service in a sequence specified by operating instructions and verified by actual experience. Burners shall be placed in service as necessary, with fuel flows and individual register or damper settings that ensure proper light-off.

8-5.1.3 The fuel pressure at the burner header for all burners served by a single control valve shall be permitted to be used as a guide in maintaining the necessary fuel flow for each burner and shall be maintained automatically within prescribed limits as additional burners are placed in service. The total number of burners placed in service shall be the number necessary to accomplish the following within the rate of rise limits specified by the boiler manufacturer:

(a) Raise boiler pressure and temperature; and

(b) Raise bed temperature.

8-5.1.4 Each burner shall be tested during initial start-up to determine whether any modifications to the procedures specified in 8-5.2 are needed in order to obtain satisfactory ignition or to satisfy other design limitations during light-off and warm-up. For example, some boilers are purged with the registers in the normal operating position. In this case, it might be necessary to momentarily close the registers of the burner being lighted to establish ignition. However, unnecessary modifications in the basic procedures shall be avoided, thereby satisfying the requirements of Section 6-1, particularly the requirement of 6-1.5(a).

8-5.2 Functional Requirements.

8-5.2.1 Cold Start.

8-5.2.1.1 Preparation for starting shall include a thorough inspection and shall verify the following:

(a) Energy is supplied to the control system and to the safety interlocks.

(b) All safety shutoff valves are closed; all sparks are de-energized.

(c) Chapter 7 shall be referenced for gas ignition system requirements.

(d) Circulating valves are open to provide and maintain hot oil in the burner headers.

(e) The proper drum water level is established in drum-type boilers, and circulating flow is established in forced circulation boilers or minimum water flow is established in once-through boilers.

(f) Burner guns have been checked for proper tips and sprayer plates.

(g) Burner elements and igniters are positioned in accordance with the manufacturer's specification.

(h) Meters or gauges are indicating fuel header pressure to the unit.

8-5.2.1.2 Starting Sequence. The starting sequence shall be performed in the following order:

(a) Verification that oil temperature or viscosity is adequate for good atomization shall be made. The circulating valve and throttle recirculating valve shall be closed, if necessary, to allow establishment of proper burner header pressure in accordance with 8-5.2.1.2(c).

(b) All fuel valve(s) shall be closed and the safety shutoff valve(s) shall be opened. The permissive conditions in the furnace purge system specified in 9-3.2 shall be satisfied before this can be accomplished.

(c) Verification that the burner fuel control valve(s) is set for light-off shall be made. Depending on the system design, this shall be accomplished by closing the burner control valve and opening a bypass valve to a light-off setting or setting the burner control valve to a light-off position.

(d) The igniter header safety shutoff valve(s) shall be opened, and verification that the igniter fuel control valve is holding the recommended fuel pressure for proper igniter capacity shall be made.

(e) The air register or damper on the burner selected for light-off shall be adjusted to the position recommended by the manufacturer.

(f) The spark or other source of ignition for the igniter(s) on the burner(s) to be lit shall be initiated. The individual igniter safety shutoff valve(s), and all igniter system atmospheric vent valves (gas igniters only) shall be closed. If flame on the first igniter(s) is not established within 10 seconds, the individual igniter safety shutoff valve(s) shall be closed and the cause of failure to ignite shall be determined and corrected. With airflow maintained at purge rate, repurge shall not be required, but at least 1 minute shall elapse before attempting a retrial of any igniter. Repeated retrials of igniters without investigating and correcting the cause of the malfunction shall be prohibited.

(g) Where Class 3 special electric igniters are used, the procedures described in 8-5.2.1.2(a) through (c), (e), and (h) through (k) shall be used, recognizing the requirements for individual burner flame supervision.

(h) After making certain that the igniter(s) is established and is providing appropriate ignition energy for the warm-up burner(s), the individual burner safety shutoff valve(s) shall be opened. A master fuel trip shall be initiated when the bed temperature falls below the main fuel ignition temperature as specified in 6-1.5.1(f) and when satisfactory ignition has not been obtained within 5 seconds following the actual entry of fuel into the burner. Purging shall be repeated, and the condition that caused the failure to ignite shall be corrected before another light-off attempt is made. For the following burner and all subsequent burners placed in operation, failure to ignite or loss of ignition for any reason on any burner(s) shall cause the fuel flow to that burner(s) to stop. All conditions for proper light-off shall exist before restarting a burner.

(i) After stable flame is established, the air register(s) or damper(s) shall be returned to normal operation, making certain that ignition is not lost in the process.

(j) Class 3 igniters shall be shut off at the end of the time trial for proving the main flame. Verification that the stable flame continues on the main burners after the igniters are shut off shall be made. Systems that allow the igniters to remain in service on either an intermittent or continuous basis shall have been tested to meet all the requirements of Class 1 igniters or Class 2 igniters with the proper associated interlocks.

(k) The procedures of 8-5.2.1.2(e) through (j) for placing additional burners in service, as necessary, to increase bed temperature, steam pressure, or carry additional load. Automatic control of burner fuel flow and burner airflow during the lighting and start-up sequence is recommended. The fuel flow to each burner (as measured by burner fuel header pressure, individual burner flows, or other equivalent means) shall be maintained at a controlled value that is compatible with the established airflow through the corresponding burner.

CAUTION: Total furnace airflow shall not be reduced below purge rate airflow and shall be at least that which is necessary for complete combustion in the furnace.

(l) After a suitable number of burners have been placed in service to allow control of the header fuel flow and temperature, the recirculating valve shall be closed, unless the system is designed for continuous recirculation.

(m) The normal on-line burner combustion control (unless designed specifically for start-up procedures) shall not be placed in service until:

1. A predetermined minimum warm-up burner fuel input has been attained.
2. The burner fuel and airflow are adjusted as necessary.
3. Stable flame has been established.

NOTE: Paragraph 8-5.2.1.2(m) does not apply to the burner fuel systems as shown in Figures A-8-5.1.1(f) through (i). Each control system should maintain the correct air/fuel ratio, a stable flame, and a firing rate in accordance with the demand for the full operating range of the burner.

(n) It shall be permitted to place a multiple number of igniters in service simultaneously from a single igniter safety shutoff valve, provided the igniters are supervised so that failure of one of the group to light causes the fuel to all igniters of the group to be shut off.

(o) It shall be permitted to place in service, simultaneously, a multiple number of burners served by their corresponding multiple igniters from a single burner safety shutoff valve, provided the burners are supervised so that failure of one of the group to light causes the fuel to all burners of the group to be shut off.

8-5.2.2 Normal Operation.

8-5.2.2.1 The firing rate shall be regulated by increasing or decreasing the fuel and air supply simultaneously to all operating burners, maintaining normal air/fuel ratio continuously at all firing rates. This shall not eliminate the requirements for air lead and lag during changes in the fuel firing rate.

Exception No. 1: This requirement shall not apply to systems provided with metering of air and fuel to each burner and designed specifically for individual burner modulating control.

Exception No. 2: In the case of a duct burner, the firing rate shall be regulated by increasing or decreasing the fuel flow. An interlock shall be provided to prevent airflow to the duct burner from falling below the minimum required for combustion as recommended by the manufacturer.

8-5.2.2.2 The firing rate shall not be regulated by varying the fuel to individual burners by means of the individual burner safety shutoff valve(s). The individual burner safety shutoff valve(s) shall be fully open or completely closed. Intermediate settings shall not be used.

8-5.2.2.3 Air registers shall be set at firing positions determined by tests.

Exception: This shall not apply to systems provided with metering of air and fuel to each burner and designed specifically for individual burner modulating control.

8-5.2.2.4 The burner fuel and airflow shall be maintained within a range between the maximum and minimum limits specified by the boiler manufacturer or, preferably, as determined by trial. These trials shall test for minimum load and for stable flame as follows:

(a) With all burners in service and combustion control on automatic; and

(b) With different combinations of burners in service and combustion control on automatic.

Where changes occur to the minimum and maximum limits because of various burner combinations and fuel conditions, retesting shall be required.

8-5.2.2.5 On loss of an individual burner flame, that individual burner's safety shutoff valve shall be automatically closed. The burner register shall be closed where it interferes with the air/fuel ratio supplied to any other individual burner flame.

8-5.2.3 Normal Shutdown.

8-5.2.3.1 The reverse procedure of that used during start-up shall be followed during shutdown. Burners shall be shut down sequentially as load is reduced.

An oil burner shall be shut down in the following sequence:

(a) The igniter shall be placed into service on the particular burner to be shut down.

(b) With the igniter in service, the burner safety shutoff valve shall be closed, and the steam (or air) clearing valves shall be opened.

(c) The clearing steam (or air) shall be left in service for a sufficient length of time to remove all oil that could carbonize and plug the burner tip.

(d) The igniter shall be removed from service, and the oil gun shall be removed or retracted.

Exception: Where cooling is provided.

8-5.2.3.2 Where fuel recirculation in the burner header is to be established:

(a) Confirmation that individual burner safety shutoff valves are closed and that flame is out on each burner shall be made.

(b) Confirmation that the main safety shutoff valve is closed shall be made.

(c) The circulating valve and recirculating valve shall be opened.

8-5.3 Mandatory Automatic Fuel Trip for Oil-Fired Warm-up Burners. A fuel trip shall result from any of the following conditions:

(a) Fuel pressure and temperature (heated oil only) outside operating limits necessary to accomplish proper atomization as established by trial or by the burner manufacturer;

(b) Atomizing medium (if provided) outside operating limits established by trial or by the burner manufacturer;

(c) Loss of air supply fan or inadequate airflow to the burner;

(d) Loss of all flame;

(e) Last individual burner safety shutoff valve closed;

(f) Master fuel trip;

(g) High burner discharge temperature (for duct burner only).

8-5.4 Emergency Conditions Not Requiring Shutdown or Trip.

8-5.4.1 If an air deficiency develops while flame is maintained at the burners, the fuel shall be reduced until the proper air/fuel ratio has been restored. Where fuel flow cannot be reduced, the airflow shall be increased slowly until the proper air/fuel ratio has been restored.

8-5.4.2 Burners with poor atomization shall be shut down.

8-5.5 General Operating Requirements — All Conditions.

8-5.5.1 The igniter for the burner always shall be used. Burners shall not be lighted one from another, from hot refractory, or from bed material.

8-5.5.2 Where operating at low capacity with multiple burners controlled by one master flow control valve, the burner fuel pressure shall be maintained above minimum by reducing the number of burners in service as necessary.

8-5.5.3 Igniters shall be in service with ignition established where clearing oil passages into the furnace.

8-5.5.4 A leak test shall be performed before the oil header is placed in service by establishing a nominal pressure on the oil header while the main and individual burner safety shutoff valves and the recirculating valves are closed. It shall be permitted to be concluded that the individual burner safety valves do not leak, provided this oil pressure remains within specified limits. Leaks can develop in the oil valves due to temperature changes.

8-6 Interlock System. See Chapter 9 .

8-7 Alarm System.

8-7.1 Functional Requirements. See Chapter 10.

8-7.2* Required Alarms. In addition to the trip alarms in the interlock system specified in Chapter 9, the separately annunciated alarms in 8-7.2(a) through (i) shall be provided.

(a) *Main Oil Supply Pressure (Low).* The oil supply pressure shall be monitored at a point as far upstream as practicable. This warns the operator of unusual pressure conditions that might result in damage to equipment or indicates a complete loss of oil supply.

(b) *Fuel Oil Burner Header Pressure (Low).* Each burner header served by a single flow control valve shall monitor oil pressure as close to the burners as practicable in order to warn the operator of low pressure in advance of conditions that lead to a trip.

