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NFPA 8504
Atmospheric Fluidized-Bed Boiler Operation
1993 Edition

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

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

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

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

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NFPA 8504

Standard on

Atmospheric Fluidized-Bed Boiler Operation

1993 Edition

This edition of NFPA 8504, *Standard on Atmospheric Fluidized-Bed Boiler Operation*, was prepared by the Technical Correlating Committee on Boiler Combustion System Hazards and the Technical Committee on Fluidized-Bed Boilers, and acted on by the National Fire Protection Association, Inc. at its Annual Meeting held May 24-27, 1993, in Orlando, FL. It was issued by the Standards Council on July 23, 1993, with an effective date of August 20, 1993, and supersedes all previous editions.

The 1993 edition of this document has been approved by the American National Standards Institute.

Origin and Development of NFPA 8504

In 1984 the Technical Committee on Boiler-Furnace Explosions started working 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.

This second edition of the document constitutes a major rewrite to address numerous technical issues. Foremost among the changes is the document being renumbered and retitled 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*.

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

Technical Correlating Committee Scope: This committee shall have primary responsibility for documents on the reduction of combustion system hazards in commercial, industrial and utility boilers with a heat input rate of 12,500,000 Btu/hr and above. This includes all fuels or heat inputs except nuclear. Also responsible for documents on reduction of hazards in pulverized fuel systems, and stoker-fired boilers with a heat input rate of 400,000 Btu/hr and above.

Contents

NFPA 8504

Standard on

Atmospheric Fluidized-Bed Boiler Operation

1993 Edition

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

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

Chapter 1 Introduction

1-1 Scope.

1-1.1 This standard applies to boilers with a fuel input rating of 12,500,000 Btu/per hour (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 are necessary 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 is applicable to new installations and to major alterations or extensions of existing equipment for the preparation and burning of fuel contracted subsequent to June 1, 1993.

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 present 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 state 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) offers 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 of requirements concerned with operating procedures, control systems, and interlocks.

1-2.2 No standard can be promulgated that will guarantee the elimination of boiler combustion hazards. Technology in this area is under constant development and will be reflected in future revisions to this standard. The user of this standard must recognize the complexity of fuel firing 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 competent engineering judgment. It is intended that a designer capable of applying more complete and rigorous analysis to special or unusual problems shall have latitude in the development of such designs. In such cases, the designer is responsible for demonstrating the validity of the approach.

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 are required. Such coordination shall include requirements for ensuring a continuous flow path from the forced draft fan inlet through the stack. This standard offers only the general requirements of these systems because of the diverse nature of their designs.

Chapter 2 General

2-1 Basic Cause of Combustion Hazards.

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, which 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 will result in rapid or uncontrolled combustion when an ignition source exists. 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 will depend upon both the relative quantity of combustibles that has accumulated and the proportion of air that is mixed therewith at the moment of ignition. Explosions, including "furnace puffs," are the result of improper procedures by operating personnel, improper design of equipment or control systems, or equipment or control system malfunction.

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

(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 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 too high an airflow, 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) Under certain unusual operating, start-up, or shutdown conditions, it is possible to accumulate combustibles in the windbox and ductwork. 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 reports of boiler explosions suggests that the occurrences of small explosions, "furnace puffs," or near-misses are more frequent than is usually recognized.

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

NOTE: During unit warm-up or operation with a slumped or semifluidized-bed, the unit will 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 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 likely to cause furnace pressure excursions in a fluidized-bed boiler is maloperation of the equipment regulating the boiler gas flow, including air supply and flue gas removal system. 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 offered by hot bed material and refractory.

2-2.3 On the basis of reported incidents and field tests, the maximum negative furnace pressure is primarily determined by the maximum head characteristic of the induced draft fan; a major objective of the final design is to limit draft equipment maximum head capacity to that required for satisfactory operation. Special consideration shall be given to selection of fans and arrangement of ductwork so as 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 needed. A bypass or other appropriate means shall be provided to counteract the potential excessively 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 Insofar as it is practical the purchaser or the purchaser's agent shall, in cooperation with the manufacturer, ensure that the unit is not deficient in apparatus that is required for proper operation, 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, considering 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 actions result in additional operations that increase exposure to hazards.

2-3.4 This standard requires a minimum degree of automation. The trend toward more complex plants or increased automation requires added provisions for:

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

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

(c) An environment that promotes 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 might exist under normal operating conditions.

2-4 Installation.

2-4.1 The boiler shall not be released for operation before the installation and checkout of the required safeguard and instrumentation systems.

(a) The constructor responsible for the erection and installation of the equipment shall ensure that all pertinent apparatus is properly installed and connected.

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

(c) The safety interlock system and protective devices shall be jointly tested and checked by the organization responsible for 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 Human error is a contributing factor in the majority of furnace explosions. Therefore, 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 human-machine relationships that will exist during the operating life of the system.

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

2-5.4 The proper integration of the various components consisting of 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:

(a) Providing design and operating personnel who possess a high degree of competence in this field and who are required to bring about these objectives.

(b) Periodically analyzing the plant's status with respect to evolving technology so that improvements for greater safety and reliability can be implemented.

(c) Maintaining documentation of plant equipment, systems, and maintenance activities.

2-6 Maintenance Organization.

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

2-7 Basic Operating Objectives.

2-7.1 Basic operating objectives shall include the following:

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

(b) Standardize 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 these 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 safely and effectively operate the equipment. 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 is responsible for periodic retraining of operators, including review of their competence.

2-8.1.4 The training program and manuals shall be periodically reviewed and kept current with changes in equipment or operating procedures. The training program and manuals covering operating and maintenance procedures should 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 whenever there is a potential for an unsafe condition that may lead to personnel danger or property damage. They 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 safely and effectively perform any required maintenance tasks. 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 manufacturers' recommendations. The procedures contained in the training programs shall be periodically reviewed 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 must be heated to a temperature above the autoignition temperature of the main fuel prior to admitting the main fuel to the bed. This is normally accomplished by warm-up burners.

2-9.2 Char Carry-Over. 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 must 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, etc.). 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. Thus, the lack of 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 affects the ignition characteristics of the coal and can affect the minimum bed temperature required prior to admission of coal into the bed. The amount of fines in the coal can also affect its ignition and burning characteristics. The minimum bed temperature permitting the admission of coal into the bed shall account for the range of ignition characteristics.

2-9.4 Waste Fuel Firing. Common hazards are involved in the combustion of waste fuels.

(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 can be even more variable in analysis and burning characteristics than conventional fuels, requiring an evaluation of special fuel handling and burning safeguards.

2-9.5 Warm-up or Auxiliary Load-Carrying Burners. The operating systems and requirements for such 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 – 1600°F (760°C – 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 are required for personnel safety. These hazards include:

(a) Hot solids

(b) Lime

(c) Hydrogen sulfide

(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 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 air supply to a hot bed

(f) Bed solidification as a result of a tube leak.

Chapter 3 Definitions

3-1 Definitions. These definitions apply to this standard.

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

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

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

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.

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

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 or procedures, equipment or materials, the authority having jurisdiction may base acceptance on compliance with NFPA or other appropriate standards. In the absence of such standards, said authority may require evidence of proper installation, procedure or use. The authority having jurisdiction may also refer to the listings or labeling practices of an organization concerned with product evaluations which is in a position to determine compliance with appropriate standards for the current production of listed items.

As-fired. Fuel properties entering a boiler furnace enclosure.

Ash. As a constituent of fuel, noncombustible mineral matter that remains after complete burning of a fuel sample. (*Also see 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 D1857, Standard Test Method for Fusibility of Coal and Coke Ash.*)

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

Atomizer, Mechanical. That 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 "authority having jurisdiction" is the organization, office or individual responsible for "approving" equipment, an installation or a procedure.

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

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 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 any combination thereof, 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 where 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 required velocities, turbulence, and concentration 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 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 can also be used for limited load carrying.

Burner Management System. The 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, finally altering to 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 standard coal, but an almost endless variety as to character and composition. Starting with lignite at one extreme, the other basic classifications are subbituminous, bituminous, and anthracite. For greater detail, see ASTM D388, *Standard for 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 required 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 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 a direction that would increase the error.

Drip Leg. A chamber of ample volume, with suitable clean-out 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.

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

Fans.

Forced Draft (FD) Fan. A device used to mechanically pressurize and supply ambient air to the boiler 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 mechanically remove the products of combustion from the boiler by introducing a negative pressure differential.

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 to ensure that a false indication of flame does not exist.

Flame Envelope. The confines (not necessarily visible) of an independent process converting 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 process in which a bed of granular particles is maintained in a mobile suspension by 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 permit 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 Cutback. An action of the combustion control system to reduce fuel flow where the air/fuel ratio is less than a prescribed value.

Fuel Gas. See LP-Gas and Natural Gas.

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

Fuel Oil. Grades 2, 4, 5, and 6 fuel oils as defined in ASTM D396, *Standard Specifications 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 required to maintain the viscosity range recommended by the burner manufacturer.

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

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 will provide 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 is also used to support ignition under low load or certain adverse operating conditions. The range of capacity of such igniters is generally 4 percent to 10 percent of full load burner fuel input. It shall not be used to ignite 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 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 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 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, providing fuel input directly into the bed.

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

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

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 Systems.* Individual devices and interconnecting wiring.

(b) *Microprocessor-based systems.*

1. Computer hardware, power supplies, input/output (I/O) devices, and interconnections between these systems.
2. 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 required to maintain the viscosity range recommended by the burner manufacturer.

Low Water Cutout. A device arranged to effect a master fuel trip when 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 or relays 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 to 1500 Btu per cu ft (26.1 to 55.9 MJ/m^3), the majority averaging 1000 Btu per cu ft (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. 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 will effectively remove any gaseous combustibles and replace them with air. Purging also can be accomplished by an inert medium.

Purge Rate. A constant flow of not less than 25 percent nor more than 40 percent of the full load volumetric airflow at the point of measurement.

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

Recycle Rate. The mass of material being 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. Used to refer 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.

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.

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

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 requiring 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. (*Also see Air, Primary.*)

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

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

Unit Purge. A flow of air at purge rate 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 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 trip of that fuel or a master fuel trip.

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

Valve, Vent. A valve used to permit 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. of water (+8.7 kPa), but not to exceed 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. of water (-8.7 kPa).

4-1.1.2 The induced draft fan head capability can increase due to significant draft losses beyond the boiler enclosure or for other reasons, such as excessive induced draft fan test block margins. When the induced draft fan test block capability is more negative than -35 in. of water (-8.7 kPa), 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 continuously convert any ignitable 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 properly sized, 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 permit suitable observation, measurements, 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 when prescribed purge procedures are followed.

3. Observation ports shall be provided to permit 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 includes the installation of breakers, cleaning screens, and magnetic separators where necessary. Detection of flow interruption and means of 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 properly transport the material 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 least at the same rate that it is 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 that 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 will 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 shall not prevent an appropriate shutdown.

4-3.2 Specific Requirements. As a minimum, the following 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.

4-3.2.1 Failure Effects. The logic system designer shall recognize the failure modes of components when considering the design application of the system. As a minimum, the following failure effects 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) Addressing errors

(g) Processor faults.

4-3.2.2 Design.

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

(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 impact on the application.

(f) Noise immunity shall be adequate to prevent false operation.

(g) A 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 independently and directly actuate the master fuel trip relay. (*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).*]

4-4 Combustion Monitoring and Tripping Systems.

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

(a) To bring combustion instability situations to the attention of the operator for remedial action; and

(b) To automatically initiate an emergency shutdown of the involved equipment upon detection of serious combustion problems likely to lead to 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. 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 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 throughout the 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 throughout the operating range of the boiler.

NOTE: To maintain a proper air/fuel ratio, the use of gravimetric- 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 fluidized before fuel is admitted to the bed. (*See Appendix B.*)

4-5.2.2 Capability shall be provided 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 When 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 prohibit provisions for air lead and lag during changes in fuel firing rate. Fuel flow control set on automatic without the airflow control set on automatic shall be prohibited and interlocked.

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

4-5.2.4 The control system shall prevent 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 permit as much on-line maintenance of combustion control equipment as practical.

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

4-5.2.9 Flue gas oxygen analyzers shall be provided for use as an operating guide. Consideration shall also 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 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 adequate for all operating requirements of the unit. These include coordination of fuel control valve, burner safety shutoff valves, and associated piping volume to ensure against 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 outside the boiler room shall be arranged to prevent excessive fuel gas pressure in the fuel burning system, even in the event of 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 operating environment and ambient conditions, including severe external conditions such as fire or mechanical damage. Special attention shall be given to routes of piping, valve locations, etc., to minimize exposure to explosion hazard or high temperature sources.

4-6.1.6 As much of the fuel subsystem as practical 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 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. These shall include providing 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 hazard. Each header vent line shall be run independently. The vents from the individual igniters, burners, and lances shall be permitted to be manifolded. However, the vents for each subsystem (i.e., igniter, burner, and lance) shall be run independently. There shall be no cross connection between venting systems of different boilers.

Exception: Special provisions shall be made for systems using LP-Gas or gases heavier than air.

4-6.1.10 Shutoff valves shall be located as close as practical to the igniters, burners, or lances to minimize the volume of fuel downstream of the valve.

4-6.1.11 Gas piping materials and system design shall be in accordance with NFPA 54, *National Fuel Gas Code*, and ANSI B31.1, *Code for Pressure Piping—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 adequate for all operating requirements of the unit. These include coordination of 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 as a result of 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, etc., shall be provided to remove harmful contaminants where practical; materials not removed shall be accommodated by special operating and maintenance procedures. Contaminants in fuel might 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 routes of piping, valve locations, etc., to minimize exposure to possible explosion hazard or to high temperature or low temperature sources. Low temperature may 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 practical 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 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 permit safe discharge of oil or vapors. This piping might have to be heat traced.