(c) *Main Oil Viscosity (High).* Each burner header served by a single flow control valve shall monitor oil temperature to warn that the fuel oil temperature is dropping and that poor atomization of the oil might occur. If the viscosity of the fuel supply is variable, a viscosity meter shall be permitted to provide the alarm. Interlocking to trip on high viscosity also shall be considered in such cases.

(d) *Atomizing Steam or Air Pressure (Low).* For steam burners and air-assisted burners, an alarm shall be provided on each burner atomizing media header served by a single control valve to warn that the steam or air pressure and oil pressure are outside of operating range and that poor oil atomization might result.

(e) *Igniter Atomizing Steam or Air Pressure (Low).* For steam igniters and air-assisted igniters, an alarm shall be provided to warn that steam or air pressure is outside of operating range and that poor oil atomization might result.

(f) *Ignition Fuel Header Pressure (High and Low).* Each igniter fuel header served by a single control valve shall monitor pressure as close to the igniters as practicable in order to warn the operator of high or low pressure in advance of conditions that lead to a trip.

(g) *Burner Valves Not Closed.* The closed position of individual burner safety shutoff valves shall be monitored, and failure of any valve to close following a trip shall be alarmed.

(h) *Loss of Combustion Air to Burners.* For individually controlled burners, the combustion air to each burner shall be monitored and alarmed if the burner register is closed, the air supply fan is tripped, or the airflow is low.

(i) *Burner Discharge Temperature (High).* The discharge temperature from a burner, such as a duct burner, that is designed to maintain a desired discharge temperature shall be monitored and alarmed when the temperature exceeds the maximum operating temperature to warn the operator in advance of the temperature that leads to a trip.

8-8 Boiler Front Control (Supervised Manual).

8-8.1 General.

8-8.1.1 System Requirements. This section provides minimum requirements for the design, installation, and operation of individually controlled warm-up burners operated from the burner location and specifies functional requirements for proper operation. No specific degree of automation beyond the minimum specified safeguards is defined or shall be required, as this is subject to many factors, such as the physical size of units, use of central control rooms, degree of reliability required, and availability of experienced operating personnel.

This section defines and specifies the requirements of the operating system that shall be used under the following conditions:

(a) A trained operator shall be in constant attendance.

(b) The start-up or normal shutdown of any burner shall be performed by an operator at the burner locations per 7-8.1.1.

(c) The operator shall have direct visual access to view the burner flame.

(d) Suitable equipment shall be provided to control burner inputs and their relative rates of change to maintain an air/fuel mixture within the limits necessary for continuous combustion and stable flame throughout the controllable operating range of the unit. *[See Figures A-8-5.1.1(a) through (p) for minimum recommended equipment.]*

8-8.1.2 System Description. This operating system is defined as a "supervised manual system." A supervised manual system is one in which a trained operator has primary responsibility for the proper start-up, operation, and normal shutdown of a boiler with interlocks to ensure that the operation follows proper established procedures. This system includes certain interlocks for preventing improper operator action, certain safety trips and flame supervisions, and an indication of the status of the start-up sequence. The operator(s) of this type of system shall be provided with and shall operate the system in accordance with a written set of operating instructions for each burner.

8-8.1.3 Fundamental Principles. The written instructions shall include, but shall not be limited to, the following:

(a) The unit shall be purged in accordance with 6-2.1.2(f).

(b) The burner, air damper, or register shall be adjusted to the light-off position. The total airflow through the unit shall not be reduced below purge rate.

(c) If flame on the igniter is not established within 10 seconds, the individual igniter safety shutoff valve shall be closed and the cause of failure to ignite shall be determined and corrected. With airflow maintained at purge rate, repurge shall not be required, but at least 1 minute shall elapse before attempting a retrial.

Exception: For direct electric (Class 3 Special) igniters, 8-8.1.3(c) shall not apply.

(d) The operator shall observe the igniter operation continuously while opening the individual burner supervisory shutoff valve. If the burner flame is not proven within 10 seconds after the individual burner shutoff valve leaves the closed position, a burner fuel trip shall occur. If no other fuel is being fired, a master fuel trip shall occur.

(e) After each stable burner flame is established, the igniter shall be shut off unless classified as Class 1 or Class 2. The stability of the burner flame shall be verified.

(f) The burner(s) shall be lighted only from its associated igniter(s).

(g) The operator shall observe flame stability while making any register or burner damper adjustments.

(h) After each successive burner light-off, the operator shall verify the flame stability of all operating burners.

(i) If the second or succeeding burner flame is not established, the operator shall close the individual burner supervisory shutoff valve immediately, open the burner register or damper to the firing position, and determine and correct the cause for failure to ignite. At least 1 minute shall elapse before attempting to light this burner or any other igniter.

8-8.1.4 Interlocks, Warm-up Burner Fuel Trip. A fuel trip with first-out annunciation shall result from any of the following conditions *(see also Section 9-3)*:

(a) Fuel pressure at the burner below the minimum established by the burner manufacturer or by trial;

(b) Loss of atomizing medium to boiler;

(c) Loss of burner flame;

(d) Loss of control energy, where fuel flow to burners is affected by such loss;

(e) Master fuel trip;

(f) Loss of or inadequate burner combustion air supply; or

(g) High burner discharge temperature (for duct burner only).

8-8.1.5 Loss of Individual Burner or Igniter Flame.

8-8.1.5.1 Loss of flame at an individual igniter shall cause the igniter individual safety shutoff valve to close and the associated sparks to de-energize.

8-8.1.5.2 Loss of flame at an individual burner shall cause the burner individual safety shutoff valve to close.

8-8.1.5.3 The conditions of 8-8.1.5.1 and 8-8.1.5.2 shall be indicated.

8-8.2 Operating Cycle. The following operating sequences are based on a typical system that includes steam-atomized main oil burners. Certain provisions and sequences shall not apply where other atomizing media or systems are used. The sequence also might vary depending on the system installed. However, the principles outlined in these sequences shall be followed, and all applicable interlocks, trips, alarms, or their equivalents shall be provided.

8-8.2.1 Prefiring Cycle. The following steps shall be taken by the operator when starting a supervised manual burner, and the required interlocks shall be satisfied at each step.

Operator Actions	Interlock Functions
(a) Inspect furnace for unburned oil accumulations, if feasible.	(a) None
(b) Confirm burner guns have proper tips and sprayer plates.	(b) None
(c) Confirm individual burner safety shutoff valve closed.	(c) Proved closed
(d) Confirm individual burner supervisory shutoff valves closed.	(d) Proved closed
(e) Confirm burner gun in proper position.	(e) None
(f) Confirm burner header fuel control valve in light-off position.	(f) Proved
(g) Confirm that atomizing medium header has been blown free of condensate and header trap is functioning.	(g) None
(h) Open main safety shutoff valve and recirculation valve to circulate heated oil through main fuel bypass control valve and burner header.	(h) Prove all required interlocks satisfied.
(i) Complete unit purge in accordance with 6-2.1.2(f).	(i) Prove purge airflow rate *[see 8-8.1.3(a) and (b).]*
(j) Open atomizing medium individual burner shutoff valve to the burner gun to be lighted. Blow free of condensate. Confirm atomizing pressure has been established.	(j) Prove atomizing medium available.
(k) Immediately proceed with light-off cycle after completion of purge.	(k) None
(l) Repurge required if airflow rate drops below purge rate.	(l) Prove purge airflow rate.

8-8.2.2 Light-Off Cycle — First Burner. All required interlocks shall be satisfied. (*See 9-3.2.*)

Operator Actions	Interlock Functions
(a) Maintain purge airflow rate.	(a) Prove that airflow has not dropped below purge rate.
(b) Adjust register of burner to be lighted to light-off position, if necessary.	(b) Prove purge airflow rate.
(c) Energize igniter for first burner. For direct electric ignition, omit 8-8.2.2(d).	(c) For fuel-fired igniters, prove flame within 10 seconds. If lame is not proved, safety shutoff valves for this igniter shall close and spark shall be de-energized.
(d) If ignition flame is not established, determine cause and make necessary corrections. Burner register shall be opened to purge position for at least 1 minute before repeating light-off cycle.	(d) None
(e) Open burner shutoff valve if igniter flame is proven.	(e) Igniter flame proven
(f) If main burner flame is not established within main flame trial for ignition period (Class 2 and Class 3 igniters), a master fuel trip shall be initiated.	(f) None

8-8.2.3 Light-Off Cycle — Subsequent Burners. [*See Figures A-8-5.1.1(a) through A-8-5.1.1(e).*]

Operator Actions	Interlock Functions
(a) Adjust register of burner to be lighted to light-off position, if necessary.	(a) Prove that airflow has not dropped below purge rate.
(b) Energize igniter. For direct electric igniters, omit 8-8.2.3(c).	(b) For fuel-fired igniters, prove flame within 10 seconds. If flame is not proven, safety shutoff valves for this igniter shall close and spark shall be de-energized.
(c) If ignition flame is not established, determine cause and make necessary corrections. Burner register shall be opened to purge position for at least 1 minute before repeating light-off cycle.	(c) None
(d) Open burner shutoff valves if igniter flame is proven.	(d) Igniter flame proven
(e) If main burner flame is not established within main flame trial for ignition period, trip the safety shutoff valves for that burner and its igniter. Determine and correct cause of failure. Wait at least 1 minute before attempting to relight this burner or any other burner.	(e) None

8-8.2.4 Normal Shutdown Cycle.

	Operator Actions		Interlock Functions
(a)	Reduce burner load to minimum. Do not reduce airflow through burner below its minimum operating rate.	(a)	None
(b)	Close individual supervisory shutoff valve at burner. Leave burner airflow at firing rate.	(b)	As each burner supervisory shutoff valve is closed, loss of flame shall cause its associated shutoff valve to close. After last burner supervisory shutoff valve is closed, loss of all burner flame shall cause header or supply safety shutoff valve to close.
(c)	Open clearing valve to clear burner.	(c)	None
(d)	Shut off igniter.	(d)	Igniter safety shutoff valves close; igniter atmospheric vent valve opens (for gas igniters).
(e)	Leave burner register at firing rate.	(e)	None
(f)	Shut off atomizing medium to each burner.	(f)	None
(g)	If oil guns are not cleared into the furnace, eliminate 8-8.2.4(a), (c), and (d). Remove oil guns and drain oil outside the furnace.	(g)	None
(h)	Purge burner for at least 1 minute. Adjust burner airflow per manufacturer's instructions.	(h)	None
(i)	Repeat 8-8.2.4(a) through (c) for subsequent burners.	(i)	None

Chapter 9 Interlock System

9-1 General.

9-1.1 The basic requirement of an interlock system for a unit is that it protect personnel from injury and also protect the equipment from damage. The interlock system functions to protect against improper unit operation by limiting actions to a prescribed operating sequence or by initiating trip devices when approaching an undesirable or unstable operating condition.

9-1.2 The mandatory automatic master fuel trips (MFT) specified in Table 6-2.5.1(a), the main fuel trips specified in 6-2.6, and the warm-up burner trips specified in 7-5.3 and 8-5.3 represent those automatic trips for which sufficient experience has been accumulated to demonstrate a high probability of successful application for all units. The use of additional automatic trips, while not mandatory, is recommended.

9-1.3 It is possible to experience conditions conducive to a furnace explosion without detection of such conditions by any of the mandatory automatic trip devices, even though they are properly adjusted and maintained. Therefore, operating personnel shall be made aware of the limitations of the automatic protection system.

9-2 Functional Requirements.

9-2.1 The operation of any interlock that causes a trip shall be annunciated.

9-2.2 An interlock system shall be of sound design and shall be properly installed, adjusted, and tested to confirm design, function and proper timing. Periodic testing and maintenance shall be performed to keep the interlock system functioning properly.

9-2.3 The design of an interlock system shall be predicated on the following fundamentals:

(a) The starting procedure and operation shall be supervised to ensure proper operating practices and sequences.

(b) The minimum amount of equipment shall be tripped in the proper sequence where the safety of personnel or equipment is jeopardized.

(c) The cause of the trip shall be indicated and shall prevent restarting of any portion of the affected equipment until proper conditions are established.

(d) The necessary trip devices shall be coordinated into an integrated system.

(e) Where automatic equipment is not available to accomplish the intended function, sufficient instrumentation to enable the operator to complete the proper operating sequence shall be provided.

(f) The design shall provide as much flexibility with respect to alternate modes of operation as is consistent with good operating practice.

(g) Proper preventive maintenance shall be provided.

(h) The design shall not require any deliberate defeating of an interlock in order to start or operate equipment. Whenever a safety interlock device is removed temporarily from service, it shall be noted in the log and annunciated if practicable, and a manual or other means shall be substituted to supervise this interlock function.

(i) *The mandatory automatic master fuel trip and mandatory automatic main fuel trip systems, including sensing elements and circuits, shall be functionally independent from all other control system functions. The warm-up burner fuel trip system, sensing elements, and circuits shall be functionally independent from all other control system functions.

Exception: Individual burner flame failure devices also shall be permitted to be used for initiating master fuel trip systems.

(j) Misoperation of the interlock system due to interruption and restoration of the interlock power supply shall be prevented.

9-2.4 The actuation values and time of action of the initiating devices shall be adjusted to the furnace and equipment on which they are installed. After adjustment, each path and the complete system shall be tested to demonstrate the adequacy of adjustment for that furnace.

9-3 System Requirements. Figures 9-3.1(a), 9-3.1(b), 9-3.2, 9-3.3, 9-3.4, and 9-3.5 show the required system of interlocks necessary to provide the basic furnace protection for fluidized-bed boilers designed and operated in accordance with this standard. The logic flow paths shown in these figures reflect the sequence of operations described in Chapters 6, 7, and 8 for either a cold start or a hot restart.

9-3.1 The master fuel trip logic that initiates the tripping of all fuel supplies through a master fuel trip device is shown in Figure 9-3.1(b). This figure illustrates a representative sample of the types of conditions that shall be required to initiate the tripping of both the main and burner fuel supplies as outlined in Chapter 6. This standard requires use of the type of master fuel trip device that remains tripped until reset by either the successful completion of the purge cycle or the main fuel temperature permit from the fuel release logic (*see Figure 9-3.2*). Each source of operation of the master fuel trip devices shall actuate a "cause of trip" indication that informs the operator of the initiating cause of trip impulse.

9-3.1.1 Blocks 1 through 4 of Figure 9-3.1(b) represent protection against loss of large quantities of combustion air. The loss of all induced draft fans or all forced draft fans shall operate the master fuel trip device.

9-3.1.2 The loss of an individual induced draft fan or forced draft fan shall cause an immediate runback in unit fuel input in order to maintain the proper air/fuel ratio. This shall be permitted to be interlocked or made a part of the combustion control system.

9-3.1.3 Furnace pressure high (block 6) shall be interlocked with the master fuel trip device to protect against abnormal furnace conditions, such as those resulting from a tube rupture or damper failure.

9-3.1.4 A manual trip switch (block 12) shall be provided for use by the operator in an emergency. The manual trip switch shall actuate the master fuel trip relay directly.

9-3.1.5 Bed temperature low (block 10), as defined in 6-1.5.1(f), and warm-up burner flame not proven (block 11) are the equivalent of a loss of all flame in a burner-fired boiler and are interlocked with the master fuel trip device in order to prevent the further admission of fuel into the furnace under "no-flame" conditions.

9-3.1.6 All Fuel Inputs Zero (Block 9). A mandatory master fuel trip shall occur once any fuel has been admitted to the unit, all fuel sources are subsequently isolated, and bed temperature is less than the main fuel operating permit. This trip shall be permitted to be reset and bypassed once the bed temperature exceeds the temperature permit level for admitting fuel.

9-3.1.7 Other trips, as required by 6-2.5, and additional automatic master fuel trips required for a particular boiler design shall actuate the master fuel trip relay.

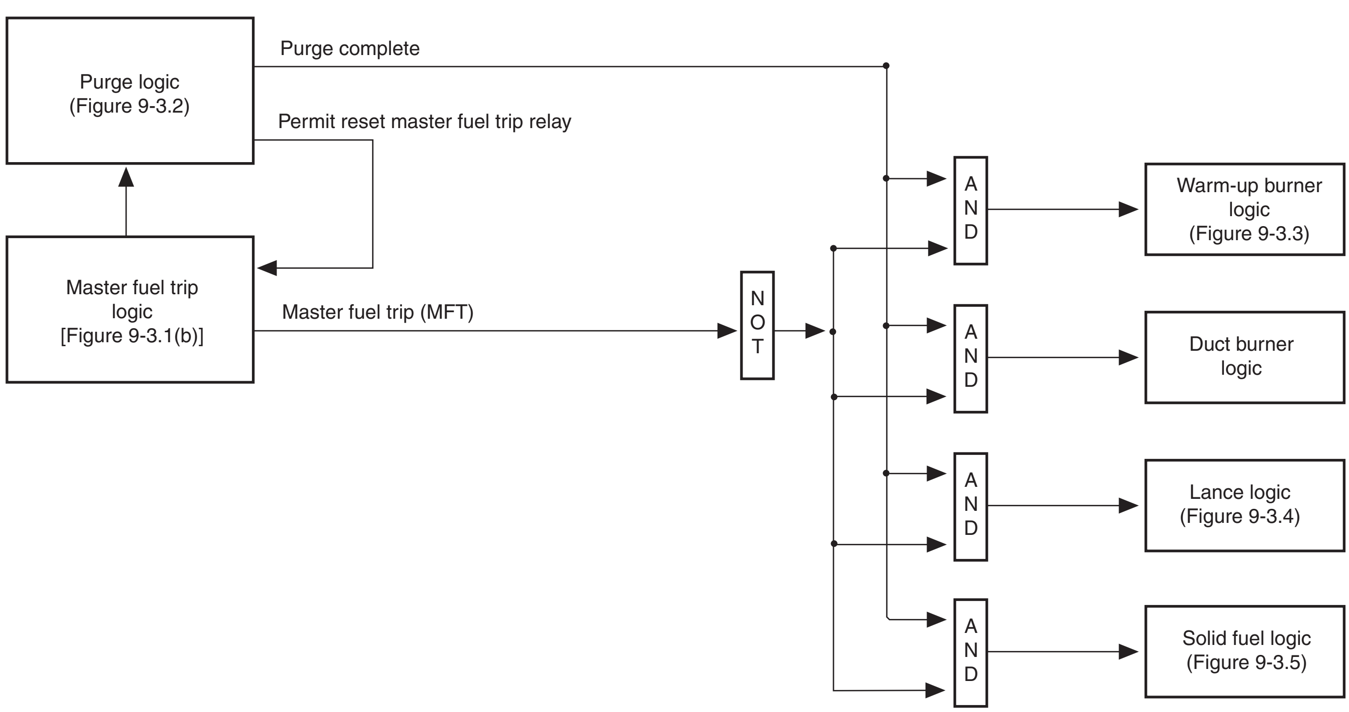
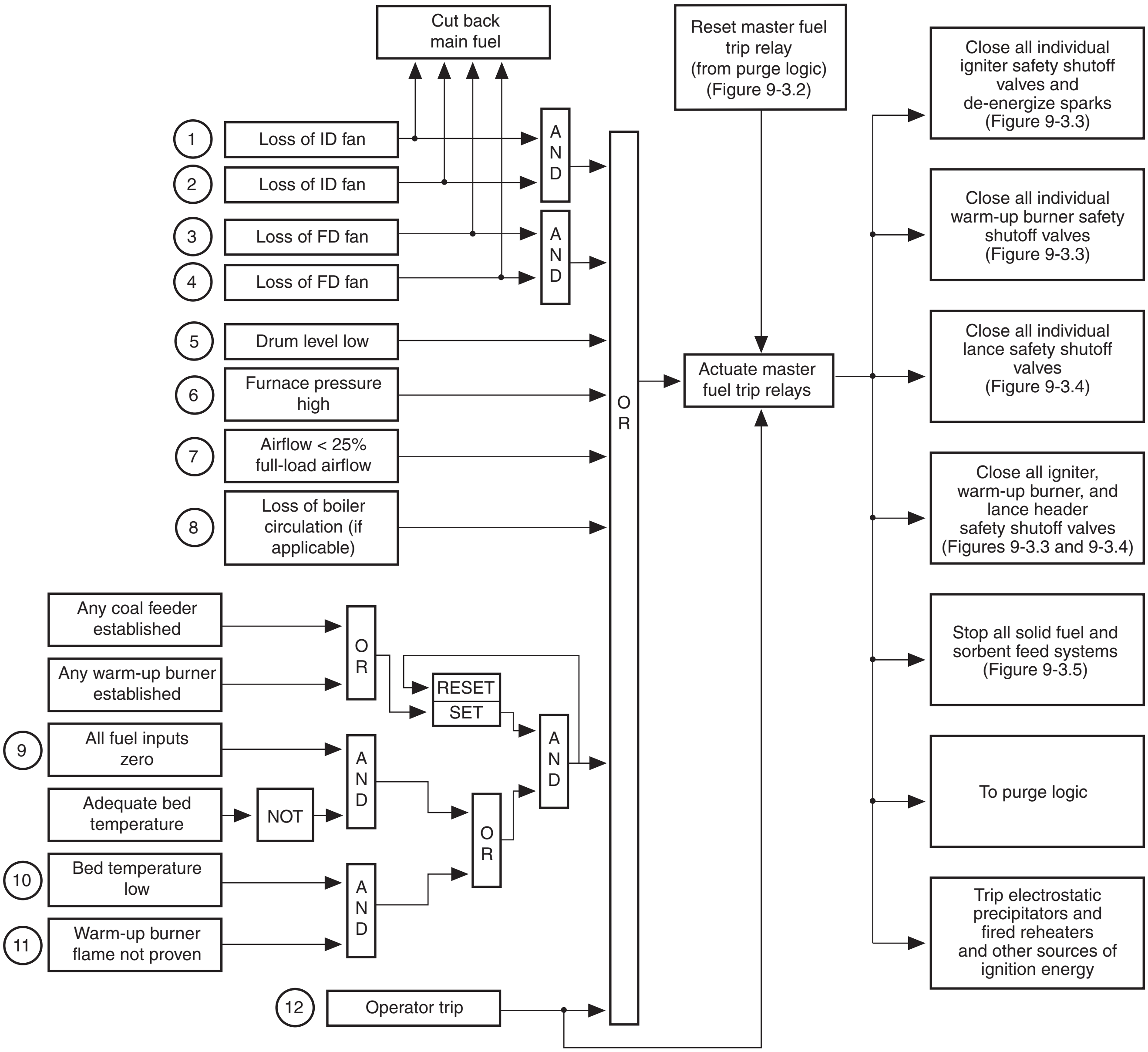


Figure 9-3.1(a) Interlock system overview.



NOTE 1: Mandatory automatic trips per Table 6-2.5.1(a) shown.
NOTE 2: Two induced draft and forced draft fans are assumed for this diagram.

Figure 9-3.1(b) Boiler trip logic.

9-3.1.8 In all cases following a master fuel trip, operator initiation of fuel input to the unit shall be required.

9-3.1.9 The master fuel trip device shall be of the type that remains tripped until the boiler purge system permits it to reset. When actuated, the master fuel trip device shall trip all sources of solid fuel input directly, close all safety shutoff valves, de-energize all igniter sparks, and de-energize all other ignition sources within the unit and flue gas path.