4-6.2.9 Shutoff valves shall be located as close as practical 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, *Code for Pressure Piping—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 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. These 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 proper temperature and pressure as recommended by the burner manufacturer to ensure proper atomization.

4-6.2.15 If 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. These systems shall be designed and operated to prevent excessively hot oil from entering fuel oil pumps that could cause them to vapor-bind, causing subsequent interruption to the fuel oil supply.

4-6.2.17 Positive means shall be provided to prevent fuel oil 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 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 notice shall be taken of the fire hazards imposed by leakage or rupture of piping near the burner. 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 in its design. Igniters are designated by 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 shall also 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 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 will 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 are 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 supervision shall include 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, that individual burner safety shutoff valve shall be automatically closed.

(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, warning the operator of potential hazard.

(e) Field testing is 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 are not intended to 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.* Flame detector sighting shall be considered in the initial burner design. Field tests are required to establish optimum sighting angles of burners or nozzles and also to check 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 have the potential to fail in the flame-proven mode, self-checking features shall be provided.

(d) 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) Capability shall be provided for setting minimum and maximum limits on the warm-up burner fuel and air control subsystems to prevent fuel and airflows beyond the stable flame limits of the burner(s). These minimum and maximum limits shall be defined by the burner manufacturer and verified by operating tests. (*See 7-3.2.*)

(d) The control system shall prevent demand for a fuel-rich mixture while in 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 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) It shall be permitted to supply a group of lances 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 burner shutoff valves, dampers, etc., that operate at speeds faster than the speed of response of other components in the system. These tests shall include the expected range of fuels.

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 maximum unit load shall be provided at the operating location. Continuous, simultaneous trend displays shall also 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 offers 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) Design the boiler enclosure, the air supply system, and flue gas removal system 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) Provide a furnace pressure control system in accordance with Section 5-2 and a furnace design as specified in 4-1.1.

NOTE: For the purpose of discussion within this chapter, 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 advisable in order to properly apply the provisions of this chapter to a specific unit. Some special considerations include:

1. Multiple air sources at different locations (i.e., primary air fans, secondary air fans)
2. The isolating effect of a slumped bed
3. 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. *(Refer to Figure 5-2.2.)*

5.2.2.1 The furnace pressure control subsystem (A) shall position the draft regulating equipment to maintain furnace pressure at the desired set point.

5-2.2.2 The control system 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), representative of 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).

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

NOTE: Purge air may be required 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.

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.

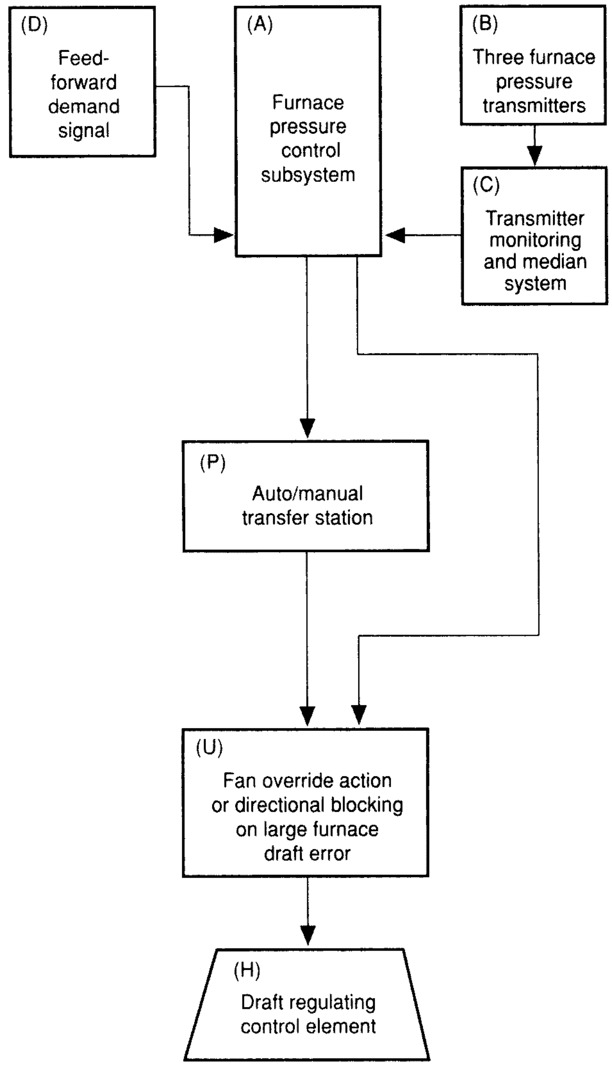


Figure 5-2.2 System requirements.

5-3 Sequence of Operations.

5-3.1 Functional Requirements.

5-3.1.1 The purpose of sequencing requirements is to ensure that the operating events occur in the proper order and not to provide fan operating procedures. The proper fan start-up and shutdown procedures are defined 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 permit the use of wide open air paths, the minimum open area air paths shall be not less than that required for purge airflow requirements 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 open 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, 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, maintaining furnace pressure conditions, and indicating 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) Start an induced draft fan, and then start a forced draft fan. 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 and maintained on automatic control as soon as practical.

5-3.1.5 Following shutdown of the last fan due to any cause, 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 if they 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 furnace pressure exceeds the normal operating pressure by a value recommended by the manufacturer. If fans are operating after trip, continue in service. Do not increase the airflow by deliberate manual or automatic control action.

2. Before main fuel firing and following a master fuel trip, trip forced draft fans if the furnace positive pressure exceeds the normal operating pressure by a value recommended by the manufacturer. The value of 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 if furnace negative pressure exceeds the normal operating pressure by a value recommended by the manufacturer. If fans are operating after trip, continue in service. Do not increase the airflow 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 main fuel firing and following a master fuel trip, trip all induced draft fans if furnace negative pressure exceeds the normal operating pressure by a value recommended by the manufacturer. The value of 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. Provide an interlock to prove each forced draft fan is running and capable of providing the required flow. Loss of this verification shall initiate appropriate loss of forced draft fan interlocks. Variable speed and axial flow fans might require special provisions.

2. Close damper(s) 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 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, unless they are 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. Initiate master fuel trip 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. Provide an interlock to prove each induced draft fan is running and capable of providing the required flow. Loss of this verification shall initiate appropriate loss of induced draft fan interlocks. Variable speed and axial flow fans might require special provisions.

2. Close damper(s) on loss of an individual induced draft fan, unless it is the last induced draft fan in service.

3. Where an interlock system is provided to start, stop, and trip induced draft 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, unless they are the last fans in service.

4. Initiate master fuel trip on loss of all induced draft fans. Trip all forced draft fans. 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 start of the first induced draft and forced draft fans, any subsequent fan(s), whether forced draft or induced draft, 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 is to ensure that operating events occur in proper order. This permits properly prepared fuel to be admitted to the fluidized-bed combustion zone only when there is sufficient bed mass and temperature, and correct 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 The sequences are based on the typical safety interlock system shown in Figure 9-3.1.(b). These sequences shall be followed whether the unit is operated manually or certain functions are accomplished by interlocks or automatic controls. Different arrangements shall be permitted if they provide equivalent protection and meet the intent of the following operating sequences.

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. Sufficient ignition energy remains in the bed material and refractory, provided the average bed temperature remains above the ignition point, 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 require a restrictive pattern of bed start-up and shutdown and not allow random bed operation. In such cases, bed sequencing shall be defined 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 in accordance with the following basic operating conditions, which will significantly improve the margin of operating safety, particularly during start-up.

(a) Minimize the number of required equipment manipulations, thereby minimizing exposure to operating errors or equipment malfunction.

(b) Minimize the hazard of dead pockets in the gas passes and the accumulation of combustibles 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 operating objectives:

(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 must 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 (1) a period of not less than 5 minutes, or (2) 5 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 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 require slumping 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 recommended by the manufacturer.

(f) Fuel input that requires ignition by the bed material shall not be fed into the bed until the average bed temperature has reached 1400°F (760°C). A lower fuel input temperature limit shall be permitted, provided the temperature has been verified through test or actual experience to safely ignite 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 objectives specified in 6-1.5.1 are required in order to obtain satisfactory ignition or to satisfy other design limitations during light-off and warm-up. However, unnecessary modifications in the basic procedure shall be avoided, thereby satisfying the basic objectives of 6-1.5, particularly that 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, particularly to verify the following:

(a) Furnace and gas passages in good repair and free of foreign material

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

(c) All air and flue gas flow control dampers operated through full range to check operating mechanism

(d) All normally adjustable individual burner dampers or registers operated through full range to check operating mechanism

(e) All safety shutoff valves operational and closed and ignition sparks deenergized

(f) Feeder equipment effectively isolated to prevent leakage of fuel or sorbent into furnace and leakage of hot air or flue gas from fluidized-bed back into feed system

(g) Proper drum water level established; circulating flow established in forced circulation boilers

(h) Feeders and associated equipment in good condition and properly adjusted for service

(i) Energy supplied to control system and to safety interlocks

(j) Oxygen analyzer and carbon monoxide or combustibles analyzer, if provided, operating satisfactorily; carbon monoxide or combustibles indication at zero and oxygen indication at maximum

(k) Complete functional check of the safety interlocks made, at minimum, after overhaul or other significant maintenance

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

(m) Proper bed inventory in furnace; bed charged if required.

NOTE: If no bed inventory material is available at start-up, consideration should be given to use of an inert material such as sand to reduce the hazard of calcium oxide to maintenance personnel (should it be 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:

NOTE: The sequence order may be varied if recommended by the boiler manufacturer.

(a) Prepare the unit for operation. Ensure adequate cooling water flow to critical components. Ensure that the plant air, instrument air, and service steam systems are operational.

(b) Verify an open flow path exists from the inlet(s) of the forced draft fans through the furnace space, and to the stack.

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

(d) Start an induced draft fan, then start forced draft fan(s) in accordance with the manufacturer's instructions. Some systems might require starting additional equipment prior to starting fans. (Follow manufacturer's recommended fan-start procedure.) Start additional induced draft or forced draft fans in accordance with Chapter 5.

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

(f) Purge the bed and boiler enclosure 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 is not 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 recommendations on gas recirculation fan operation during purge and light-off shall be followed.

(h) Establish proper bed height if required at this time 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.

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

1. The bubbling fluidized-bed process might require 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 recommendations.

2. Combustion airflow through the bed can be reduced to the level required 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 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. Continue heating the bed at a rate recommended by the manufacturer. Maintain proper bed level by adding sorbent or inert solids as needed.

6. Fuel input that requires 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). A lower fuel input temperature limit shall be permitted, provided the temperature has been verified through test or actual experience to safely ignite the fuel. 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. Warm-up burners shall remain in service until the stable ignition of this fuel has been established. *(See Appendix B.)*

7. Maintain duct temperature within the manufacturer's recommended limits.

8. Ensure that the fuel is igniting by watching for a steady increase in bed temperature and a decreasing oxygen level. Increase fuel flow to maintain bed temperature as required. Increase airflow as necessary to maintain the desired oxygen level. For solid fuel, if 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. Expand the active bed area by activating idle bed sections according to steam load demands by following manufacturer's suggested 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 recommendations of the manufacturer shall be followed.

2. After placing the first bed warm-up burner in service, heat the bed material and refractory at the manufacturer's recommended rate.

3. Add warm-up burners, if required, to maintain the required bed heat-up rate. Place any fans and blowers that might have been shut down for the warm-up cycle back in service when the bed temperature reaches the required temperature permit. Prepare to admit main fuel.

4. Fuel input requiring ignition by the bed material shall not be fed into the bed until the average bed temperature has reached 1400°F (760°C). A lower fuel input temperature limit shall be permitted, provided the temperature has been verified through test or actual experience to safely ignite the fuel. 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. Warm-up burners shall remain in service until the stable ignition of this fuel has been established. *(See Appendix B.)*

5. Ensure that the fuel is igniting by watching for a steady increase in bed temperature and a decrease in oxygen. Remove warm-up burners and increase fuel flow to maintain bed temperature at the recommended level. Increase airflow as necessary to maintain the desired oxygen level. For 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) Automatic Operation. 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 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 does not prohibit provisions for air lead and lag during changes in fuel firing rate.

6-2.2.2 For those applications firing gas or oil, 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 wide 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. 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, remove feeder(s) (and associated bed sections if applicable) from service. Operate the remaining feeder(s) 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 required warm-up burner(s) are 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 volumetric 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 shall be brought down to a minimum load.

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

(a) If the unit is scheduled to be out of operation for a significant period of time, trip the main fuel and allow the forced draft and induced draft fans to remain in operation. Following a 5-minute postpurge, allow fans to operate until unit is sufficiently cooled for maintenance.

(b) If the unit is scheduled to be restarted soon, the fans can 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 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 shall not be required prior to introduction of main fuel if the bed temperature is above the main fuel temperature specified in 6-1.5.1(f).

NOTE: The bed temperature measurement is only valid when 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 deenergized. 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 will not permit 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 and induced draft fan trip. [*See 6-2.3.2(b).*] Where design permits, char recirculation shall be stopped.

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

(a) Loss of any induced draft or forced draft fan required to sustain safe combustion. (*See Chapter 5.*)

(b) Furnace pressure greater than 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) Whenever the total airflow drops below the purge rate by 5 percent of the full load volumetric airflow.

(f) Bed temperature below value specified in 6-2.2.5 when main fuel is being admitted to bed and no start-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 Automatic

(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 less than 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 required.

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 require 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. Do not immediately increase the airflow 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 Tables 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) 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 Automatic

(a) 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 main fuel, reduce the fuel until the proper air/fuel ratio has been restored.

6-3.3 Momentary interruptions in 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. If 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 return 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 Gas-Fired Warm-up Burners, Sequence of Operations

7-1 General. This chapter contains the 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 cannot usually 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 makes it possible to experience severe departures from proper air/fuel ratios that can progress to a hazardous condition without any visible evidence at the burners, furnace, or stack. Thus, 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 carry-over 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. (*See NFPA 54, National Fuel Gas Code.*)

(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. (*See NFPA 54, National Fuel Gas Code.*)

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 burning characteristics of the fuel, and the normal variations in fuel handling 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 burner shutoff valves, dampers, etc., 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 Provisions 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 in 4-6.3.2.2(b), 4-6.3.2.2(c), and 7-3.2 shall also 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 turndown 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. Requirements of good housekeeping shall be practiced.

7-3.6 All burner safety shutoff valves shall be located as close as practical 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 individually supervised. Upon detection of loss of flame on a burner, that individual burner safety shutoff valve shall be automatically closed.

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 sequences are based on the typical fuel supply system shown in Figures A-7-5.1.1(a) through (i). Different arrangements shall be permitted if they provide equivalent protection and meet the intent of the operating sequences specified in this chapter.

7-5.1.2 Burners shall be placed in service in a sequence defined by operating instructions and verified by actual experience. Burners shall be placed in service as required, 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 required 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 required to accomplish the following within the rate of rise limits defined 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 procedure specified in 7-5.2 are required 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 procedure shall be avoided, thereby satisfying the basic objectives set forth in Section 6-1, particularly that of keeping the number of equipment manipulations to a minimum.

7-5.2 Functional Requirements.

7-5.2.1 Cold Start.

7-5.2.1.1 Preparation for starting shall include a thorough inspection, particularly for the following:

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

(b) For oil ignition systems, see Chapter 8

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

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

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

(f) Energy supplied to control systems and to safety interlocks

(g) Meters or gauges 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) If a charging valve (required self-closing) on the main gas supply is furnished, it shall be opened in conjunction with the furnace purge to bypass the main safety shutoff valve. Open main fuel control valve(s). Vent the burner supply piping or header until it is filled with gas. Close burner header or supply piping atmospheric vent valve(s). Leave charging valve open until the gas pressure on the burner supply piping or header is raised sufficiently so that a significant drop in pressure can be detected using a switch or transmitter after the main safety shutoff valve and charging valve are closed. If any significant leakage occurs during the purge, this pressure will decrease and shall trip the system. This step is normally performed as a part of the unit start-up and purge [see 6-2.1.2(a) through (h)]. In any case, the leak test shall prove no leakage for a period not less than 5 minutes prior to proceeding to 7-5.2.1.2(b).

(b) Close all fuel valve(s) and open the safety shutoff valve(s). See 9-3.2 for permissive conditions in the furnace purge system that shall be satisfied before this can be accomplished.

(c) Verify that all burner fuel control valve(s) are set for light-off. Depending on system design, this shall be accomplished by (1) burner control valve closed with a bypass valve opened to a light-off setting, or (2) burner control valve set 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) shall regulate and maintain the correct fuel pressure or flow for burner light-off.

(d) Open the igniter header safety shutoff valve, and verify that the igniter fuel control valve is holding the recommended fuel pressure for proper igniter capacity. The igniter headers shall be vented to fill them with gas and to provide a flow (if necessary), so that the igniter fuel control valve can function to regulate and maintain the correct pressure for lighting the igniters.

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

(f) Initiate the spark or other source of ignition for the igniter(s) on the burner(s) to be lit. Open the individual igniter safety shutoff valve(s), and close all igniter system atmospheric vent valves. If flame on first igniter is not established within 10 seconds, close the individual igniter safety shutoff valve(s) and determine and correct the cause of failure to ignite. With airflow maintained at purge rate, repurge is not necessary, but a waiting period of 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), open the individual burner safety shutoff valve(s), and close the individual burner atmospheric vent valves. A master fuel trip shall be initiated when the bed temperature is below the main fuel ignition temperature as defined in 6-1.5.1(f) and when satisfactory ignition has not been obtained within 5 seconds following fuel actually entering the burner. Repurge and correct the conditions that caused the failure to ignite before another light-off attempt is made. For the next 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, return the air register(s) or damper(s) 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 main flame. Verify that the stable flame continues on the main burners after the igniters are shut off. 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 proper associated interlocks.

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

(l) Follow the procedures of 7-5.2.1.2(e) through (j) for placing additional burners in service, as required, to increase bed temperature, raise steam pressure, or to 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 required for complete combustion in the furnace.

(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. 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 over 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 that the igniters are supervised, so that failure of one of the group to light shall cause 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 shall cause 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 prohibit provisions for air lead and lag during changes in fuel firing rate.

Exception No. 1: This 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 valves shall be wide 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 the 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 (1) with all burners in service and combustion control on automatic, and (2) 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 if 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 Follow the reverse procedure of that used during start-up. Shut down burners 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. The following fuel trips shall be required:

(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

(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, reduce the fuel until the proper air/fuel ratio has been restored. If fuel flow cannot be reduced, slowly increase airflow until proper air/fuel ratio has been restored.

7-5.5 General Operating Requirements — All Conditions.

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

7-5.5.2 When operating at low capacity with multiple burners controlled by one master flow control valve, maintain a burner fuel pressure 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 alarms in the interlock system shown in Chapter 9, the following separately annunciated alarms 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 indicate 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 possible in order to warn the operator, in advance of trip conditions, of abnormal fuel pressures. Furnace pressure fluctuations at burner throat shall be considered in determining location of and 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 possible 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 alarmed 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 standards for design, installation, and operation of individually controlled warm-up burners operated from the burner location and describes functional requirements for proper operation. No specific degree of automation beyond the minimum specified safeguards is defined or required, as this is subject to many factors, such as physical size of units, use of central control rooms, degree of reliability required, availability of experienced operating manpower, etc.

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; and

(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 required for continuous combustion and stable flame throughout the controllable operating range of the burner.

NOTE: Minimum recommended equipment is shown in Figures A-7-5.1.1(a) through (i).

7-8.1.2 System Description. This operating system is defined as "supervised manual." 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 indication of the status of the start-up sequence. In this type of system, the operator(s) shall be provided with and be required to operate 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) Purge the unit in accordance with 6-2.1.2(f).

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

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

Exception: For direct electric (Class 3 Special) igniters, (c) does not apply.

(d) The operator shall continuously observe igniter operation 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. Verify the stability of the burner flame.

(f) The burner(s) shall only be lighted 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 immediately close the individual burner supervisory shutoff valve, 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.

7-8.1.4.1 Any of the following conditions shall cause a burner fuel trip (*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 if 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 associated sparks to deenergize.

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 shall be indicated.

NOTE: Recommended additional alarms are listed in A-7-7.2.

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 equivalent 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 7-8.1.4.1 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 required;	(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 (e);	(d) Prove flame within 10 seconds. If flame is not proved, safety shutoff valves for this igniter shall close and spark shall be deenergized;
(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 required;	(a) Prove that airflow rate is not less than purge rate;
(b) Energize igniter. For direct electric igniters, omit (c);	(b) Prove flame within 10 seconds. If flame is not proven, safety shutoff valves for this igniter shall close, and spark shall be deenergized;
(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.

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 safety supply shutoff valve to close;
(c) Purge burner for at least 1 minute. Adjust burner airflow per manufacturer's instructions;	(c) None;
(d) Repeat (a) through (c) for subsequent burners.	(d) None.

7-8.2.5 Emergency Shutdown.

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

(b) For the conditions that shall accomplish an emergency shutdown, see 7-8.1.4.1.

7-8.2.6 Operator Actions Following an Emergency Shutdown.

(a) Close all individual burner supervisory shutoff valves. Leave burner register positions unchanged.

(b) The burners shall be purged in accordance with the following procedure: Fans that are operating after the burner fuel trip shall be continued in service. Do not immediately increase the airflow by deliberate manual or automatic control action. If the airflow is above purge rate, it shall be permitted to be gradually decreased to this value and a post-firing burner purge shall be performed. 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 gradually increased to purge rate and held at this value for a post-firing unit purge.

(c) If the burner fuel trip is caused by loss of draft fans, or draft fans have also tripped, slowly open all dampers in the air and flue gas passages of the unit to the wide 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 coastdown. Maintain this condition for a period of not less than 15 minutes. At the end of this period, close the flow control dampers and immediately start the fan(s). Gradually increase airflow to at least purge rate.

(d) Determine cause of emergency shutdown and correct.

(e) Proceed with light-off cycle (*see 7-8.2.2*) if restart of unit is required.

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

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

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) When firing oils that require 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 single 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 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 will result 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 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 upon:

1. Rapid operation of the oil supply valve.
2. Rapid operation of individual burner shutoff valves.
3. Rapid operation of the regulating valve in the return oil line from the burner header (on systems using this type of control).

(j) 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 the normal variations in fuel handling 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 adversely affect the burners in operation. Such transients are generated by burner shutoff valves, dampers, etc., 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 shall also 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 turn-down 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 integrity of flexible hoses or swivel joints. Requirements of good housekeeping shall be practiced.

8-3.7 All burner safety shutoff valves shall be located as close to the burner as practical to minimize the volume of oil that might be left downstream of the burner valve in the burner lines or that might flow 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, this 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 required 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 individually supervised. Upon detection of loss of flame on a burner, that individual burner safety shutoff valve shall be automatically closed.

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 sequences of operations are based on the typical fuel supply system shown in Figures A-8-5.1.1(a) through (p). Different arrangements shall be permitted if they provide equivalent protection and meet the intent of the operating sequences specified in this chapter.

8-5.1.2 Burners shall be placed in service in a sequence defined by operating instructions and verified by actual experience. Burners shall be placed in service as required, 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 required 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 required to accomplish the following within the rate of rise limits defined 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 procedure specified in 8-5.2 are required 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 procedure shall be avoided, particularly that of keeping the number of equipment manipulations to a minimum. (*See Section 6-1.*)

8-5.2 Functional Requirements.

8-5.2.1 Cold Start.

8-5.2.1.1 Preparation for starting shall include a thorough inspection, particularly for the following:

(a) Energy supplied to control system and to safety interlocks

(b) All safety shutoff valves closed; all sparks deenergized

(c) For gas ignition systems, see Chapter 7

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

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

(f) Burner guns checked for proper tips or sprayer plates

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

(h) Meters or gauges 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) Verify that oil temperature or viscosity is adequate for good atomization. Close circulating valve and throttle recirculating valve, if required, to permit establishment of proper burner header pressure in accordance with 8-5.2.1.2(c).

(b) Close all fuel valve(s) and open the safety shutoff valve(s). See 9-3.2 for permissive conditions in the furnace purge system that shall be satisfied before this can be accomplished.

(c) Verify that all burner fuel control valve(s) are set for light-off. Depending on system design, this shall be accomplished by (1) burner control valve closed with a bypass valve opened to a light-off setting, or (2) burner control valve set to a light-off position.

(d) Open the igniter header safety shutoff valve, and check that the igniter fuel control valve is holding the recommended fuel pressure for proper igniter capacity.

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

(f) Initiate the spark or other source of ignition for the igniter(s) on the burner(s) to be lit. Open the individual igniter safety shutoff valves, and close all igniter system atmospheric vent valves (gas igniters only). If flame on first igniter(s) is not established within 10 seconds, close the individual igniter safety shutoff valves and determine and correct the cause of failure to ignite. With airflow maintained at purge rate, repurge is not necessary, but a period of 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), open the individual burner safety shutoff valve(s). A master fuel trip shall be initiated when the bed temperature is below the main fuel ignition temperature as defined in 6-1.5.1(f) and when satisfactory ignition has not been obtained within 5 seconds following fuel actually entering the burner. Repurge and correct the condition that caused the failure to ignite before another light-off attempt is made. For the next 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, return the air register(s) or damper(s) 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 main flame. Verify that the stable flame continues on the main burners after the igniters are shut off. 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 proper associated interlocks.

(k) Follow the procedures of 8-5.2.1.2(e) through (j) for placing additional burners in service, as required, to increase bed temperature, steam pressure, or to 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 required for complete combustion in the furnace.

(l) After a suitable number of burners have been placed in service to allow control of header fuel flow and temperature, close the recirculating valve 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. 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 over 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 shall cause 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 shall cause 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, and maintaining normal air/fuel ratio continuously at all firing rates. This shall not prohibit provisions for air lead and lag during changes in fuel firing rate.

Exception No. 1: This 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 valves. The individual burner safety shutoff valves shall be wide 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 the 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 (1) with all burners in service and combustion control on automatic, and (2) 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 if 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 Follow the reverse procedure of that used during start-up. Shut down burners sequentially as load is reduced.

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

(a) Place the igniter 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 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 unless cooling is provided.

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

(a) Confirm that individual burner safety shutoff valves are closed and that flame is out on each burner.

(b) Confirm that main safety shutoff valve is closed.

(c) Open circulating valve and recirculating valve.

8-5.3 Mandatory Automatic Fuel Trip for Oil-Fired Warm-up Burners. The following fuel trips are required:

(a) Fuel pressure and temperature (heated oil only) outside operating limits required 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, reduce the fuel until the proper air/fuel ratio has been restored. If fuel flow cannot be reduced, slowly increase airflow until 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 shall always be used. Burners shall not be lighted one from another, from hot refractory, or from bed material.