9-3.2 Unit Purge. A proper purge of the unit shall be ensured by successfully completing a series of successive purge permissive interlocks, which are functionally outlined in Figure 9-3.2. This series of interlocks shall ensure that the unit purge has been completed with all sources of fuel admission proven isolated, all required air sources proven in service, all air paths in purge position, and no boiler trip conditions in existence prior to or during the purge cycle.

9-3.2.1 Interruption of the furnace purge by either the master fuel trip interlock logic, or through the loss of any required purge interlocks, shall cause the purge sequence to reset, and a complete and successful repurge of the unit shall be required prior to admitting fuel.

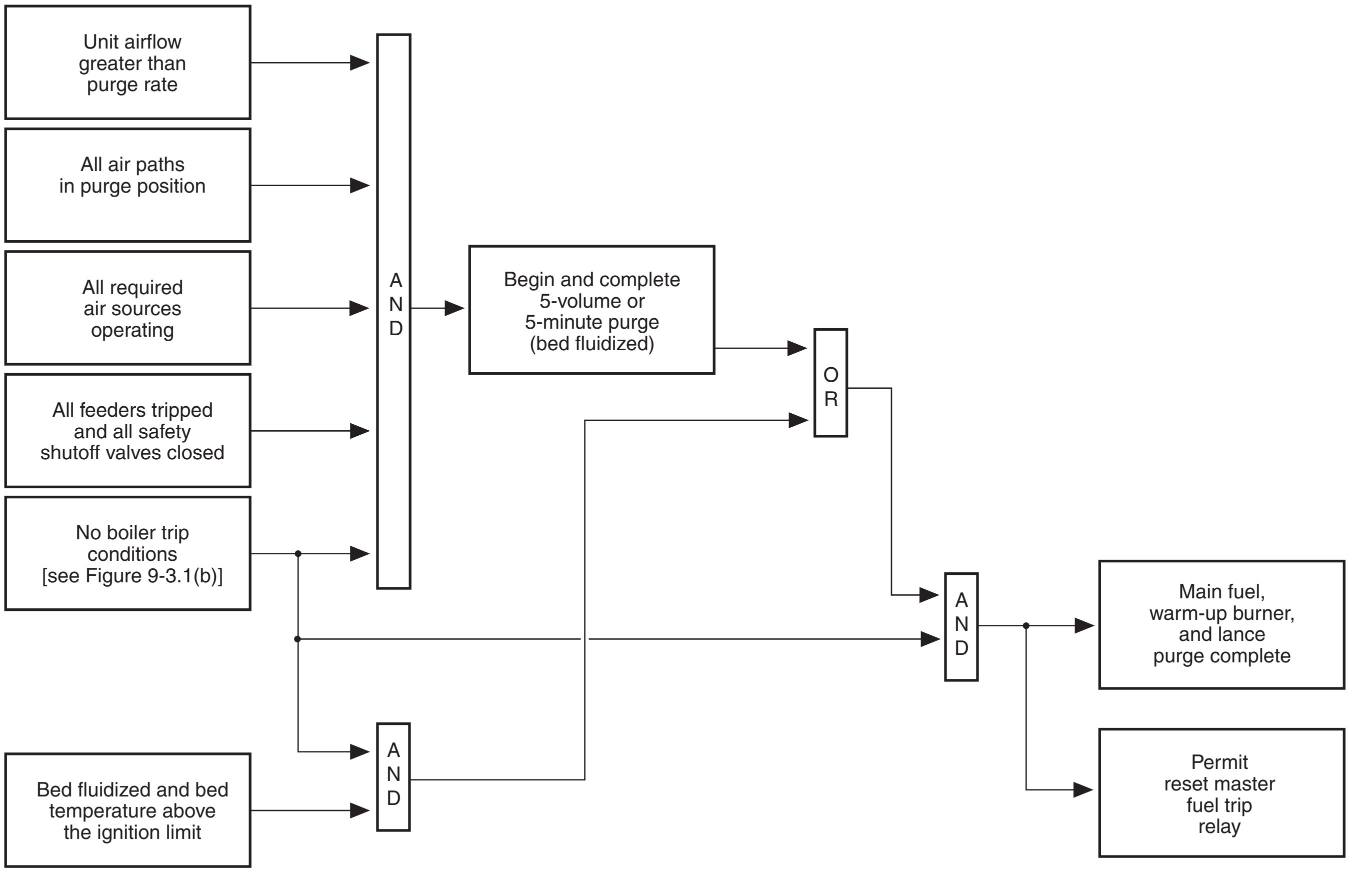


Figure 9-3.2 Purge logic.

9-3.2.2 Cold Start. During initial start-up, or if the bed temperature is less than either the main fuel or the auxiliary fuel permits (*see 6-2.1*), a complete purge of the unit as outlined in Figure 9-3.2 shall be required.

9-3.2.3 Hot Restart. If operating conditions at the time of reset are such that the bed temperature permits for the main fuel are available (*see 6-2.4*), a purge reset and bypass shall be permitted.

NOTE: It is recommended that manual initiation be required before the purge reset of the master fuel trip device is completed.

9-3.2.4 Upon the successful completion of the purge, or following the completion of the purge bypass and reset, the master fuel trip device shall be reset.

9-3.3 Warm-up Burners. The warm-up burners shall not be placed in service until the master fuel trip relay has been reset. (*See Figure 9-3.3.*)

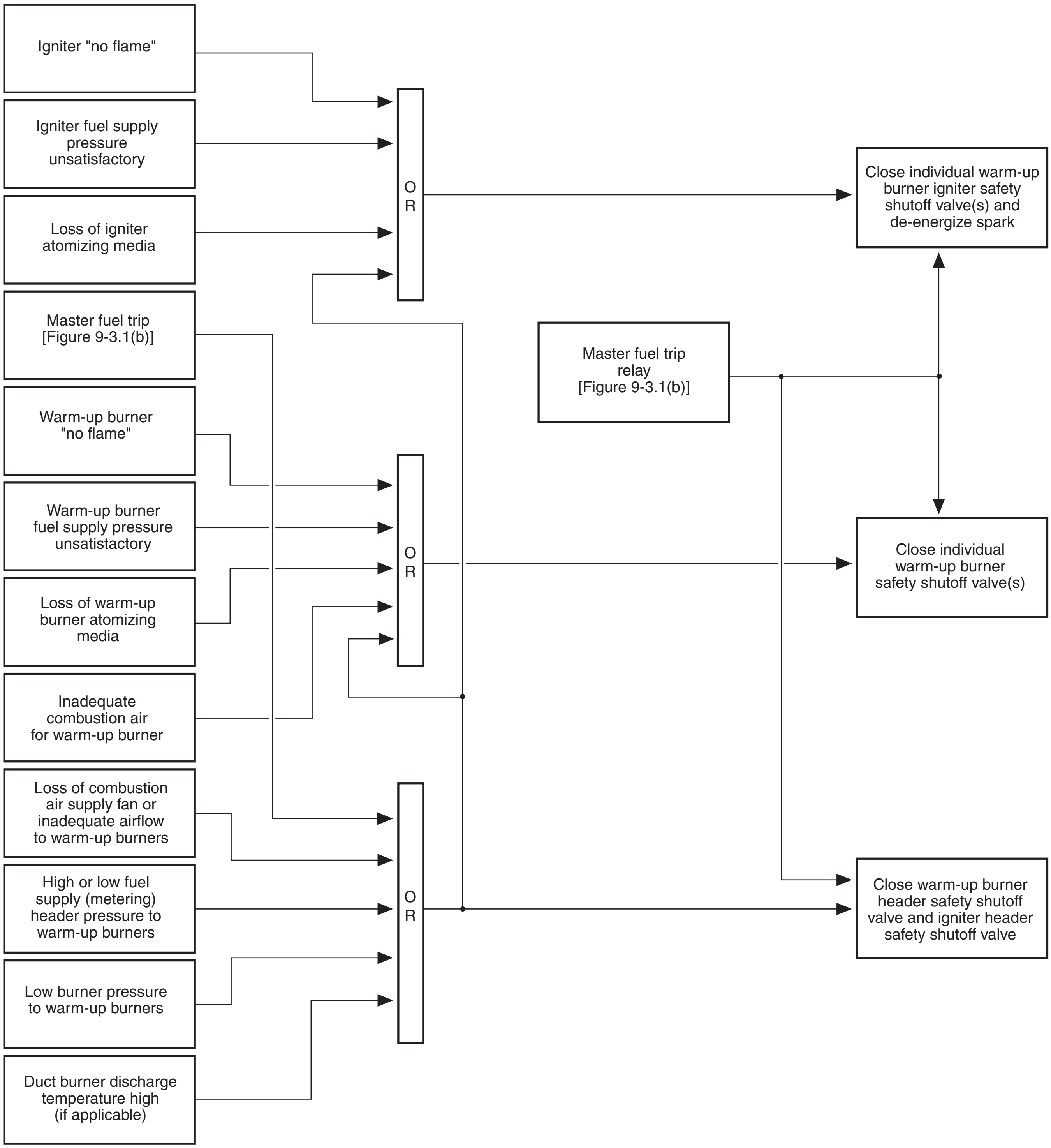
CAUTION: Some fuel supply systems for warm-up burners are configured with sensors and interlock logic for monitoring and tripping burners on a per burner basis. Others are configured with sensors and interlocks for monitoring and tripping warm-up burners as a group. Care must be taken to ensure interlocks are designed for use with the fuel supply piping arrangement used.

9-3.3.1 Loss of an individual warm-up burner flame shall initiate the tripping of the individual burner safety shutoff valve(s) and its individual igniter safety shutoff valve(s) and shall de-energize associated sparks.

9-3.3.2 Improper warm-up burner fuel pressure shall be interlocked to initiate the tripping of the individual warm-up burner safety shutoff valve(s) and de-energize the associated sparks. Where gas is used for fuel, both high and low pressure shall be interlocked. Where oil is used, low pressure shall be interlocked. Burner fuel pressure shall be monitored to ensure each warm-up burner is being operated within its capacity and stability limits as designated by the burner manufacturer and demonstrated by test.

NOTE: Monitoring of header pressure to multiple warm-up burners with individual flow control capability does NOT satisfy this requirement. With low pressure gas burners, furnace pressure fluctuations might be more influential on burner gas flow than burner pressure drop.

9-3.3.3 For gas-fired warm-up burners, improper gas supply (metering) pressure shall initiate tripping of the burner header and individual warm-up burner safety shutoff valves and igniter header and individual igniter safety shutoff valves and shall de-energize associated sparks. [*See Figure A-7-5.1.1(a).*]



NOTE: A specific fuel system might not require all the trips shown.

Figure 9-3.3 Warm-up burner safety subsystem.