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

8-5.5.3 Igniters shall be in service with ignition established when 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 with the main and individual burner safety shutoff valves and the recirculating valves closed. It shall be permitted to be concluded that the individual burner safety valves do not leak if this oil pressure remains within defined 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 trip alarms in the interlock system shown in Chapter 9, the following separately annunciated alarms 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 to indicate 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 possible 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 or 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 or 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 possible 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 standards for design, installation, and operation of individually controlled warm-up burners, operated from the burner location and describes functional requirements for proper operation. No specific degree of automation beyond the minimum specified safeguards is defined or required, as this is subject to many factors, such as physical size of units, use of central control rooms, degree of reliability required, availability of experienced operating manpower, etc.

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 accomplished by an operator at the burner locations;

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

(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 required for continuous combustion and stable flame throughout the controllable operating range of the unit.

NOTE: Minimum recommended equipment is shown in Figures A-8-5.1.1(a) through (p).

8-8.1.2 System Description. This operating system is defined as "supervised manual." 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 supervision, and an indication of the status of the start-up sequence. In this type of system, the operator(s) shall be provided with and be required to operate 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) Purge the unit in accordance with 6-2.1.2(f).

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

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

Exception: For direct electric (Class 3 Special) igniters, (c) does not apply.

(d) The operator shall continuously observe igniter operation 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. Verify the stability of the burner flame.

(f) The burner(s) shall only be lighted 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 immediately close the individual burner supervisory shutoff valve, 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. Any of the following conditions shall cause a fuel trip with first-out annunciation (*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, if 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 associated sparks to deenergize.

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 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 might also vary depending on the system installed. However, the principles outlined in these sequences shall be followed, and all applicable interlocks, trips, alarms, or their equivalent 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 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 required;	(b) Prove purge airflow rate;
(c) Energize igniter for first burner. For direct electric ignition, omit (d);	(c) For fuel-fired igniters, prove flame within 10 seconds. If flame not proved, safety shutoff valves for this igniter shall close and spark shall be deenergized;
(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.

Operator Actions [*See Figures A-8-5.1.1(a) through A-8-5.1.1(e)*]	Interlock Functions
(a) Adjust register of burner to be lighted to light-off position, if required;	(a) Prove that airflow is not less than purge rate;
(b) Energize igniter. For direct electric igniters, omit (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 deenergized;
(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;

Operator Actions	Interlock Functions
(d) Open burner shutoff valve 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 (a), (c), and (d) above. 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 (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) shown 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 mandated, is encouraged.

9-1.3 It is possible to experience conditions conducive to a furnace explosion that will not be detected by any of the mandatory automatic trip devices, even if 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 requires sound design, proper installation, adjustment, and testing to ensure 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) Supervise starting procedure and operation to ensure proper operating practices and sequences;

(b) Trip the minimum amount of equipment in the proper sequence where the safety of personnel or equipment is jeopardized;

(c) Indicate the cause of the trip and prevent restarting any portion of the affected equipment until proper conditions are established;

(d) Coordinate the necessary trip devices into an integrated system;

(e) Provide sufficient instrumentation to enable the operator to complete the proper operating sequence where automatic equipment is not provided to accomplish the intended function;

(f) Retain in the design as much flexibility with respect to alternate modes of operation as is consistent with good operating practice;

(g) Permit proper preventive maintenance;

(h) Require no deliberate defeating of an interlock in order to start or operate equipment. Whenever a safety interlock device has been temporarily removed from service, this action 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)* Provide mandatory automatic master fuel trip and mandatory automatic main fuel trip systems, including sensing elements and circuits, that 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; and

Exception: Individual burner flame failure devices also shall be permitted to be used for initiating master fuel trip systems.

(j) Prevent misoperation of the interlock system due to interruption and restoration of the interlock power supply.

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 in block form 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 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 will inform the operator of the initiating cause of trip impulse.

9-3.1.1 Items 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 or all forced draft fans shall operate the master fuel trip device.

9-3.1.2 The loss of an individual induced draft or forced draft fan shall cause an immediate runback in unit fuel input in order to maintain the proper air/fuel ratio. This may be interlocked or made a part of the combustion control system [item 13 of Figure 9-3.1(b)].

9-3.1.3 Furnace pressure high (item 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 (item 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 (item 10) as defined in 6-1.5.1(f) and warm-up burner flame not proven (item 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 (Item 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 bed temperature exceeds the temperature permit level for admitting fuel.

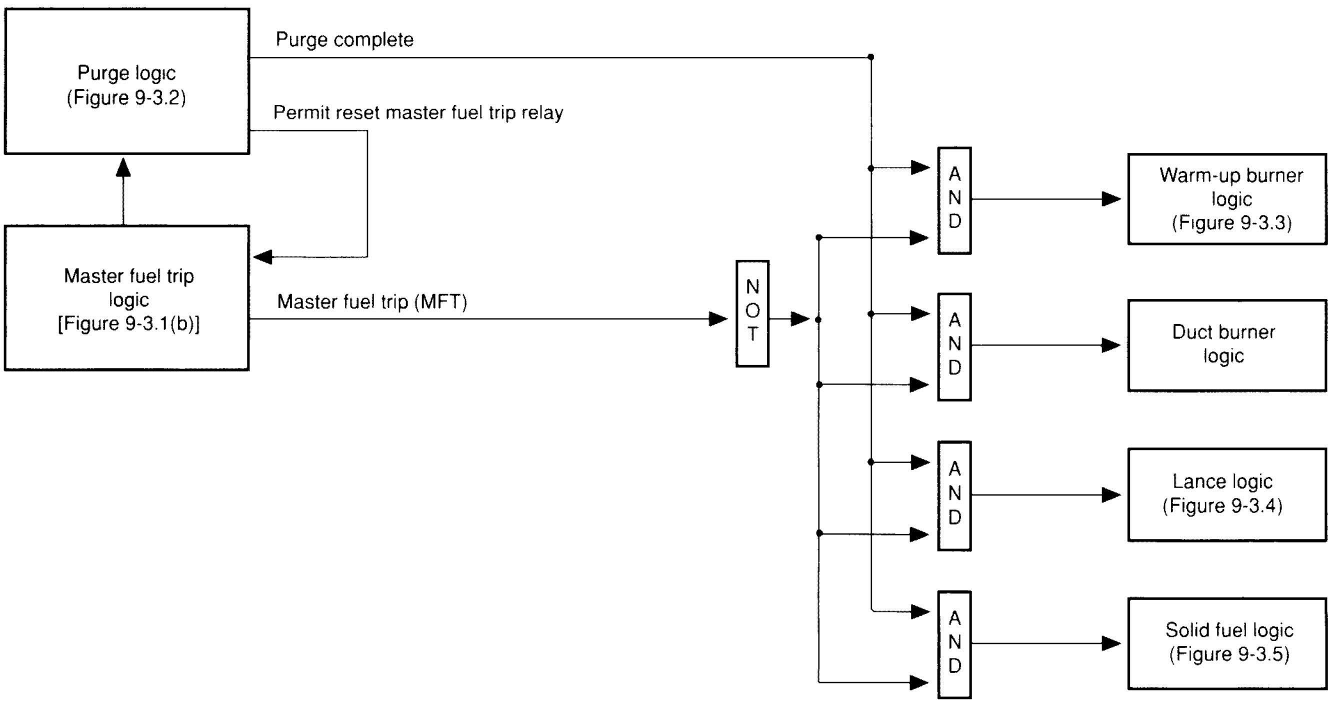
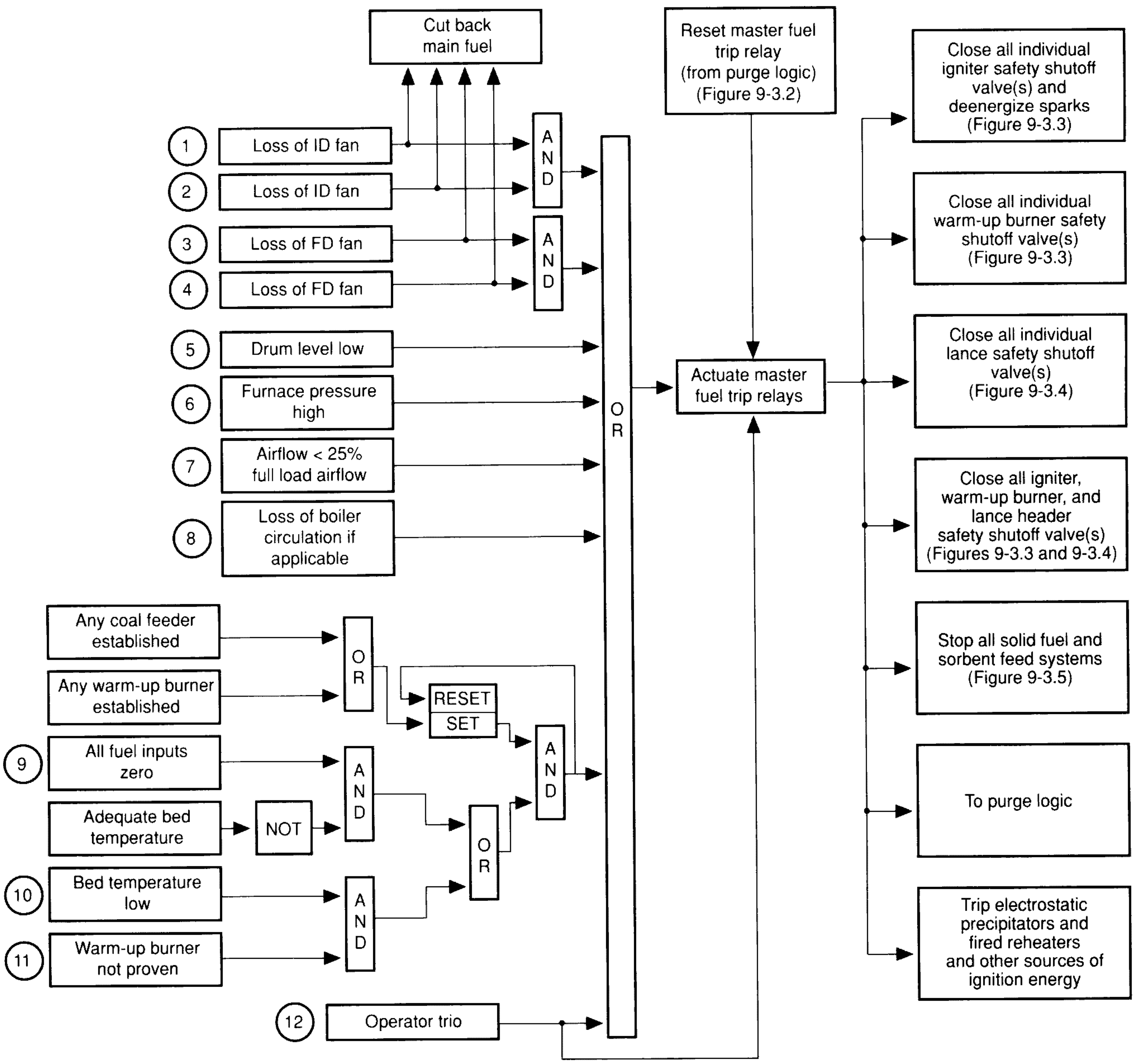


Figure 9-3.1(a) Interlock system overview.



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.

9-3.1.7 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.

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 directly trip all sources of solid fuel input, close all safety shutoff valves, deenergize all igniter sparks, and deenergize 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.

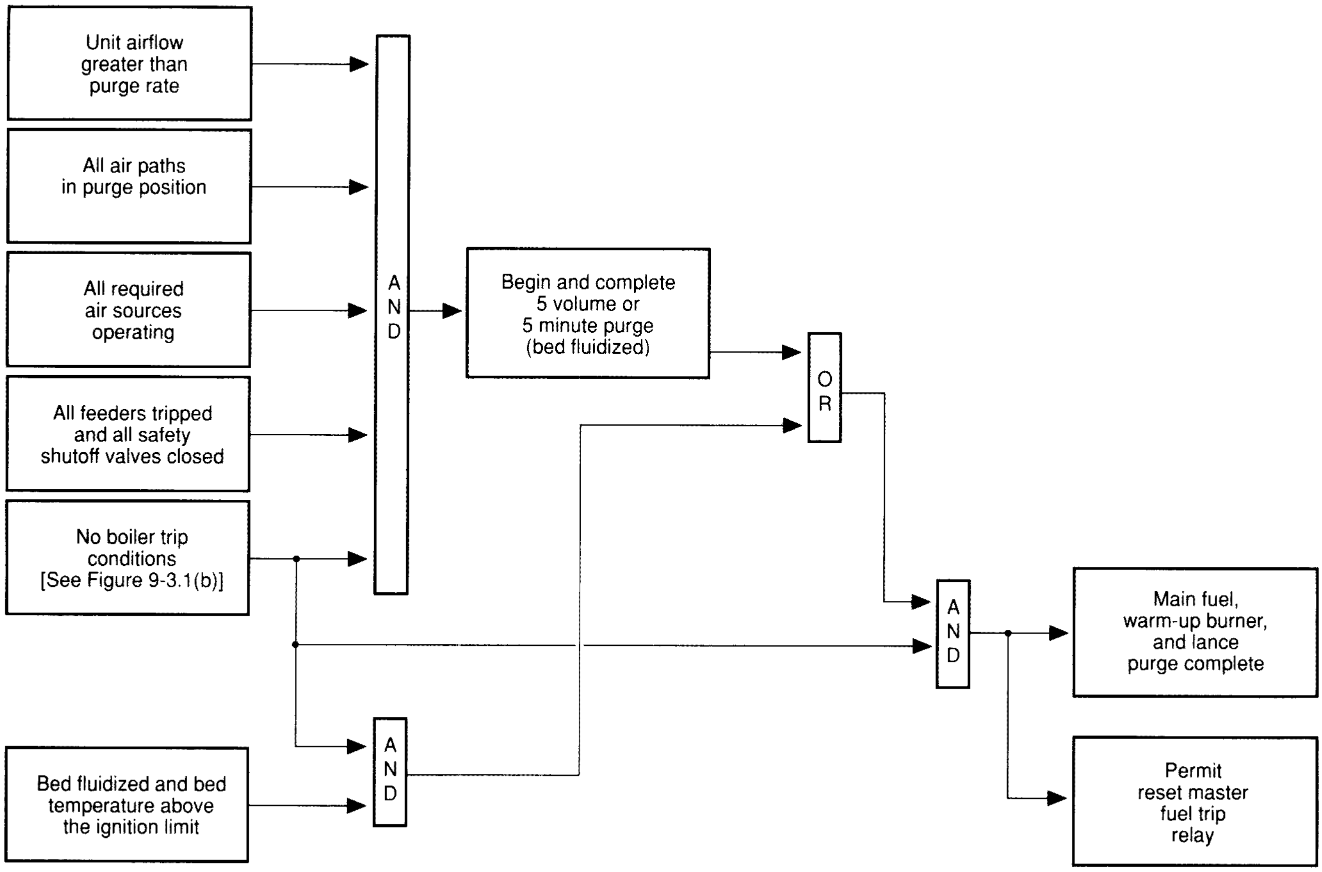


Figure 9-3.2 Purge logic.

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 is required.

9-3.2.3 Hot Restart. If operating conditions at the time of reset are such that the bed temperature permits for 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 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 a unit purge has been completed and the master fuel trip relay has been reset. (*See Figure 9-3.3.*)

9-3.3.1 Loss of 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 deenergize associated sparks.

9-3.3.2 Improper warm-up burner fuel pressure shall be interlocked so as to initiate the tripping of the individual warm-up burner safety shutoff valves and deenergize the spark. Where gas is used for fuel, both high and low pressure shall be interlocked. Where oil is used, low pressure shall be interlocked.

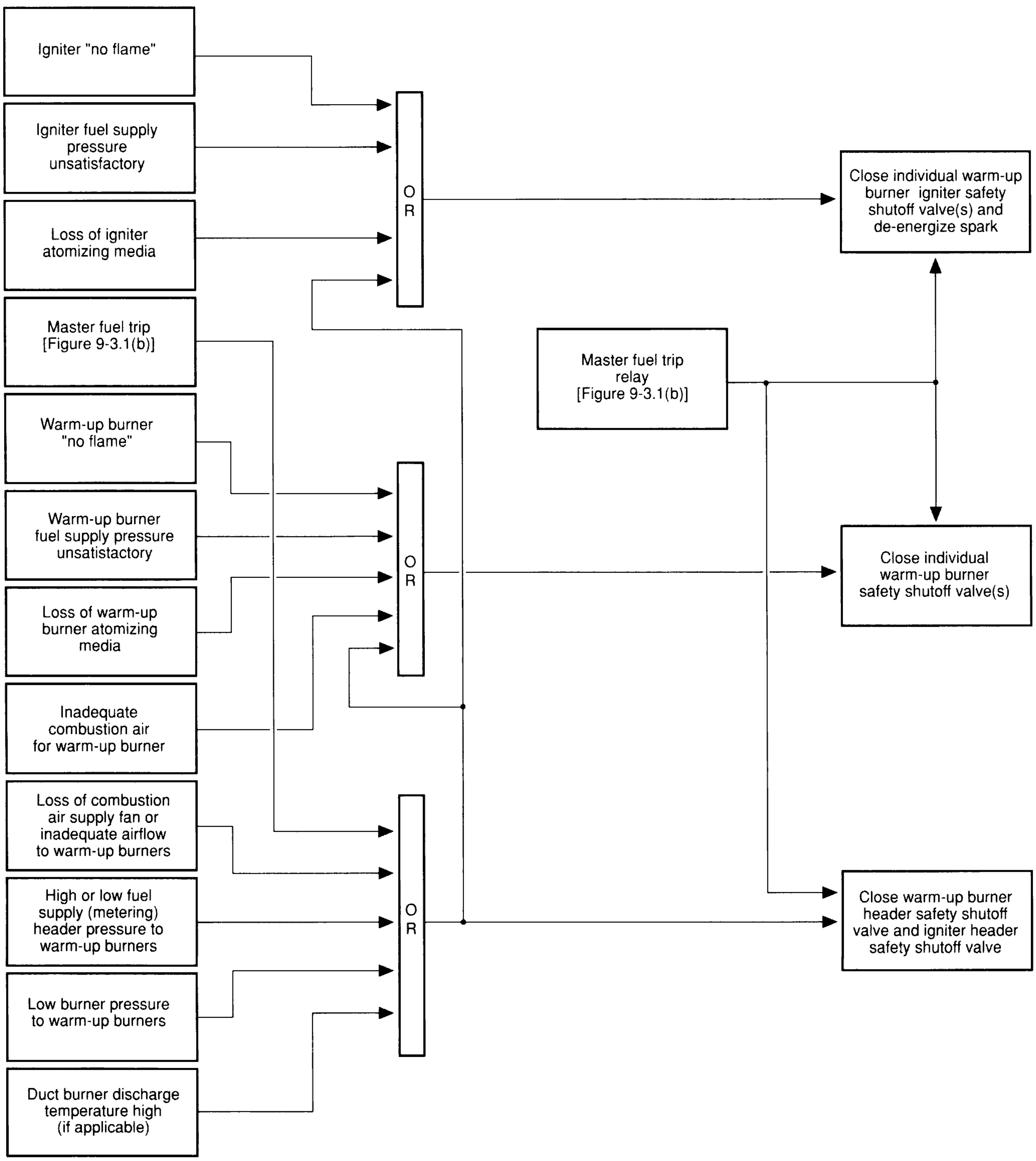
NOTE: Monitoring of header pressure to multiple warm-up burners with individual flow control capability does NOT satisfy this requirement. With low pressure gas burners, furnace pressure fluctuations might be more influential on burner gas flow than burner pressure drop.

9-3.3.3 Where oil is used as an igniter fuel with air or steam for atomization, loss of atomizing media shall trip the igniter fuel header, safety shutoff valves, and individual igniters, and deenergize the associated sparks. The associated warm-up burners shall also be tripped if in service and no other proof of flame exists.

9-3.3.4 Where oil is used as a warm-up burner fuel with air or steam for atomization, loss of atomizing media shall trip the warm-up burner fuel header safety shutoff valves and individual warm-up burners.

9-3.3.5 An interlock from the master fuel trip device shall also initiate tripping of the igniter and warm-up burner fuel header safety shutoff valves and individual igniter and warm-up burner safety shutoff valves and shall deenergize all sparks.

NOTE: 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.



NOTE: A specific fuel system may not require all the trips shown.

Figure 9-3.3 Warm-up burner safety subsystem.

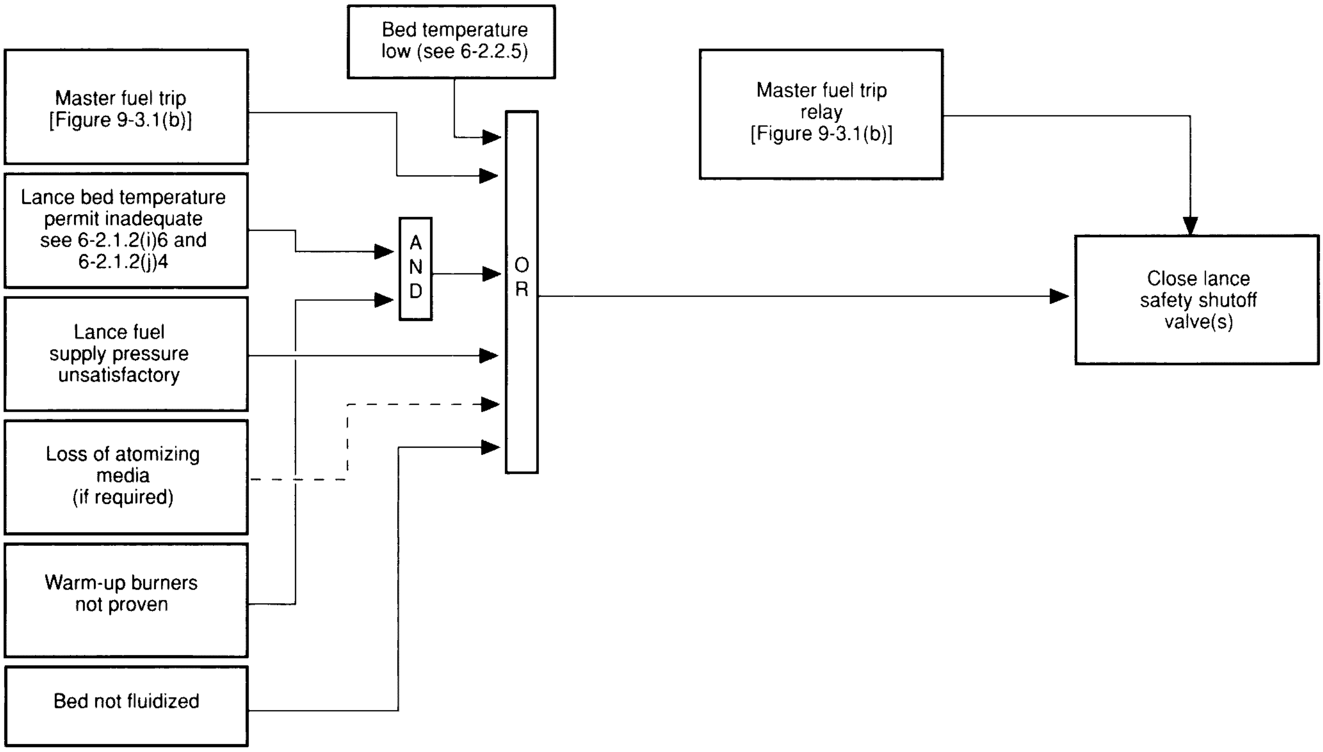


Figure 9-3.4 Lance safety subsystem.

9-3.3.6 If individually flow-controlled burners are used and the fuel flow or airflow is shown to be below the manufacturer's recommended minimum flow, the burner shall be immediately tripped.

9-3.4 Lances. Lances shall not be placed in service until a unit purge has been completed, 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 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.

9-3.4.2 Improper lance fuel pressure shall be interlocked so as to initiate the tripping of the individual lance safety shutoff valves.

NOTE: Monitoring of header pressure to multiple lances with individual flow control capability does NOT satisfy this requirement.

9-3.4.3 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).

9-3.4.4 Loss of adequate airflow to fluidize the bed shall result in a lance trip.

9-3.4.5 An interlock from the master fuel trip device shall also initiate tripping of the header and individual lance safety shutoff valves.

9-3.4.6 The master fuel trip relay(s) shall trip all lance safety shutoff valves.

9-3.5 Solid Fuel. The solid fuel feed system shall not be placed in service until a unit purge has been completed, the master fuel trip relay has been reset, and the bed temperature has reached the ignition temperature of the solid fuel being fired. (*See Figure 9-3.5.*)

9-3.5.1 Loss of the appropriate bed temperature permit shall cause all solid fuel feed systems to trip.

9-3.5.2 Solid fuel feed system operation shall be interlocked so as to initiate the tripping of upstream solid fuel feed train components following a component malfunction.

9-3.5.3 An interlock from the master fuel trip device shall also initiate tripping of the solid fuel feed system's components.

9-3.5.4 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 purpose 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. The visual indication shall identify the

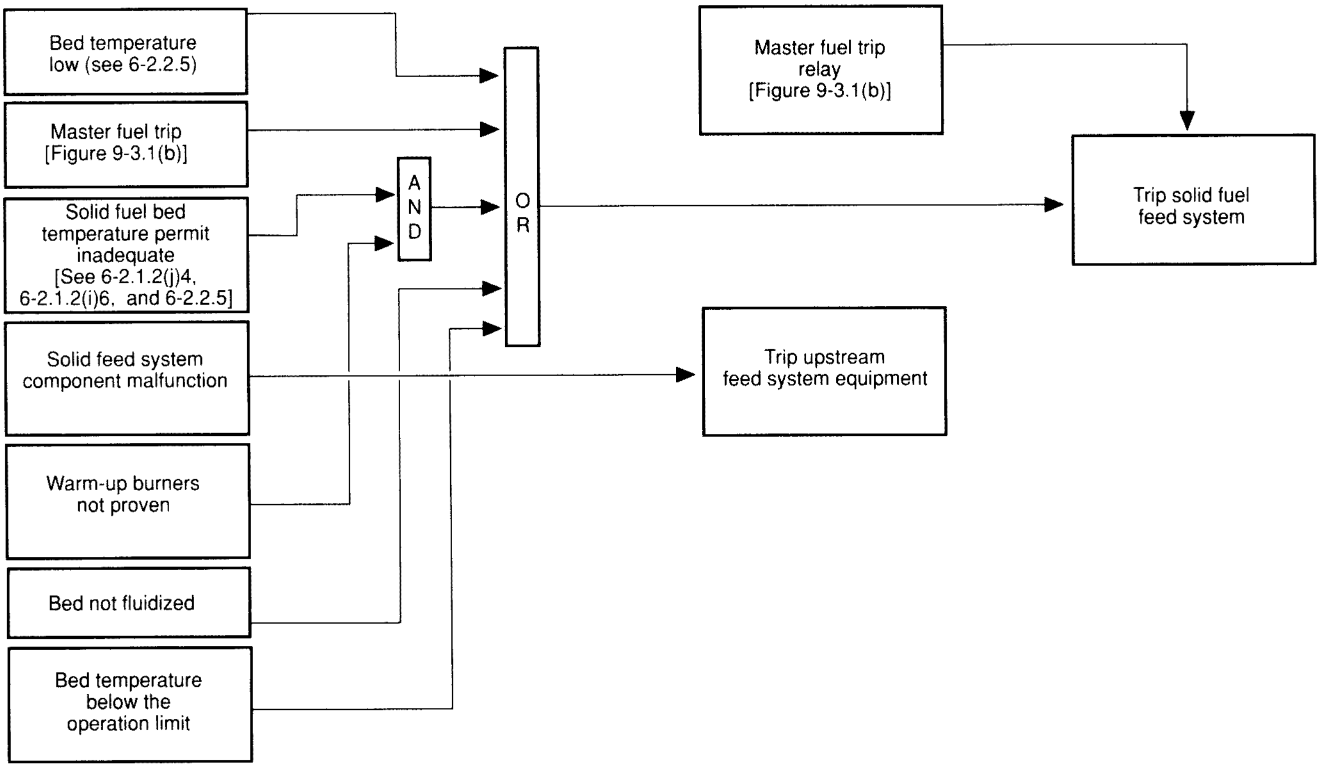


Figure 9-3.5 Solid fuel safety subsystem.

source or cause of the alarm. Means shall be permitted to silence the audible alarm, but the visual indication shall remain 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 done by authorized personnel, and the alarm shall be tagged as inoperative.