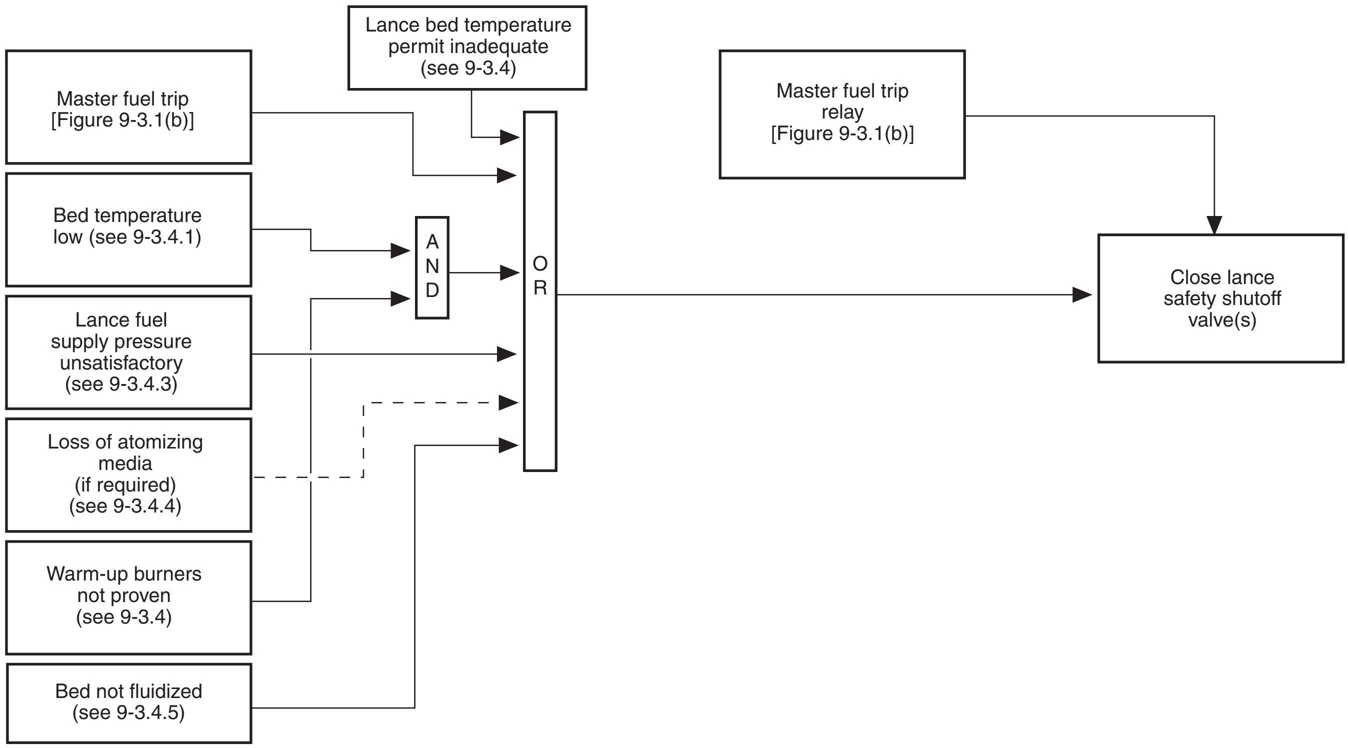


Figure 9-3.4 Lance safety subsystem.

9-3.3.4 Where oil is used as an igniter fuel with air or steam for atomization, loss of atomizing media shall trip the igniter header and individual igniter safety shutoff valves and shall de-energize the associated sparks. The associated warm-up burners also shall be tripped if in service and no other proof of flame exists.

9-3.3.5 Where oil is used as a warm-up burner fuel with air or steam for atomization, loss of atomizing media shall trip the burner header and individual warm-up burner safety shutoff valves and igniter header and individual igniter safety shutoff valves and shall de-energize associated sparks.

9-3.3.6 A master fuel trip shall trip all warm-up burner header and all individual warm-up burner safety shutoff valves and all igniter header and all individual igniter safety shutoff valves and shall de-energize all associated sparks.

The master fuel trip relay shall trip all warm-up burner header and all individual warm-up burner safety shutoff valves directly and all igniter header and all individual igniter safety shutoff valves and shall de-energize all associated sparks.

9-3.3.7 If individually flow-controlled burners are used and the fuel flow or airflow falls below the manufacturer's recommended minimum flow, the burner shall be tripped immediately.

9-3.4 Lances. Lances shall not be placed in service until the master fuel trip relay has been reset and the bed temperature has reached the ignition temperature for the fuel being fired in the lance. [*See 6-1.5.1(f), 6-2.1.2(i)6, 6-2.1.2(j)4, and Figure 9-3.4.*]

9-3.4.1 Loss of the appropriate bed temperature permit shall cause the individual lance safety shutoff valves to close. (*See 6-2.2.5.*)

9-3.4.2 For gas-fired lances, improper gas supply (metering) pressure shall initiate tripping of the lance header and individual lance safety shutoff valves. [*See Figure A-7-5.1.1(a).*]

9-3.4.3 Improper lance fuel pressure shall be interlocked to ensure each lance is being operated within its capacity as designated by the lance manufacturer and shall initiate a trip of the individual lance safety shutoff valves.

Lance fuel pressure shall be monitored to ensure each lance is being operated within its capacity as designated by the lance manufacturer.

NOTE: The monitoring of header pressure to multiple lances with individual flow control capability does NOT satisfy this requirement.

9-3.4.4 Where oil is used as a lance fuel with air or steam for atomization, loss of atomizing media shall trip the header and safety shutoff valve(s).

9-3.4.5 Loss of adequate airflow to fluidize the bed shall result in a trip of the lance header and individual lance safety shutoff valves.

9-3.4.6 A master fuel trip shall trip all lance header and individual lance safety shutoff valves.

9-3.4.7 The master fuel trip relay shall trip all lance header and individual lance safety shutoff valves directly.

9-3.5 Solid Fuel. The solid fuel feed system shall not be placed in service until the master fuel trip relay has been reset and the bed temperature has reached the ignition temperature of the solid fuel being fired. [*See 6-1.5.1(f), 6-2.1.2(i)6, 6-2.1.2(j)4, and Figure 9-3.5.*]

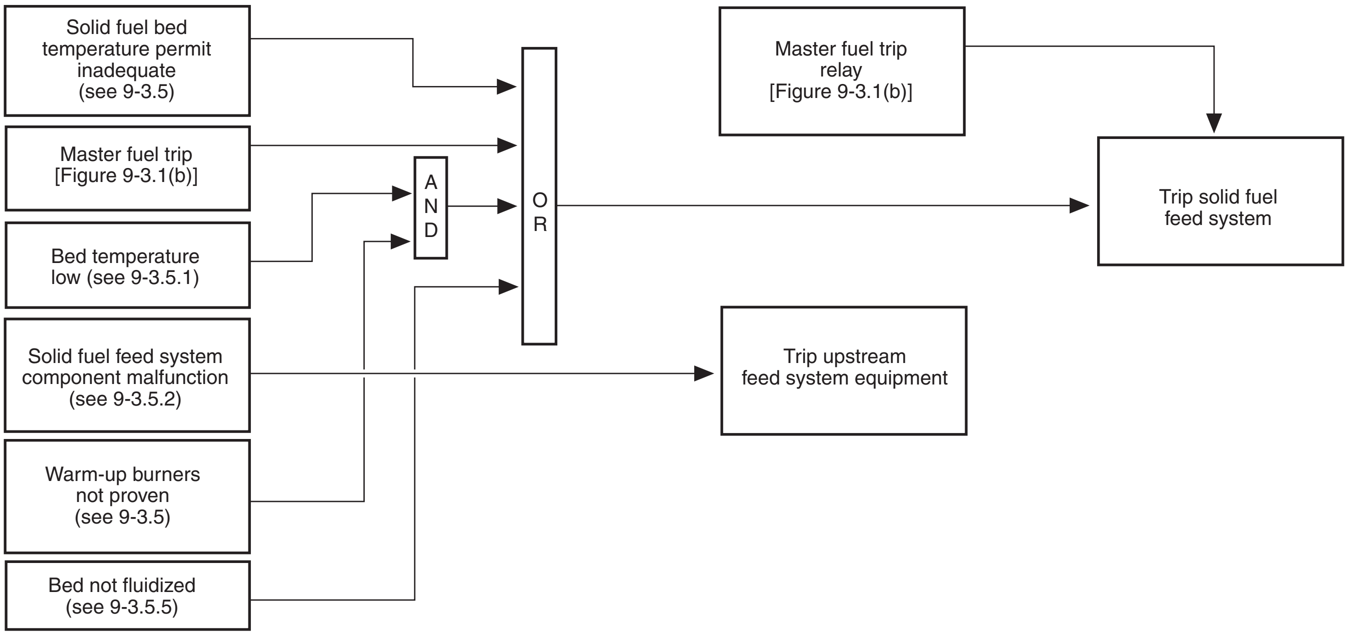


Figure 9-3.5 Solid fuel safety subsystem.

9-3.5.1 Loss of the appropriate bed temperature permit shall cause all solid fuel feed systems to trip. (*See 6-2.2.5.)*

9-3.5.2 Solid fuel feed system operation shall be interlocked to trip upstream solid fuel feed train components following a solid fuel system component malfunction.

9-3.5.3 A master fuel trip shall trip the solid fuel feed system.

9-3.5.4 The master fuel trip relay shall trip the solid fuel feed system directly.

9-3.5.5 Loss of adequate airflow to fluidize the bed shall result in a solid fuel trip.

Chapter 10 Alarm System

10-1 Functional Requirements.

10-1.1 The functional requirement of the alarm system is to bring a specific abnormal condition to the attention of the operator. Alarms shall be used to indicate equipment malfunction, hazardous conditions, and misoperation. For the purpose of this standard, the primary function of alarms is to indicate abnormal conditions that might lead to impending or immediate hazards.

10-1.2 Alarm systems shall be designed so that, for all required alarms, the operator receives an audible as well as visual indication of the condition. The visual indication shall identify the source or cause of the alarm. Means shall be permitted to silence the audible alarm after actuation, but the visual indication shall continue until the condition has been returned to normal.

10-1.3 The design shall make it difficult to manually defeat the alarm, and, where equipment malfunction makes this necessary, it shall be performed by authorized personnel, and the alarm shall be tagged as inoperative.

10-1.4 The design shall eliminate all nuisance alarms to the extent possible.

10-1.5 Consideration shall be given to the use of an additional annunciator dedicated to high priority critical alarms.

10-2 System Requirements.

10-2.1 Required Alarms. In addition to the safety features of the interlock system (*see 9-2.1*), and the required alarms of 5-5.2, 7-7.2, and 8-7.2, the following alarms shall be provided:

(a) *Lance Atomizing Steam or Air Pressure (Low).* For steam or air-assisted lances, an alarm shall be provided to warn that steam or air pressure and fuel pressure are outside of operating range and that poor oil atomization might result.

(b) *Lance Fuel Header Pressure (High and Low).* The lance fuel header pressure shall be monitored as close to the lances as practicable in order to warn the operator of abnormal pressure in advance of conditions that lead to a trip.

(c) *Solid Fuel Feeder Tripped.* An alarm shall indicate when a feeder has tripped (not normal shutdown).

(d) *Solid Fuel Transport Air Fan Tripped.* An alarm shall indicate when a transport air fan has tripped (not normal shutdown).

(e) *Solid Fuel Plugged.* An alarm shall indicate when the feeder is running and the fuel flow detecting device downstream of the feeder indicates no fuel flow.

(f) *Furnace Pressure High or Low.* An alarm shall warn the operator of furnace pressure outside the region of normal operation and an approach to a trip condition.

(g) *Loss of Operating Forced Draft Fan.* This condition shall be sensed and alarmed only when the fan is not operating at the times expected.

(h) *Loss of Operating Induced Draft Fan.* This condition shall be sensed and alarmed only when the fan is not operating at the times expected.

(i) *Boiler Airflow (Low).* This condition shall be sensed and alarmed when total airflow nears the minimum purge rate.

(j) *Loss of Interlock Power.* This condition shall be sensed and alarmed and shall include all sources of power necessary to complete interlock functions. For example, if both a 125-volt dc electric circuit and a compressed air circuit are needed for an interlock scheme, then loss of either circuit shall be annunciated separately.

(k) *Loss of Control Power.* This condition shall be sensed and alarmed to include all sources of power for the combustion control or the fluidized-bed boiler safety interlocks.

(l) *Bed Temperature Out of Limits.* The bed temperature shall be monitored and alarmed when it drifts out of the normal operating range and approaches a trip condition (not on shutdown).

(m) *Ash Cooler Discharge Material Temperature High.* An alarm shall indicate when the material temperature about to be discharged from the ash cooler reaches a predetermined high limit.

(n) *Lance Valve Not Closed.* The closed position of individual lance safety shutoff valves shall be monitored, and failure of any valve to close following a trip shall be alarmed.