10-1.4 The design shall eliminate to the extent possible all nuisance alarms.

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 (*see 9-2.1*) system, 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 possible in order to warn the operator of abnormal pressure in advance of conditions that lead to a trip.

(c) *Solid Fuel Feeder Tripped.* Alarms when a feeder has tripped (not normal shutdown).

(d) *Solid Fuel Transport Air Fan Tripped.* Alarms when a transport air fan has tripped (not normal shutdown).

(e) *Solid Fuel Plugged.* Alarms 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.* Warns the operator of furnace pressure outside the region of normal operation and an approach to a trip condition.

(g) *Loss of Any 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 Energy.* This condition shall be sensed and alarmed and shall include all sources of power required to complete interlock functions. For example, if both a 125-volt DC electric circuit and a compressed air circuit are required for an interlock scheme, then loss of either shall be annunciated separately.

(k) *Loss of Control Energy.* This condition shall be sensed and alarmed to include all sources of energy 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.* Alarms 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.* Warns 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.* Warns the operator of a possible hazardous condition by alarming when measurable combustibles are indicated.

(c) *Air/Fuel Ratio (High and Low).* If proper metering is installed, alarms to indicate a potentially hazardous air/fuel ratio.

(d) *Oxygen Analyzer Trouble.* 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 Publications. 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.

NFPA 54, *National Fuel Gas Code,* 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, *Code for Pressure Piping — Power Piping,* 1992.

11-1.2.3 ASTM Publication. American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19105.

ASTM D396, *Standard Specifications 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 information purposes only.

A-2-6.1 Maintenance and Equipment Inspection.

I. 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 maintenance of equipment at intervals consistent with the type of equipment, service requirements, and manufacturer's recommendations.

(a) As a minimum, the maintenance program should include the following:

(i) In-service inspections to identify conditions requiring corrective action or further study.

(ii) Detailed, knowledgeable planning for effecting repair or modifications using qualified personnel, procedures, and equipment.

(iii) Use of comprehensive equipment history that records conditions found, maintenance work done, changes made, and the corresponding dates for each.

(iv) Written comprehensive maintenance procedures incorporating manufacturer's instructions to define tasks and skills required. Any special techniques, such as nondestructive testing, or those tasks requiring 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.

(v) Shutdown maintenance inspections, comprehensive in scope, to cover all areas.

(vi) Availability of adequate spare parts meeting specifications that will provide reliable service without necessitating makeshift repairs.

(b) An inspection and maintenance schedule should be established and followed.

(c) Operation, set points, and adjustments should be verified by periodic testing and the results documented.

(d) Defects should be reported and corrected and the repairs documented.

(e) System configuration, including logic, set points, and sensing hardware, should not be changed without the effect being evaluated and approved.

(f) 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.

II. Training.

(a) Operator Training.

(i) A formal training program should be established to prepare personnel to safely and effectively operate equipment. This program can consist of 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.

(ii) 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.

(iii) Operating procedures should be directly applicable to the equipment involved and consistent with safety requirements and manufacturer's recommendations.

(iv) Procedures should be periodically reviewed and kept current with changes in equipment and personnel.

(b) Maintenance Training.

(i) A formal maintenance training program should be established to prepare personnel to safely and effectively perform any required maintenance tasks. This program can consist of 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.

(ii) 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.

(iii) Procedures should be consistent with safety requirements and manufacturer's recommendations.

(iv) Procedures should be periodically reviewed to keep them current with changes in equipment and personnel.

III. Housekeeping.

(a) 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.

(b) 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 preferred.

IV. Safety.

(a) General Safety Precautions. Protective clothing, including but not limited to hard hats and safety glasses, should be used by personnel during maintenance operations.

(b) Special Safety Precautions.

(i) 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.

(ii) 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.*)

(iii) Fire-resistant blankets or other approved methods should be used in such a manner as to confine weld spatter or cutting sparks.

(iv) A careful inspection of all areas near where welding or cutting has taken place, 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.

(v) 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®*.

(vi) Either ground-fault protected or specially approved low voltage (6- or 12-volt) extension cords and lighting should be used for all confined spaces and where moisture might be a hazard.

(vii) 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.

(c) Confined Space.

(i) A confined space is any work location or enclosure in which any of the following exist:

1. The dimensions are such that 6-ft (1.8-m) tall 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 may include but are not limited to ducts, heaters, windboxes, cyclones, dust collectors, furnaces, bunkers, or bins.

(ii) Specific procedures should be developed and used for personnel entering a confined space to:

1. Positively prevent inadvertent introduction of fuel, hot air, steam, or gas.

2. Positively prevent inadvertent starting or moving of mechanical equipment or fans.

3. Prevent accidental closing of access doors or hatches.

4. Include tags, permits, or locks to cover confined space entry.

5. Determine 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 use of proper safety belts or harnesses, which should be properly tied off where such use is practical.

(iii) 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 bed and refractory store large quantities of heat, which cause the behavior of a FBC boiler to be different from that of other fuel combustion systems.

(iv) Because ignition energy is supplied by the hot bed, a 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.

(v) An operating FBC boiler will continue 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, 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 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 amounts 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 the responsibility for mitigating these hazards to the extent possible.

(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 hotter. 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 clearly marked.

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 required to 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 adequately trained 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, commonly referred to as quicklime. The presence of calcium oxide, CaO, in the solids demands care to prevent equipment damage or injury to personnel. CaO reacts with water or water vapor to generate heat and will react with moisture on skin or eyes to cause chemical burns.

2. Recommendations.

a. If 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 will necessitate that personnel enter the FBC, the boiler manufacturer should recommend that the initial charge of bed material be not limestone but sand, coal ash, or other chemically inert material.

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, 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 means to detect the presence of blockages, especially in instrument lines, and provide means to safely remove blockages.

e. Safety equipment required for dealing with lime should be provided, including breathing masks, protective clothing, and eye protection. Provide first-aid facilities needed for chemical burns, especially for eyes. Train operators to test for the presence of quicklime before entering an enclosure filled with solids. One simple test is to sample the solids. Place the sample in a metal (not glass) container, wearing gloves and eye protection. Add an approximately equal volume of water, stir, and wait about 15 minutes 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 will concentrate in poorly ventilated low points in the plant creating the potential for personnel injury.

2. Recommendations.

a. Provide adequate seals/gaskets on components that can be opened or disassembled that are located in the dense bed region. Seal weld components that need not be opened or disassembled.

b. Provide written guidelines on H_2S with the equipment manuals.

c. Train operators to anticipate the presence of H_2S.

d. Provide means for measuring the concentration of H_2S in the boiler house and other plant facilities.

(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, 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 proper procedures for entering enclosed spaces.

A-4-1.1.1 With reference to Figure A-4-1.1.1, the following provides an example of boiler enclosure structural design:

(a) **Area A**, Normal Operating Pressure = +4.0″ w.g. (+1.0 kPa)

(1) +4.0″ w.g. (+1.0 kPa) × 1.67 = 6.7″ w.g. (+1.7 kPa)

(2) Select the higher of +35″ w.g. (+8.7 kPa) or +6.7″ w.g. (+1.7 kPa)

(3) Select the lower of the result of (2) or the forced draft maximum head capability at ambient conditions.

(4) Design Area A of furnace to +35″ w.g. (+8.7 kPa) at yield.

(b) **Area B**, Normal Operating Pressure = +20″ w.g. (+5.0 kPa)

(1) +20″ w.g. (+5.0 kPa) × 1.67 = +33.4″ w.g. (+8.3 kPa)

(2) Select the higher of +35″ w.g. (+8.7 kPa) or +33.4″ w.g. (+8.3 kPa)

(3) Select the lower of the result of (2) or the forced draft maximum head capability at ambient conditions.

(4) Design Area B of furnace to +35″ w.g. (+8.7 kPa) at yield.

(c) **Area C**, Normal Operating Pressure = +50″ w.g. (+12.4 kPa)

(1) +50″ w.g. (+12.4 kPa) × 1.67 = +83.5″ w.g. (+20.8 kPa)

(2) Select the higher of +35″ w.g. (+8.7 kPa) or +83.5″ w.g. (+20.8 kPa)

(3) Select the lower of the result of (2) or the forced draft maximum head capability at ambient conditions.

(4) Design Area C of furnace to +83.5″ w.g. (+20.8 kPa) at yield

(d) **Area D**, Normal Operating Pressure = +70″ w.g. (+17.4 kPa)

(1) +70″ w.g. (+17.4 kPa) × 1.67 = +116.9″ w.g. (+29.1 kPa)

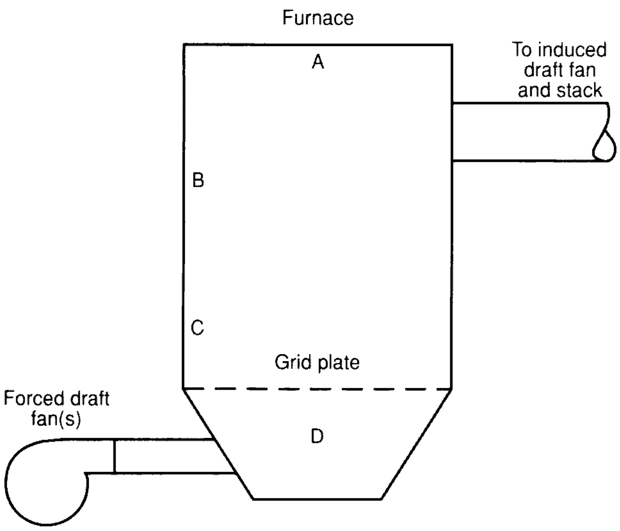
(2) Select the higher of +35″ w.g. (+8.7 kPa) or +116.9″ w.g. (+29.1 kPa)

(3) Select the lower of the result of (2) or the forced draft maximum head capability at ambient conditions.

(4) Design Area D of the furnace to +110″ w.g. (+27.4 kPa) at yield.

A-4-4.2 Determination of Bed Temperature for Operational Permissives. The text 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.



Maximum Head Capability = + 110″ w.g. (+27.4 kPa) at ambient conditions
Normal Operating Pressure: A = +4.0″ w.g. (+1.0 kPa)
B = +20″ w.g. (+5.0 kPa)
C = +50″ w.g. (+12.4 kPa)
D = +70″ w.g. (+17.4 kPa)

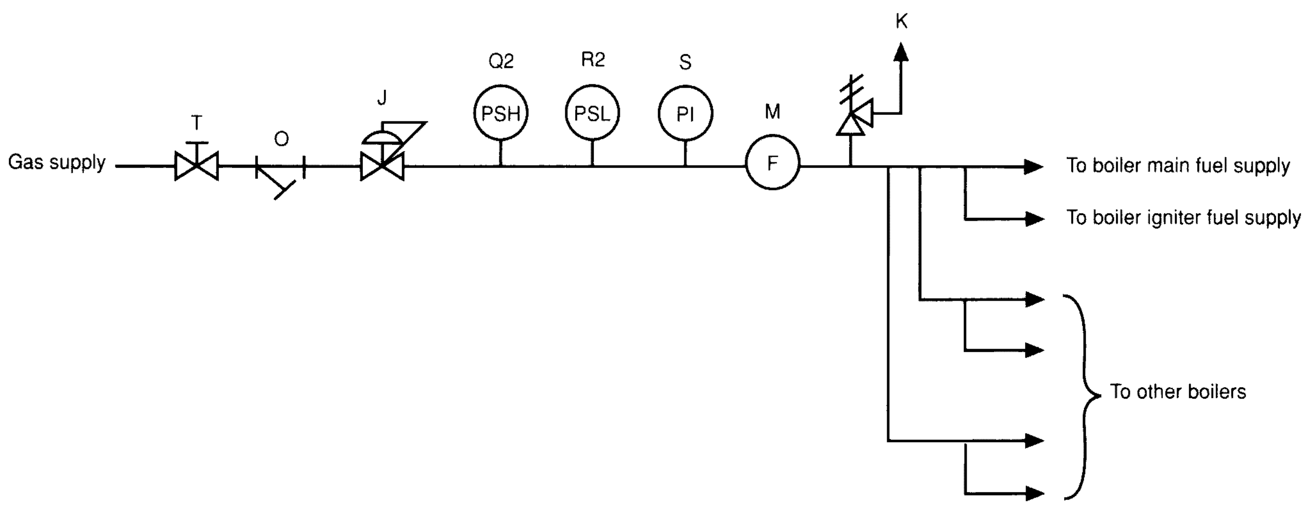
Figure A-4-1.1.1 Boiler enclosure structural design diagram.