(o) *Low Oxygen.* An alarm shall warn the operator of a possible hazardous condition in the flue gas.

10-2.2 Recommended Alarms. In addition to the required alarms, the following alarms shall be permitted to indicate abnormal conditions and, where applicable, to alarm in advance of a safety shutdown.

(a) *Flame Detector Trouble.* All burner or igniter flame detectors are monitored to warn the operator of a flame detector malfunction.

(b) *Combustible or Carbon Monoxide High.* An alarm warns the operator of a possible hazardous condition when measurable combustibles are indicated.

(c) *Air/Fuel Ratio (High and Low).* If proper metering is installed, an alarm indicates a potentially hazardous air/fuel ratio.

(d) *Oxygen Analyzer Trouble.* An alarm warns the operator of a malfunctioning flue gas oxygen analyzer.

Chapter 11 Referenced Publications

11-1 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.

11-1.1 NFPA Publication. National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101.

NFPA 31, *Standard for the Installation of Oil-Burning Equipment*, 1992 edition.

11-1.2 Other Publications.

11-1.2.1 AISC Publication. American Institute of Steel Construction, 1 East Wacker Drive, Suite 3100, Chicago, IL 60601.

AISC M016, *Manual of Steel Construction Allowable Stress Design*, 1989.

11-1.2.2 ANSI Publication. American National Standards Institute, Inc., 1430 Broadway, New York, NY 10018.

ANSI B31.1, *Power Piping*, 1995.

11-1.2.3 ASTM Publication. American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19105.

ASTM D 396, *Standard Specification for Fuel Oils*, 1992.

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-1-1.4 In existing units, it is not always practicable to apply the provisions of this standard strictly. Physical limitations might necessitate disproportionate effort or expense with little increase in protection. In such cases, the authority having jurisdiction must be satisfied that reasonable protection is ensured.

In existing units, it is intended that any condition that represents a serious boiler combustion system hazard should be mitigated by application of appropriate safeguards. It is not the intent to require modification for conditions that do not represent a significant threat, even though such conditions are not literally in conformance with the requirements of this standard.

A-2-2 Furnace Pressure Excursion Protection. No standard can guarantee the elimination of furnace implosions. Chapter 5 provides a balance between the complications of reinforcement of equipment, limitations and reliability of operating procedures, control systems, and interlocks to minimize the occurrence of the conditions leading to furnace implosions.

If worst case conditions are assumed (e.g., cold air, high head induced draft fan, forced draft fan flow shutoff, induced draft control dampers open with induced draft fan operating), the furnace cannot be protected by reasonable structural design.

Using the provisions outlined in Chapter 5, the likelihood of furnace damage is believed to be remote, provided the induced draft fan has reasonable head capability. If the induced draft fan head capability is increased significantly, then special consideration of induced draft fan characteristics or special duct arrangements or special instrumentation or control should be investigated.

A-2-6.1 Maintenance and Equipment Inspection.

(a) The objective of a maintenance program is to identify and correct conditions that adversely affect the safety, continued reliable operation, and efficient performance of equipment. A program should be provided for the maintenance of equipment at intervals consistent with the type of equipment, service requirements, and manufacturer's recommendations.

1. As a minimum, the maintenance program should include:

a. In-service inspections to identify conditions needing corrective action or further study.

b. Detailed, knowledgeable planning for effecting repair or modifications using qualified personnel, procedures, and equipment.

c. Use of comprehensive equipment history that records conditions found, maintenance work done, changes made, and the corresponding dates for each.

d. Written comprehensive maintenance procedures incorporating the manufacturer's instructions to define the necessary tasks and skills. Any special techniques, such as nondestructive testing, or those tasks needing special tools, should be defined. Special environmental factors should be covered, such as temperature limitations, dusts, contaminated or oxygen-deficient atmospheres, and limited access or confined space requirements.

e. Shutdown maintenance inspections, comprehensive in scope, to cover all areas.

f. Availability of adequate spare parts meeting specifications will provide reliable service without necessitating makeshift repairs.

2. An inspection and maintenance schedule should be established and followed.

3. Operation, set points, and adjustments should be verified by periodic testing and the results documented.

4. Defects should be reported and corrected and the repairs documented.

5. System configuration, including logic, set points, and sensing hardware, should not be changed without the effect being evaluated and approved.

6. Inspections, adjustments, and repairs should be performed by trained personnel, using tools and instruments suitable for the work. Maintenance and repairs should be performed in accordance with the manufacturer's recommendations and applicable standards and codes.

(b) **Training.**

1. *Operator Training.*

a. A formal training program should be established to prepare personnel to operate equipment safely and effectively. This program can consist of a review of operating manuals, videotapes, programmed instruction, testing, field training, and other modes of instruction. The training program should be appropriate to the type of equipment and hazards involved.

b. Operating procedures should be established that cover normal and emergency conditions. Start-up and shutdown procedures, normal operating conditions, and lockout procedures should be covered in detail.

c. Operating procedures should be directly applicable to the equipment involved and consistent with safety requirements and manufacturer's recommendations.

d. Procedures should be reviewed periodically and kept current with changes in equipment and personnel.

2. *Maintenance Training.*

a. A formal maintenance training program should be established to prepare personnel to perform any required maintenance tasks safely and effectively. This program can consist of a review of maintenance manuals, videotapes, programmed instruction, testing, field training, manufacturer equipment training, and other modes of instruction. The training program should be specifically applicable to the equipment involved and to potential hazards.

b. Maintenance procedures should be established to cover routine and special techniques. Any potential environmental factors such as temperature, dust, contaminated or oxygen-deficient atmosphere, internal pressures, and limited access or confined space requirements should be included.

c. Procedures should be consistent with safety requirements and the manufacturer's recommendations.

d. Procedures should be reviewed periodically to keep them current with changes in equipment and personnel.

(c) **Housekeeping**.

1. Good housekeeping is essential for safe operation and prevention of fires or explosions; therefore, provision should be made for periodic cleaning of horizontal ledges or surfaces of buildings and equipment to prevent the accumulation of appreciable dust deposits.

2. The creation of dust clouds should be minimized during cleaning. Compressed air should not be used to dislodge coal dust accumulations; washing with water or vacuum cleaning methods are recommended.

(d) **Safety.**

1. *General Safety Precautions.* Protective clothing including, but not limited to, hard hats and safety glasses should be used by personnel during maintenance operations.

2. *Special Safety Precautions.*

a. Severe injury and property damage can result from careless handling of unconfined pulverized fuel; therefore, extreme caution should be used in cleaning out plugged burners, burner piping, pulverized fuel bins, feeders, or other parts of the system.

b. Welding and Flame Cutting. (*See also NFPA 51, Standard for the Design and Installation of Oxygen-Fuel Gas Systems for Welding, Cutting, and Allied Processes, and NFPA 51B, Standard for Fire Prevention in Use of Cutting and Welding Processes. For work on pulverized fuel systems, see NFPA 8503, Standard for Pulverized Fuel Systems.*)

c. Fire-resistant blankets or other approved methods should be used in such a manner as to confine weld spatter or cutting sparks.

d. A careful inspection of all areas near where welding or cutting has been performed, including the floors above and below, should be made when the job is finished or interrupted, and such areas should be patrolled for a period sufficient to make certain that no smoldering fires have developed.

e. Where flammable dusts or dust clouds are present, sparking electrical tools should not be used. All lamps should be suitable for Class II, Division 1, locations as defined in NFPA 70, *National Electrical Code*®.

f. Either ground-fault protected or specially approved low voltage (6-volt or 12-volt) extension cords and lighting should be used for all confined spaces and where moisture might be a hazard.

g. Explosion-operated tools and forming techniques should not be used where flammable dust or dust clouds are present. Where these operations are necessary, all equipment, floors, and walls should be cleaned, and all dust accumulation removed, by an approved method. A careful check should be made to ensure that no cartridges or charges are left in the work area.

3. *Confined Space.*

a. A confined space is any work location or enclosure in which any of the following conditions exist:

1. The dimensions are such that 6-ft (1.8-m) individuals cannot stand up in the middle of the space or extend their arms in all directions without hitting the enclosure.

2. Access to or from the enclosure is by manhole, hatch, port, or other relatively small opening that limits ingress and egress to one person at a time.

3. Confined spaces can include, but are not limited to, ducts, heaters, windboxes, cyclones, dust collectors, furnaces, bunkers, or bins.

b. Specific procedures should be developed and used for personnel entering a confined space to:

1. Positively prevent the inadvertent introduction of fuel, hot air, steam, or gas.

2. Positively prevent the inadvertent starting or moving of mechanical equipment or fans.

3. Prevent the accidental closing of access doors or hatches.

4. Include tags, permits, or locks to cover confined space entry.

5. Determine the need for ventilation or self-contained breathing apparatus where the atmosphere is likely to be stagnant, depleted of oxygen, or contaminated with irritating or combustible gases. Tests for an explosive or oxygen-deficient atmosphere should be made.

6. Provide for a safety attendant. The safety attendant should remain outside of the confined space with appropriate rescue equipment and should be in contact (preferably visual contact) with those inside.

7. Provide for the use of proper safety belts or harnesses, which should be properly tied off where such use is practicable.

c. An operating fluidized-bed combustion (FBC) boiler, either bubbling or circulating, contains as the bed a large quantity of hot, granular solids. In some designs, there is also substantial hot refractory. Both the bed and refractory store large quantities of heat, which cause the behavior of an FBC boiler to be different from that of other fuel combustion systems.

d. Because ignition energy is supplied by the hot bed, an FBC boiler can be operated at fuel/air ratios much higher than can be sustained in a suspension burner. Consequently, an inventory of unburned fuel can accumulate within the boiler enclosure.

e. An operating FBC boiler continues to produce steam after a fuel supply trip if the air supply continues to operate. The source of heat might not be the fuel remaining in the bed after the fuel supply trip but, rather, could come from the heat stored in the granular bed material and refractory. Experience has demonstrated that, while steam production drops, it can continue at above 50 percent of the full-load rating for several minutes after a fuel supply trip. However, if the air supply is stopped and the bed defluidized, the heat removal from the bed becomes very low because the bed material is a good insulator, and steam production drops to less than 10 percent of full-load production in a matter of seconds.

A-2-9.7 Special Hazards in Fluidized-Bed Combustion (FBC) Systems. FBC boilers differ from conventional boilers in important features. Some of these differences can lead to special hazards, several of which are included in the following discussion. These hazards include large quantities of hot, solid materials, significant concentrations of reactive compounds in the solids, and hazardous gaseous species.

Extensive treatment of these special hazards is beyond the scope of this standard. Since FBC technology is still relatively new, recognition of these hazards is warranted. The boiler manufacturer, the plant designer, and the operator all have responsibility for mitigating these hazards to the extent practicable.

(a) **Hot Solids.**

1. *Description of Hazard.* Fluidized-bed combustion systems contain large quantities of granular solids. A typical 100-MW(e) FBC boiler can contain as much as 100 tons of free-flowing solids at 1500°F (815°C) or higher. These hot solids can spill out of the furnace or other components because of equipment failures, poor design, or misoperation. There have been several such incidents in operating plants. In the event of uncontrolled hot-solid spills, personnel can be injured or equipment damaged, or both.

2. *Recommendations.*

a. The designers of the boiler and related plant equipment should identify the potential sources of hot solids and associated hazards and make recommendations for personnel safety.

b. The designer should give careful consideration to the selection of materials that come into direct contact with hot solids.

c. Clean-out ports, fittings that might be used as clean-out ports, and spool pieces that might be removed for rodding out blockages should be positioned so that a sudden rush of hot solids does not lead to personnel injury. Components that are removable for maintenance when the plant is out of service, but that should not be removed when the plant is in service because of the risk of hot spills, should be marked clearly.

d. Instrumentation and wiring needed for the safe operation of the plant should not be routed near potential sources of hot solids. If such routing is necessary, the wiring should be protected from the direct flow of the solids.

e. Fuel lines should not be located near potential sources of hot solids. The fuel lines should be protected from the direct flow of the solids.

f. Plant personnel should be trained in the potential sources of hot solids, associated hazards, and the corresponding safety procedures.

g. Procedures should be developed for cleaning obstructions that provide safety to personnel and equipment. Protective clothing and eye protection should be provided for personnel who rod out obstructions.

h. Components that might contain hot solids should be inspected frequently.

i. Water-cooled screws have failed when suddenly flooded with hot bed material following the removal of an upstream blockage. The sudden transfer of large amounts of heat has resulted in overpressurizing the cooling water passages. The operators should be trained adequately and the systems designed with appropriate instrumentation, interlocks, and pressure relief devices to mitigate the risks associated with this type of event.

(b) **Lime.**

1. *Description of Hazard.* Limestone is normally fed to fluidized-bed boilers to reduce the emissions of sulfur dioxide. More limestone should be added to comply with emission limits than is theoretically needed to react with all of the fuel's sulfur. A significant amount of the limestone is not converted to calcium sulfate and exists as calcium oxide, com-

monly referred to as quicklime. Care should be used where calcium oxide (CaO) is present in the solids to prevent equipment damage or injury to personnel. CaO reacts with water or water vapor to generate heat and reacts with moisture on skin or eyes to cause chemical burns.

2. *Recommendations.*

a. Where limestone is used as an initial bed charge, it is quickly calcined to CaO (quicklime) before a large fraction reacts to $CaSO_4$. In some instances, where limestone has been used for the initial charge, personnel have experienced chemical burns when entering the furnace because the limestone had turned to quicklime. Because of the likelihood that, during initial plant start-ups, a number of plant problems necessitate that personnel enter the FBC, the boiler manufacturer should recommend that the initial charge of bed material be comprised of sand, coal ash, or other chemically inert material rather than limestone.

b. Where three parts lime are wet with approximately one part water, the highest temperature is reached due to a chemical reaction. Where the reaction of pure, reactive lime occurs within a large volume (providing insulation), temperatures of about 600°F (315°C) can be reached. This temperature is sufficiently high to ignite paper, for example, which, in turn, could lead to a plant fire. Also, equipment designed for ambient temperature and pressure can fail when heated by a large lime-water reaction. Therefore, relevant plant components should be designed to perform safely at high temperatures, and means of avoiding pressure buildup should be provided. Provisions should be made for detecting high temperatures within tanks and other components.

c. Waste conditioning systems do mix FBC wastes with water. The designers of these components should be made aware of the likelihood and effects of lime-water reactions by the system integrator, normally an architect, an engineer, or the plant owner.

d. Lime-water reactions can occur while the plant is in service in "dead zones" due to the humidity in air or flue gas. These reactions might or might not lead to particularly high temperatures, but they often do lead to hard blockages. These blockages might disable safety instrumentation, ash removal systems, or other components. Designers should anticipate this problem and provide a means to detect the presence of blockages, especially in instrument lines, as well as a means to remove blockages safely.

e. The safety equipment necessary for dealing with lime should be provided, including breathing masks, protective clothing, and eye protection. First-aid facilities needed for chemical burns, especially for eyes, should be provided. Operators should be trained to test for the presence of quicklime before entering an enclosure filled with solids. One simple test can be performed by sampling the solids. The sample is placed in a metal (not glass) container, wearing gloves and eye protection. An approximately equal volume of water is added, the solution is stirred, and approximately 15 minutes are allowed to pass in order to detect a temperature rise.

(c) **Hydrogen Sulfide.**

1. *Description of Hazard.* Fluidized-bed boilers that operate substoichiometrically in the lower combustion zone can produce hydrogen sulfide (H_2S) as an intermediate product before the sulfur is fully oxidized. Because of the positive pressure in the lower combustion zone, H_2S can leak out of the furnace and into an area where personnel are working. Hydrogen sulfide is heavier than air and concentrates in poorly ventilated low points in the plant, creating the potential for personnel injury.

2. *Recommendations.*

a. Adequate seals/gaskets on components that can be opened or disassembled that are located in the dense bed region should be provided. Weld components that do not need to be opened or disassembled should be sealed.

b. Written guidelines on H_2S should be provided with the equipment manuals.

c. Operators should be trained to anticipate the presence of H_2S.

d. Means for measuring the concentration of H_2S in the boiler house and other plant facilities should be provided.

(d) **Calcium Sulfide.**

1. *Description of Hazard.* The bottom ash (and under some modes of misoperation, fly ash) from a fluidized-bed boiler might contain some calcium sulfide, which is a reaction product of H_2S with limestone in the absence of sufficient oxygen. Calcium sulfide can react with CO_2 and H_2O, which are constituents of air, and release H_2S. If this occurs, for example, in a waste storage silo, the silo's environment can reach a hazardous concentration of H_2S.

2. *Recommendations.* Calcium sulfide in FBC waste products can lead to the release of H_2S in waste storage silos and piles. Operators should be trained in the proper procedures for entry of enclosed spaces.

A-4-1.1.1 The following equations provide an example of boiler enclosure structural design as shown in Figure A-4-1.1.1:

(a) *Area A:* Normal operating pressure = +4.0 in. w.g. (+1.0 kPa).

1. +4.0 in. w.g. (+1.0 kPa) × 1.67 = 6.7 in. w.g. (+1.7 kPa).

2. The higher of +35 in. w.g. (+8.7 kPa) or +6.7 in. w.g. (+1.7 kPa) is selected.

3. The lower of the result of item 2 or the forced draft maximum head capability at ambient conditions is selected.

4. Area A of furnace is designed to +35 in. w.g. (+8.7 kPa) at yield.

(b) *Area B:* Normal operating pressure = +20 in. w.g. (+5.0 kPa).

1. +20 in. w.g. (+5.0 kPa) × 1.67 = +33.4 in. w.g. (+8.3 kPa).

2. The higher of +35 in. w.g. (+8.7 kPa) or +33.4 in. w.g. (+8.3 kPa) is selected.

3. The lower of the result of item 2 or the forced draft maximum head capability at ambient conditions is selected.

4. Area B of furnace is designed to +35 in. w.g. (+8.7 kPa) at yield.

(c) *Area C:* Normal operating pressure = +50 in. w.g. (+12.4 kPa).

1. +50 in. w.g. (+12.4 kPa) × 1.67 = +83.5 in. w.g. (+20.8 kPa).

2. The higher of +35 in. w.g. (+8.7 kPa) or +83.5 in. w.g. (+20.8 kPa) is selected.

3. The lower of the result of item 2 or the forced draft maximum head capability at ambient conditions is selected.

4. Area C of furnace is designed to +83.5 in. w.g. (+20.8 kPa) at yield.

(d) *Area D:* Normal operating pressure = +70 in. w.g. (+17.4 kPa).

1. +70 in. w.g. (+17.4 kPa) × 1.67 = +116.9 in. w.g. (+29.1 kPa).

2. The higher of +35 in. w.g. (+8.7 kPa) or +116.9 in. w.g. (+29.1 kPa) is selected.

3. The lower of the result of item 2 or the forced draft maximum head capability at ambient conditions is selected.

4. Area D of the furnace is designed to +110 in. w.g. (+27.4 kPa) at yield.

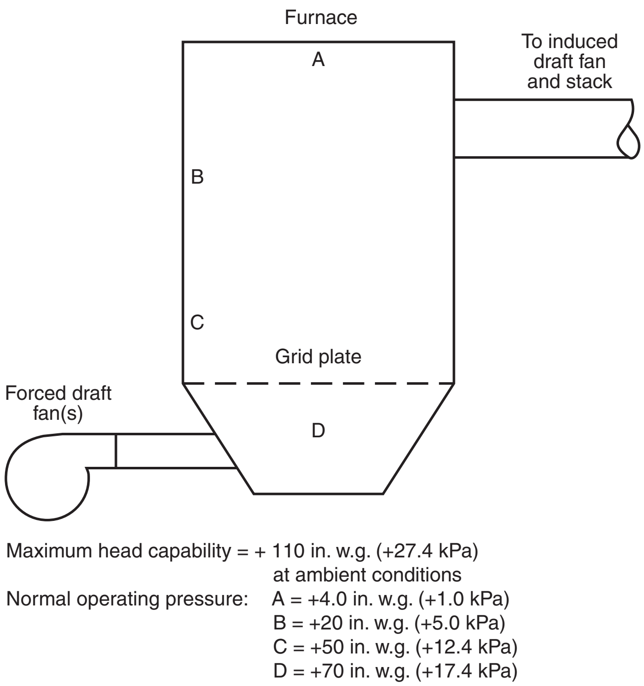


Figure A-4-1.1.1 Boiler enclosure structural design diagram.

A-4-4.2 Determination of Bed Temperature for Operational Permissives. "Bed temperature" refers to the average bed temperature of a fluidized-bed combustion (FBC) boiler at which certain steps can be taken. This appendix provides general guidelines for the measurement of bed temperatures.

The requirement is for the FBC designer to furnish a temperature measuring system and logic to provide a reliable bed temperature value during the various conditions of operation, including start-up, hot restart, low load, and normal operation.

A system that has been shown to satisfy the requirement consists of a number of thermowells, roughly proportional to the capacity of the FBC, positioned in the nominally vertical walls surrounding the bed at elevations below and above the level of the slumped bed. A penetration of a well at a location 2 in. (5.1 cm) from the wall provides a reliable bed temperature measurement without extensive erosion of the well. Materials are selected that are appropriate for temperature elevation, erosion, and corrosion potentials.

Where the bed is fluidized, the measurements above and below the slumped bed level fall within a narrow range. Rather than taking an average of these temperatures, a method is used in which an established minimum percent of each of the upper and the lower bed temperature elevations exceeds the established permissive in order to meet interlock requirements.

Because of the variations in FBC designs, each supplier is responsible for meeting the requirements for a reliable bed temperature measurement and logic system.

A-4-5.2.9 Accumulated Fuel in Bed. Fluid bed combustors under certain abnormal operating conditions can accumulate significant quantities of unburnt fuel without an obvious indication of abnormality. Such conditions can occur where the fuel input exceeds the available air for combustion over an extended period of time. This condition is of particular concern where nonhomogeneous fuel of widely varying heating values is fired. The combustion control system is currently required to include features to reduce the likelihood of this occurrence.

The continuous indication of critical process variables referred to in 2-3.4(a) and described more thoroughly in Section 4-8 is a key aid to the operators in avoiding ongoing operation while fuel input exceeds air input.

Oxygen analyzers are necessary for fluidized bed combustion in order to keep the fuel input calibrated to true air demand for comparison to actual air input. Oxygen analyzers also advise the operator when air input rate relative to fuel input falls below the acceptable range.

Combustibles analyzers are recommended in the note to 4-5.1.3 and in 4-5.2.9 as an aid in avoiding excess fuel operation. Combustibles analyzers provide valuable data in addition to the previously described measurements and information. The deficiency of air might not always deplete flue gas oxygen before high levels of combustible products are observed. Particularly in the event of inadequate bed mixing, flue gas oxygen and flue gas combustibles can coexist and actually present a more difficult situation than a purely air-deficient circumstance.

A-4-6.1.9 Atmospheric vent valves located between shutoff valves are intended to relieve any gas pressure that builds up due to failure leakage of the first (upstream) shutoff valve. This minimizes the potential for leakage into an idle furnace. To perform properly, these valves should be large enough to relieve gas to atmosphere at a rate equal to the potential leakage rate. In the absence of other justification, vent pipe sizes and vent valve port diameters should conform to Table 4-6.1.9.