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 the well of 2 in. (5.1 cm) from the wall provides reliable bed temperature measurement without extensive erosion of the well. Suitable materials are selected for temperature elevation, erosion, and corrosion potentials.

Where the bed is fluidized, the measurements above and below the slumped bed level converge toward a narrow band. Rather than taking an average of the temperatures, a voting 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-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.



The following apply to Figures A-7-5.1.1(a) through A-7-5.1.1(i).

A Main Safety 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 Main Fuel Control Valve
D_1 Main 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 — must 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 Main 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.

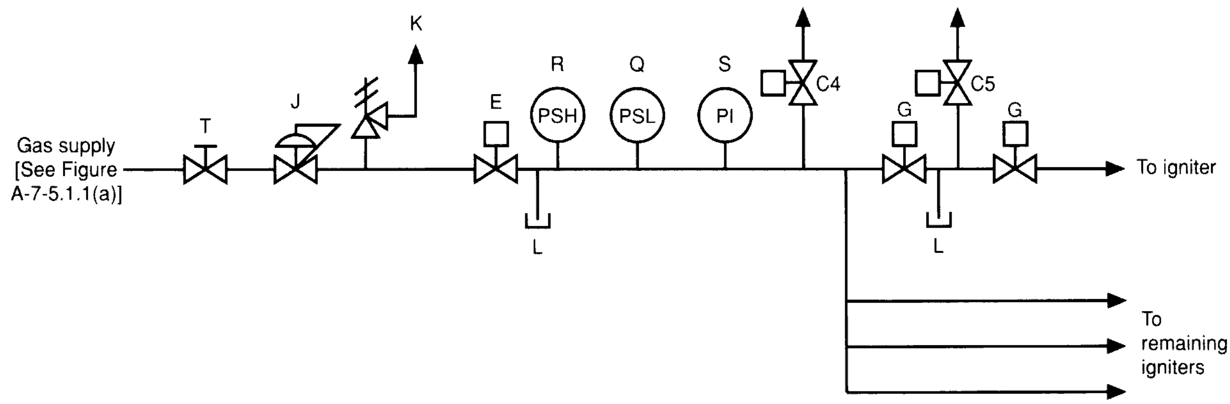


Figure A-7-5.1.1(b) Typical fuel gas ignition system — multiple igniters supplied from a common header (automatic).

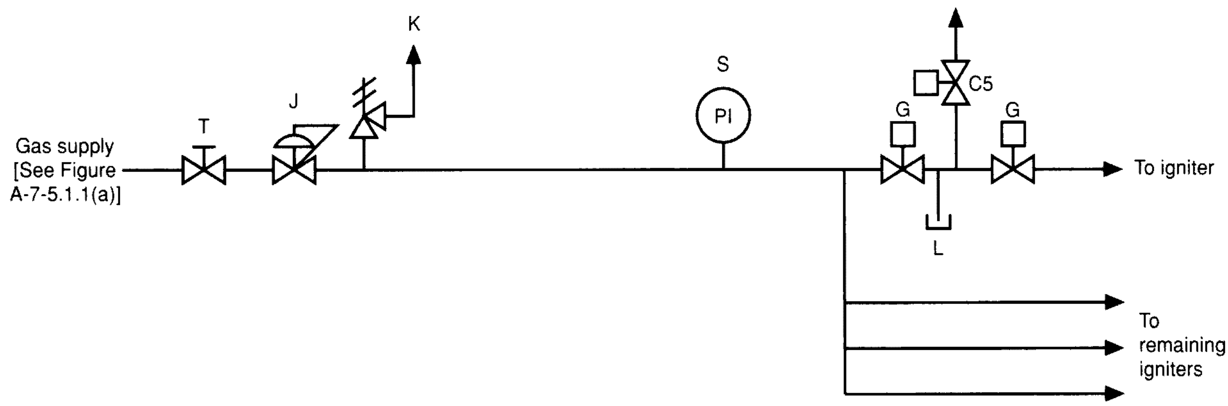


Figure A-7-5.1.1(c) Typical fuel gas ignition system — multiple igniters supplied from a common header (supervised manual).

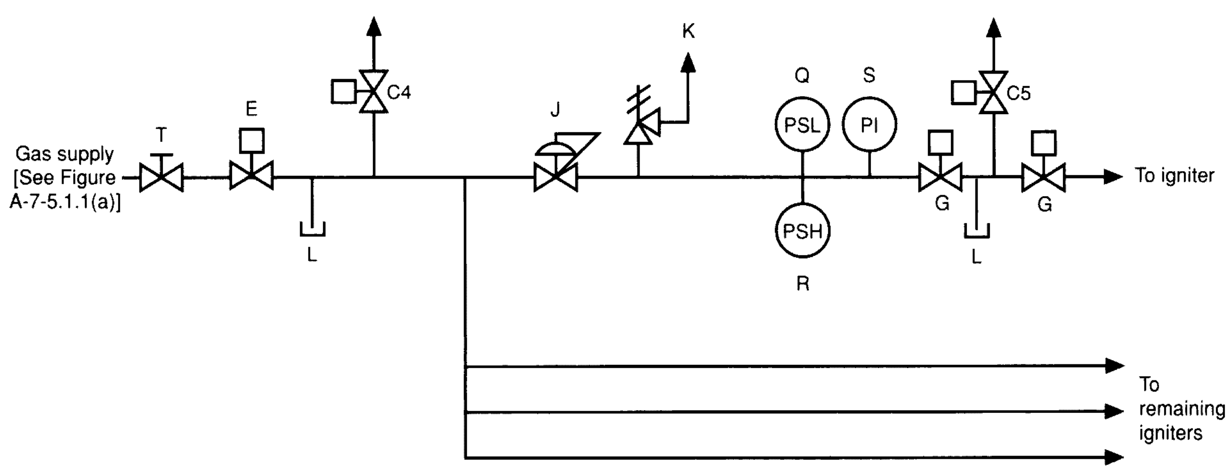


Figure A-7-5.1.1(d) Typical fuel gas ignition system — individually controlled igniters (automatic).

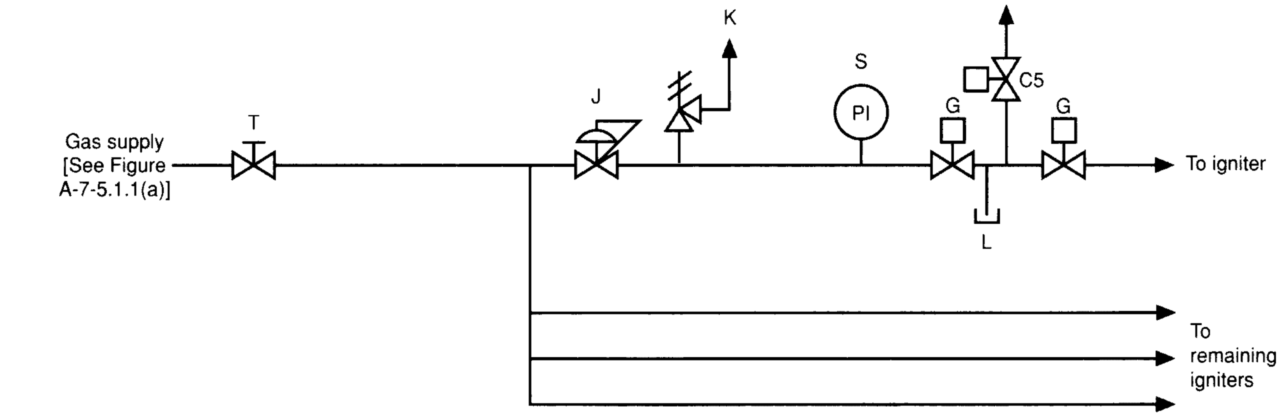


Figure A-7-5.1.1(e) Typical fuel gas ignition system — individually controlled igniters (supervised manual).

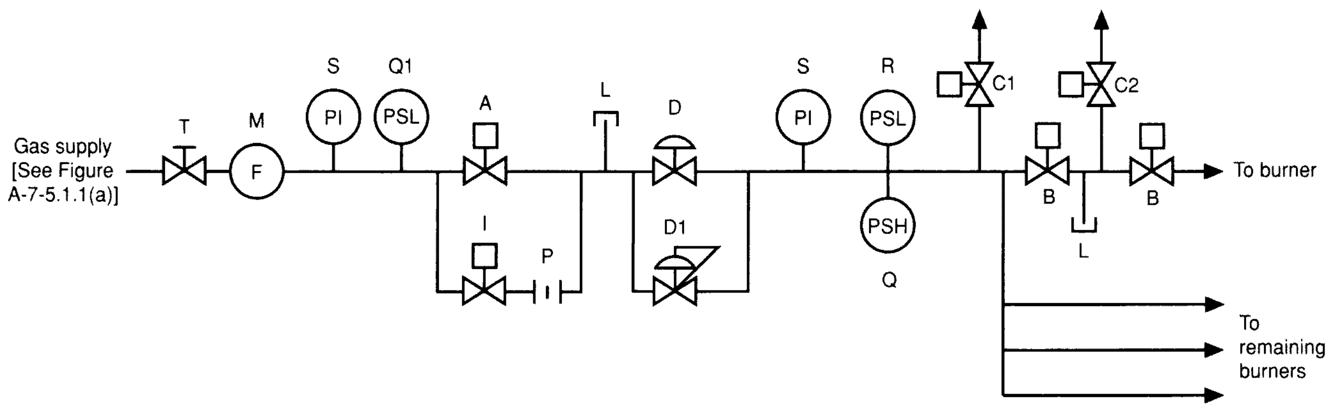


Figure A-7-5.1.1(f) Typical fuel gas burner/lance system master flow control valve for multiple burners (automatic).

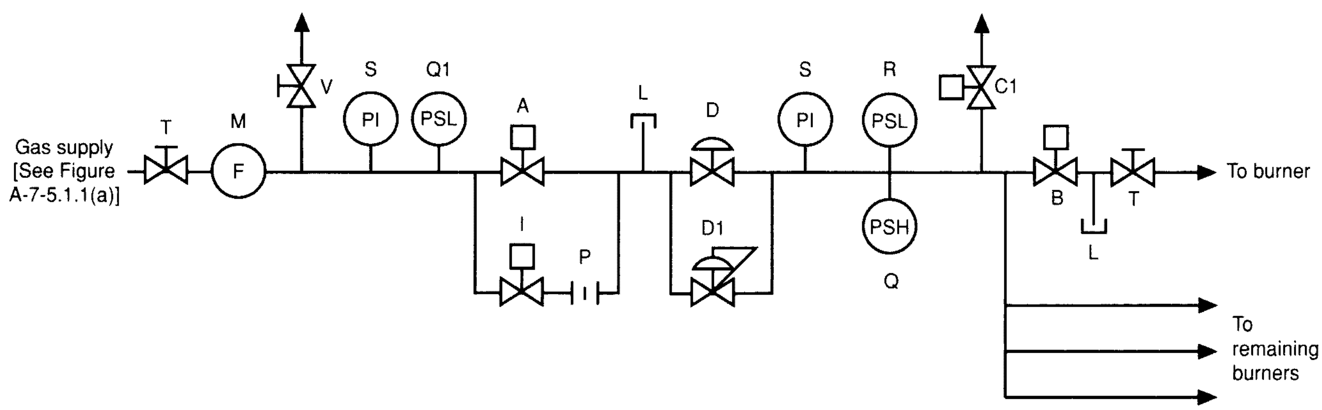


Figure A-7-5.1.1(g) Typical fuel gas burner/lance system master flow control valve for multiple burners (supervised manual).

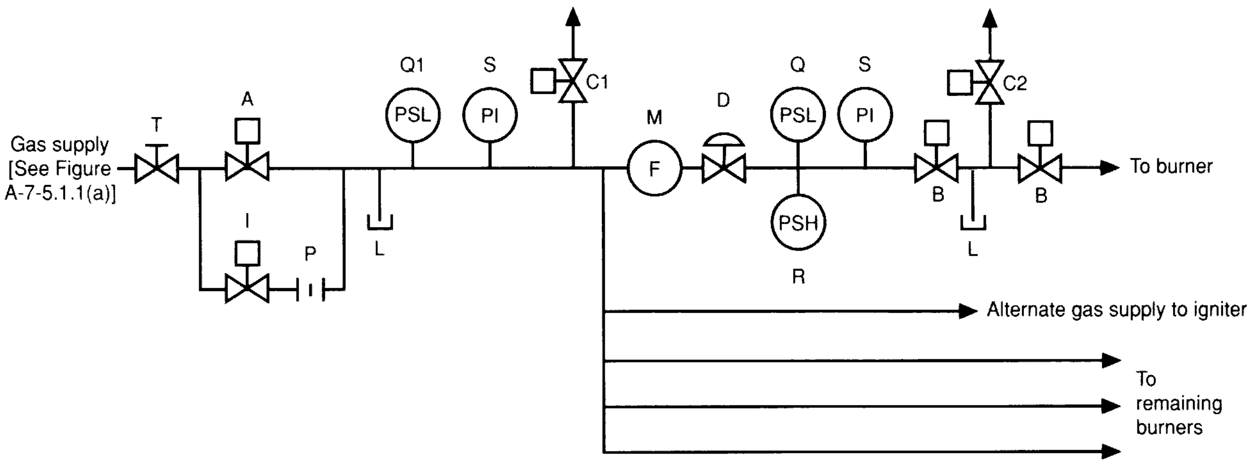


Figure A-7-5.1.1(h) Typical fuel gas burner/lance system individual fuel control valve (automatic).