A-6-2.2.5 The intent of 6-2.2.5 is to require tripping the main fuel if, during normal operation, the bed temperature drops below a predefined value. This trip temperature is higher than the light-off permit because, during start-up, main fuel is being fed under carefully controlled conditions and under the direct, constant attention of an operator [*see 6-2.1.2(i)6 and 6-2.1.2(j)4*]. This condition might not occur during normal operation.

A-6-2.5 If the forced draft fan(s) trips with fuel in the bed and an induced draft fan remains running, a forced draft fan should be restarted at a low output sufficient to pressurize the combustion air ducts or the furnace pressure should be decreased using the induced draft fan, or both. If all forced draft and induced draft fans trip with fuel in the bed, an induced draft fan should be restarted and a lower than normal furnace pressure should be established. These actions are intended as immediate actions to prevent back flow of gaseous combustibles into the combustion air ductwork. Long-term corrective actions should be taken after an assessment of the boiler condition.

A-7-5.2.1.2(a) If a charging valve (required to be self-closing) on the main gas supply is furnished, this should be opened to bypass the main safety shutoff valve; otherwise the main safety shutoff valve should be opened. The main fuel control valve should be opened as required. The burner header should be vented until it is filled with gas. The burner header atmospheric vent valve should be closed. The charging or main safety shutoff valve should be left open to establish a nominal pressure on the burner header. The charging or main safety shutoff valve then should be closed. It may be permitted to be concluded that the safety shutoff valves do not leak if the nominal pressure remains within specified limits.

A-7-7.2 Recommended Additional Alarms for Automatic Systems (Fuel Gas). In addition to the required alarms, the following alarms are recommended to indicate abnormal conditions and, where applicable, to alarm in advance of an emergency shutdown. It is recommended that provision be made in the design for possible future conversion to automatic trips in the interlock system.

(a) **Burner Register Closed.** This provides control room indication or alarm for the condition that all secondary air burner dampers are closed on an operating burner.

(b) **Change in Btu Content of the Fuel Gas.** In the event that the gas supply is subject to Btu fluctuations in excess of 50 Btu/ft^3 (1861 kJ/m^3), a meter in the gas supply or an oxygen meter on the flue gas should be provided.

(c) **Air/Fuel Ratio (High and Low).** If proper metering is installed, this may be permitted to be used to indicate a potentially hazardous air/fuel ratio with an initial alarm indicating approach to a fuel-rich condition and a second alarm indicating approach to a hazardous fuel-rich condition.

(d) **Flame Detector Trouble.** This warns the operator of a flame detector malfunction.

The following legend applies to Figures A-7-5.1.1(a) through A-7-5.1.1(i).

A Burner header shutoff valve
B Individual burner safety shutoff valve
C_1 Burner header atmospheric vent valve
C_2 Individual burner atmospheric vent valve
C_4 Igniter header atmospheric vent valve
C_5 Individual igniter atmospheric vent valve
D Burner header fuel control valve
D_1 Burner header fuel bypass control valve
E Igniter header safety shutoff valve
F Igniter fuel control valve
G Individual igniter safety shutoff valve
H Recirculating valve
I Charging valve (optional — required to be self-closing)
J Constant fuel pressure regulator
K Pressure relief valve
L Leakage test connection
M Flow meter
N Low atomizing media pressure switch
O Strainer or cleaner
P Restricting orifice
Q Low fuel pressure switch
Q_1 Low fuel pressure switch (alternate location)
Q_2 Low fuel supply pressure switch
R High fuel pressure switch
R_1 High fuel pressure switch (alternate location)
R_2 High fuel supply pressure switch
S Pressure gauge
T Manual shutoff valve
U Temperature indicator
V Burner header atmospheric vent valve, manual
W Scavenging valve
Y Check valve
Z Atomizing media pressure regulator
II Circulating valve
QQ Low temperature or high viscosity alarm switch
SS Individual burner supervisory shutoff valve
T_5 Atomizing media shutoff valve

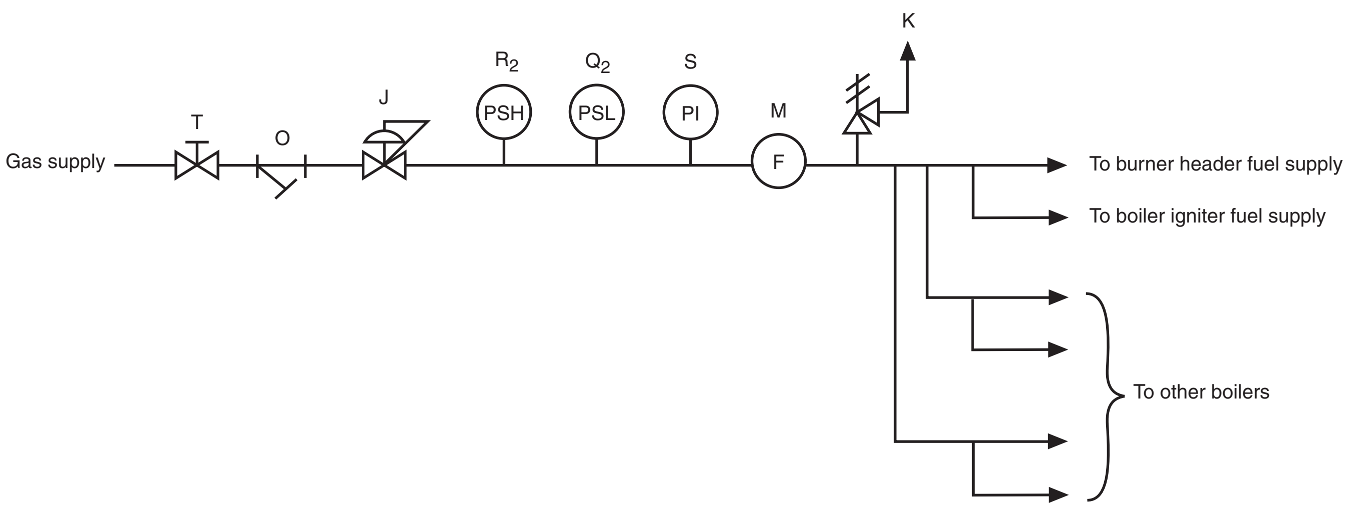


Figure A-7-5.1.1(a) Typical fuel gas supply to powerhouse.

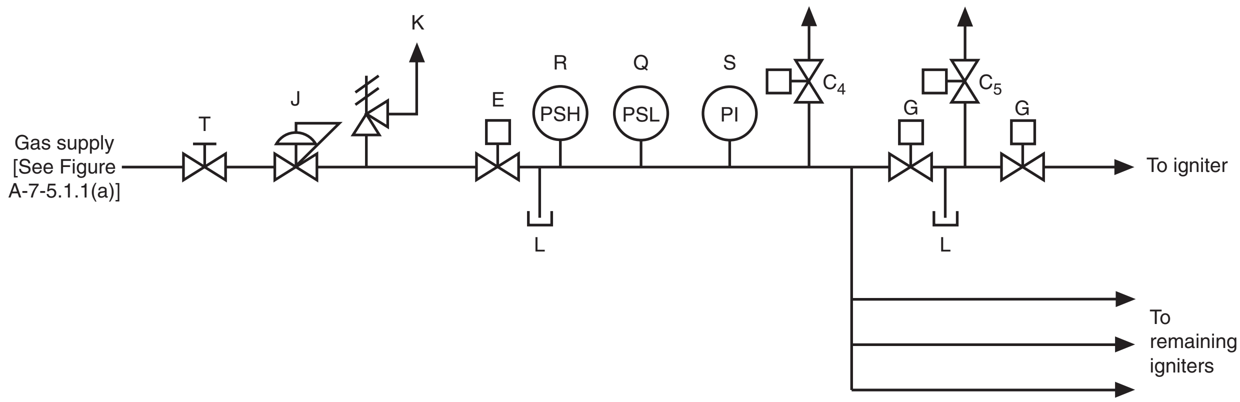


Figure A-7-5.1.1(b) Typical fuel gas ignition system — multiple igniters supplied from a common header (automatic).

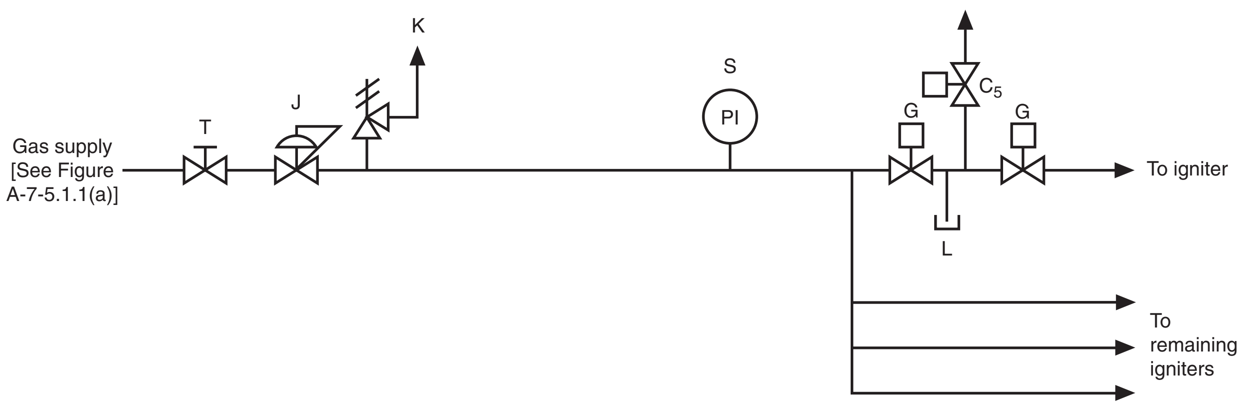


Figure A-7-5.1.1(c) Typical fuel gas ignition system — multiple igniters supplied from a common header (supervised manual).

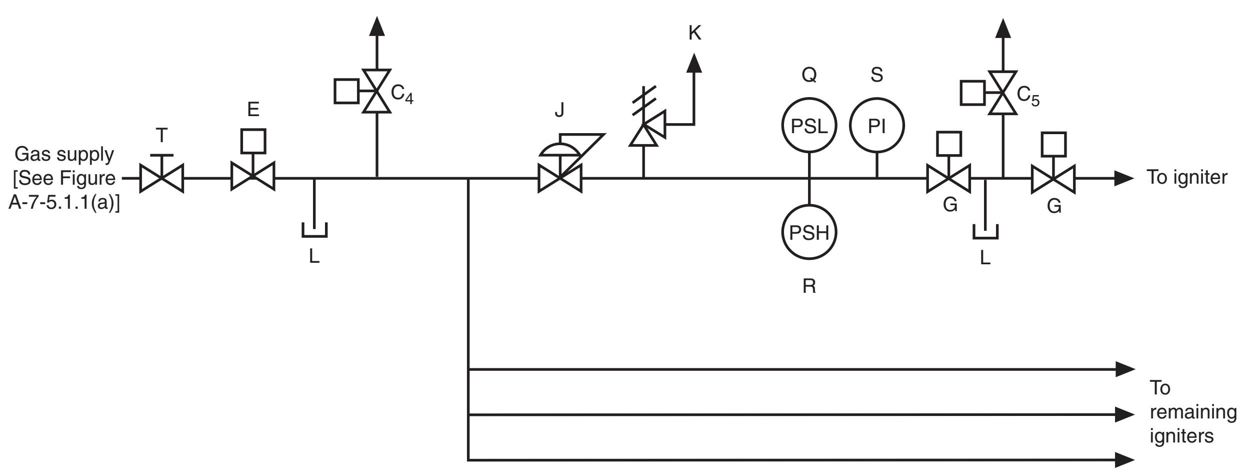


Figure A-7-5.1.1(d) Typical fuel gas ignition system — individually controlled igniters (automatic).