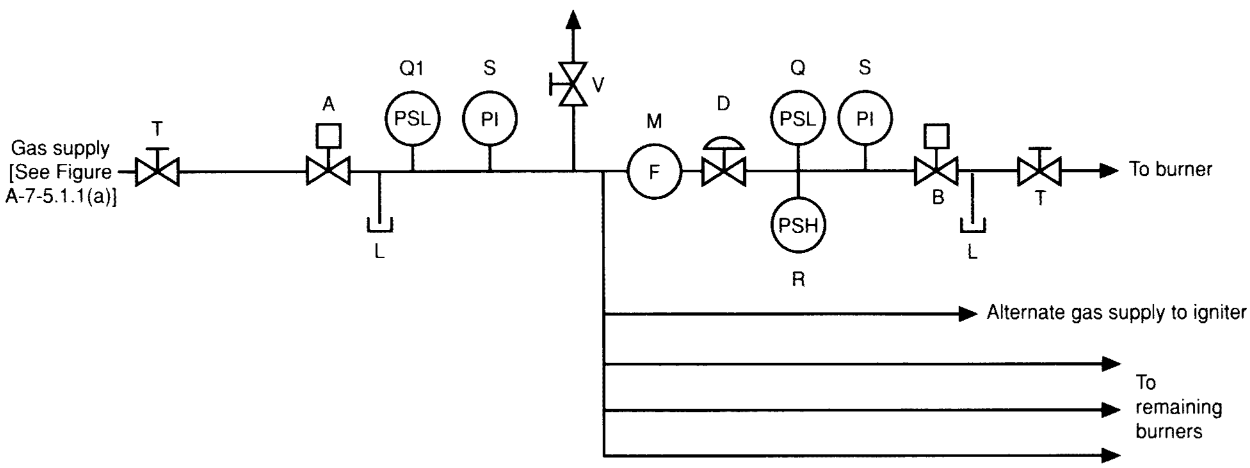


Figure A-7-5.1.1(i) Typical fuel gas burner/lance system individual fuel control valve (supervised manual).

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 desirable that the design provide for possible future conversion to automatic trips in the interlock system.

(a) *Burner Register Closed.* Provide control room indication or alarm for the condition of all secondary air burner dampers 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 per cu ft (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, it can 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.* Warns operator of a flame detector malfunction.

A-7-8.1.1 Recommended Additional Alarms for Supervised Manual 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.

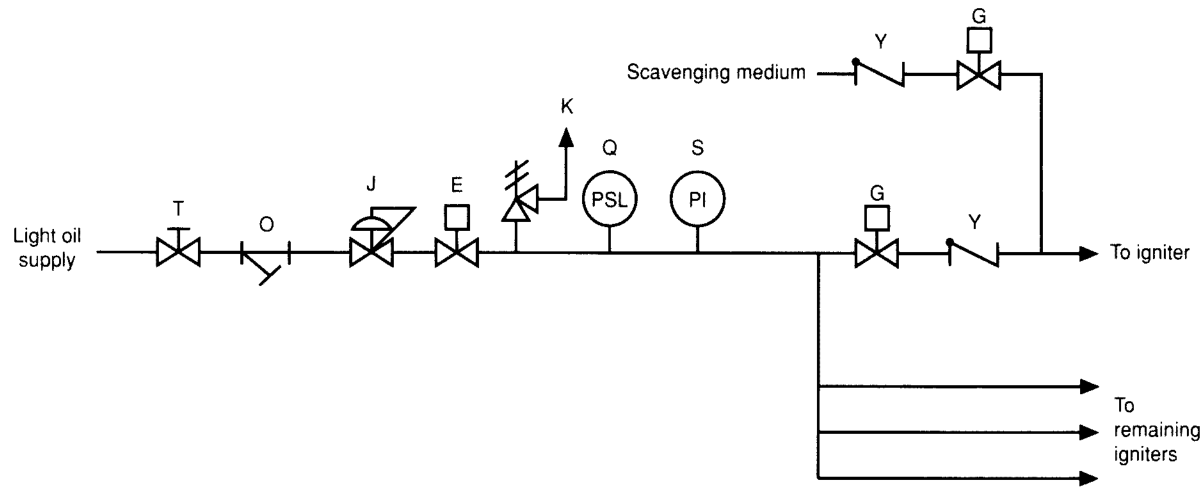
(a) High fuel supply pressure

(b) Low fuel supply pressure

(c) Low combustion airflow

(d) Failure of burner safety shutoff valve to close

(e) Flame detector trouble.



The following apply to Figures A-8-5.1.1(a) through A-8-5.1.1(p).

A Main Safety 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 Main Fuel Control Valve
D_1 Main 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 - must 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 Main 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-8-5.1.1(a) Typical light oil ignition system — multiple mechanically atomized igniters supplied by a common header (automatic).

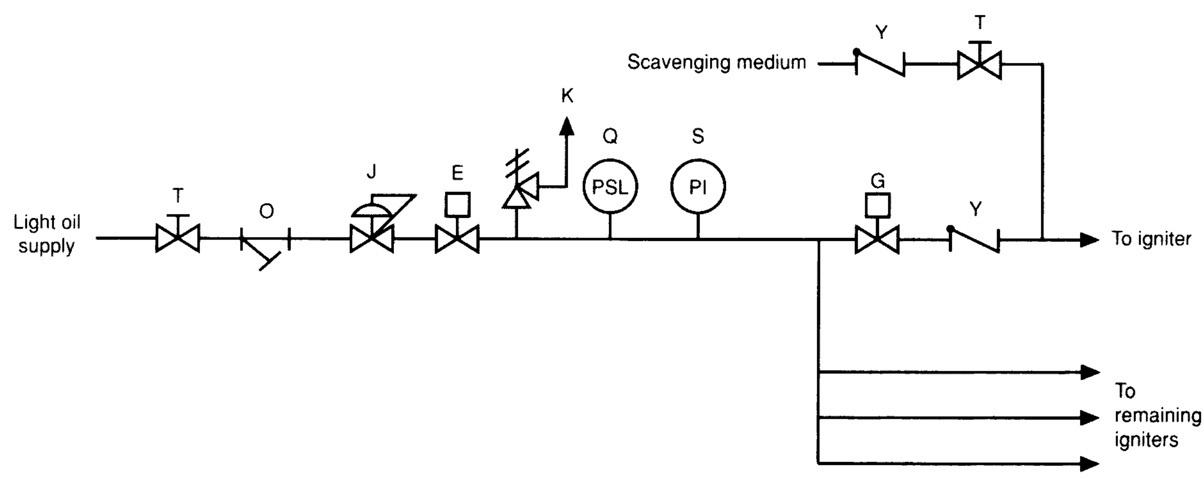


Figure A-8-5.1.1(b) Typical light oil ignition system — multiple mechanically atomized igniter supplied by a common header (supervised manual).

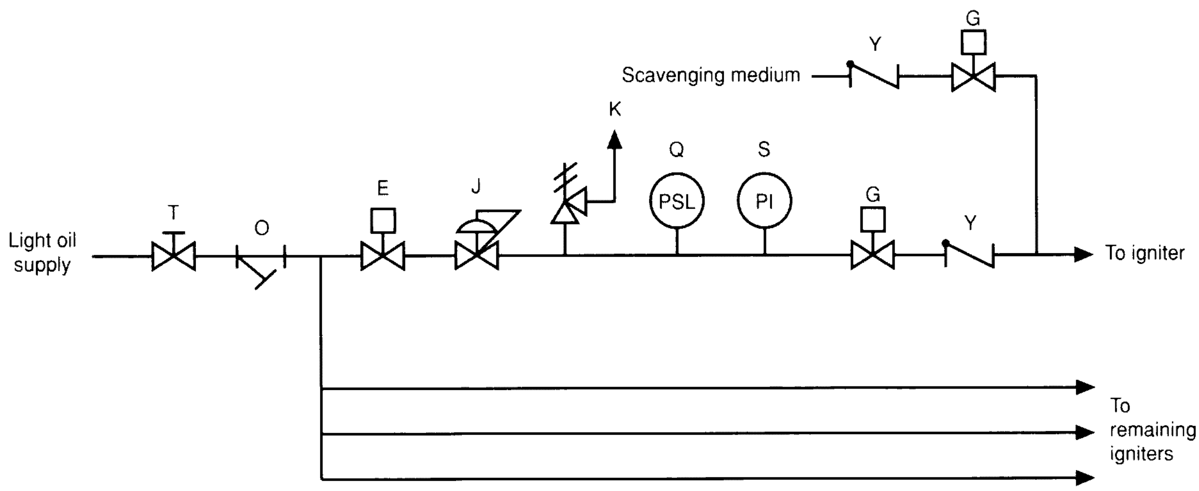


Figure A-8-5.1.1(c) Typical light oil ignition system — individually controlled mechanically atomized (automatic).

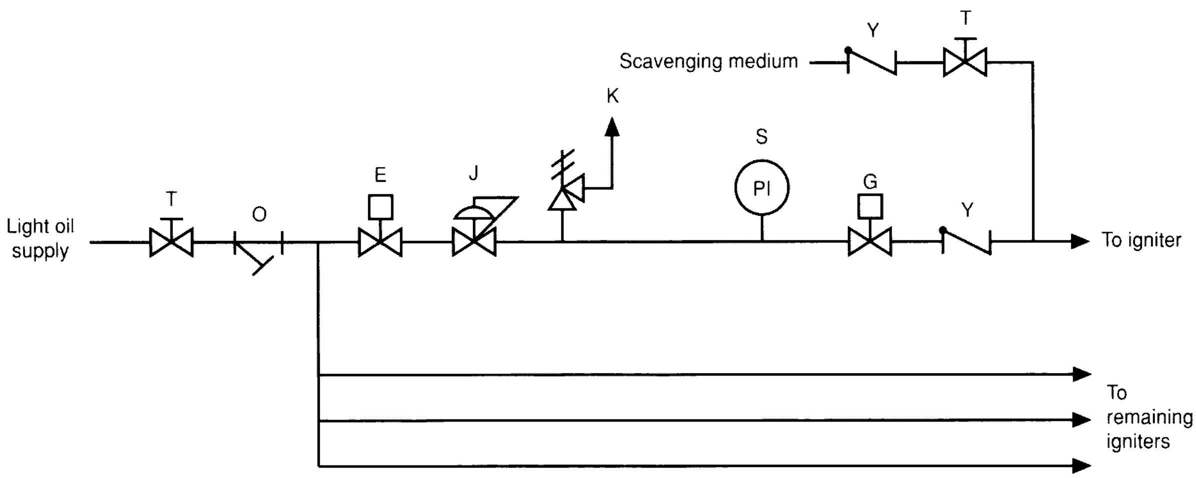


Figure A-8-5.1.1(d) Typical light oil ignition system — individually controlled mechanically atomized (supervised manual).

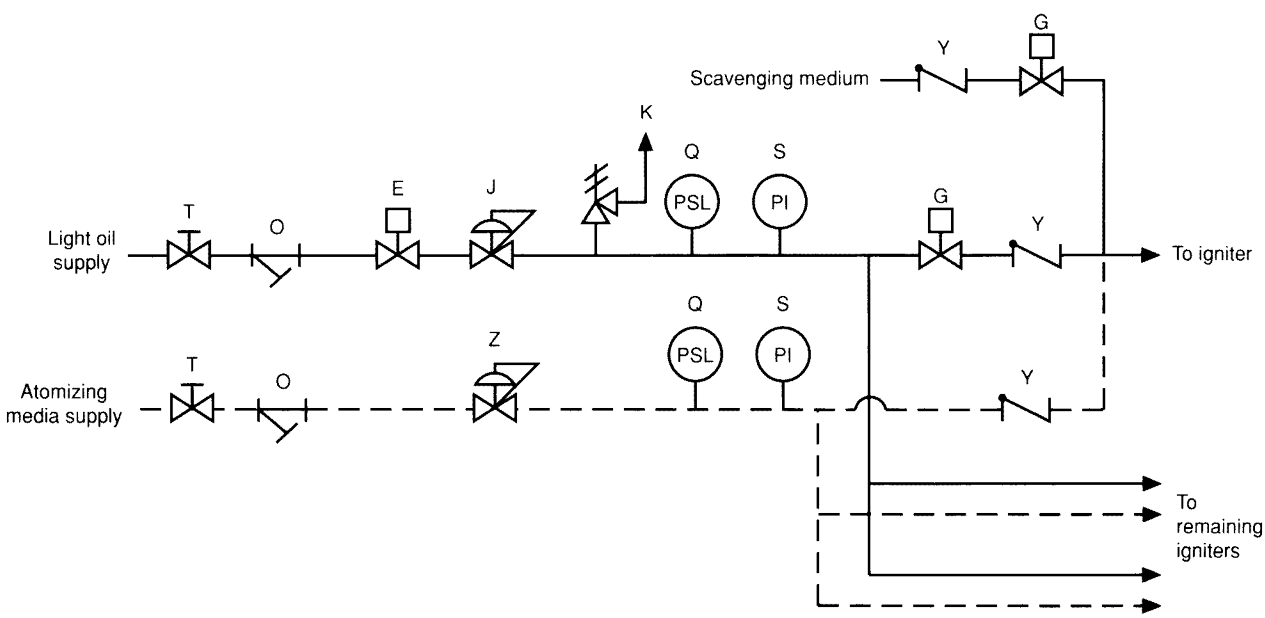


Figure A-8-5.1.1(e) Typical light oil system — steam/air atomized — igniters supplied from a common header (automatic).