Y/DV-1421, Rev. 1

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LOCKHEED MARTIN

HOLDEN GAS-FIRED FURNACE BASELINE DATA

K. A. Weatherspoon

November 1996

MANAGED BY
LOCKHEED MARTIN ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

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DISCLAIMER

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HOLDEN GAS-FIRED FURNACE BASELINE DATA

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Development Organization

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Prepared by the
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LOCKHEED MARTIN ENERGY SYSTEMS, INC.
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ABSTRACT

The Holden gas-fired furnace is used in the enriched uranium recovery process to dry and combust small batches of combustibles. The ash is further processed. The furnace operates by allowing a short natural gas flame to burn over the face of a wall of porous fire brick on two sides of the furnace. Each firing wall uses two main burners and a pilot burner to heat the porous fire brick to a luminous glow.

Regulators and orifice valves are used to provide a minimum gas pressure of 4 in. water column at a rate of approximately 1450 scf/h to the burners. The gas flow rate was calculated by determining the gas flow appropriate for the instrumentation in the gas line. Observed flame length and vendor literature were used to calculate pilot burner gas consumption.

Air for combustion, purging, and cooling is supplied by a single blower. Rough calculations of the air-flow distribution in piping entering the furnace show that air flow to the burners approximately agrees with the calculated natural gas flow.

A simple on/off control loop is used to maintain a temperature of 1000°F in the furnace chamber. Hoods and glove boxes provide contamination control during furnace loading and unloading and ash handling. Fan EF-120 exhausts the hoods, glove boxes, and furnace through filters to Stack 33.

A review of the furnace safety shows that safety is ensured by design, interlocks, procedure, and a safety system. Recommendations for safety improvements include installation of both a timed ignition system and a combustible-gas monitor near the furnace. Contamination control in the area could be improved by redesigning the loading hood face and replacing worn gaskets throughout the system.

The furnace operates on all shifts and requires one operator, cooling water, 480-V electrical power, and pressurized air. The operating temperature is adequate for the task of removing water, decomposing cellulosic materials, and combusting volatiles. The energy required to accomplish the task is calculated as 700,000 Btu/h, implying a furnace efficiency of 51%.

INTRODUCTION

The "luminous wall" furnace built by the A. F. Holden Company was installed at the Y-12 Plant in 1963–1964. Designated the "Holden gas-fired furnace," the operating unit consists of a direct-fired natural gas furnace, a natural gas supply system, and a safety system. It is used either to dry wet batches of various contaminated residues or to burn small batches of combustibles at 1000°F. The material is held in muffle pans while it is burning, and the ash is collected for further processing.

An evaluation of the Holden gas-fired furnace is required before the system can be restarted. This report develops and summarizes a technical basis for the design and operation of the furnace.

DESCRIPTION

The operating unit designated "Holden gas-fired furnace" consists of a direct-fired natural gas furnace, a natural gas supply system, a combustion and furnace air supply system, an exhaust system, a process control system, and a safety system. The unit is used either to dry wet batches of various contaminated residues or to burn small batches of combustibles at 1000°F. The material is held in muffle pans while it is burning, and the ash is collected for further processing.

The furnace is in Building 9212, Room 29, and is one of the Headhouse operations. Furnace operation is described in Procedure Y50-37-98-403, *Holden Gas-Fired Furnace Operation.*[1] The furnace has a very high usage rate and is operated, typically, in batch mode to process 18 pans (7 ft^3) of material daily.

THE FURNACE

The "luminous wall" furnace (Figs. 1 and 2) built by the A. F. Holden Company was installed at the Y-12 Plant in 1963–1964 on Purchase Order 62Y-48964.[2] The furnace is covered by patents 3,008,513, "Safety Construction for Luminous Wall Furnace," and 2,828,813, "Gas-Fueled Heating Apparatus."[3,4] The furnace has a removable steel cover filled with porous castable refractory material surrounded by insulating firebrick (IFB). Patent 2,828,813 indicates that the porosity of the refractory material could be from 40% to 80%. An air plenum, bounded by a perforated steel plate, precedes the porous refractory. In the Room 29 furnace, the combination of a plenum and a porous barrier evenly distributes the air entering the top of the furnace. Examination of the patents shows that a similar construction is used for the furnace firing surfaces.

The furnace cover measures approximately 5 ft 10 in. by 6 ft 1 in. by 9 1/16 in. and weighs approximately 1500 lb. The cover can be moved by a manually operated hoist so that the furnace chamber can be entered for cleaning, inspecting, and repairing. To prevent the escape of harmful combustion gases from the furnace, the joint between the furnace cover and the furnace shell is filled with magnesium oxide sand and covered with steel foil tape.

The furnace shell is of steel construction with gas-tight welds. Inlets for furnace purging and cooling air are provided in the top of the furnace cover and in the north and south sides of the shell. On the east side of the furnace is a ported door opening measuring 8 1/4 in. by 32 7/16 in. The door port connects to a hood port and is sealed with an asbestos gasket. On the west side of the furnace is a ported exhaust opening that connects to an exhaust duct and is sealed with an asbestos gasket. To measure chamber pressure, a manometer connection is located near the door opening. Two thermocouple feedthroughs enter the east side of the furnace. Two drain holes exit through the bottom of the furnace for nuclear criticality safety. A Hastelloy® rack for the muffle pans is inside the furnace chamber.

The furnace measures 2 ft 3 in. by 3 ft 10 in. by 4 ft 2 in. The chamber front and back are lined with two layers of IFB; the chamber bottom is lined with one layer of IFB. Patent 2,828,813 indicates that lightweight, porous brick is not required for nonfiring surfaces within the furnace and that any conventional, heavy firebrick capable of withstanding the operating temperature is suitable.[3] Nothing in the patents precludes the use of porous brick, and the only identification of the type of firebrick originally used in the Room 29 furnace is that it be IFB.[5] Thermal Ceramics K30 IFB and brick from several other vendors have been recommended for use in the furnace.[6]

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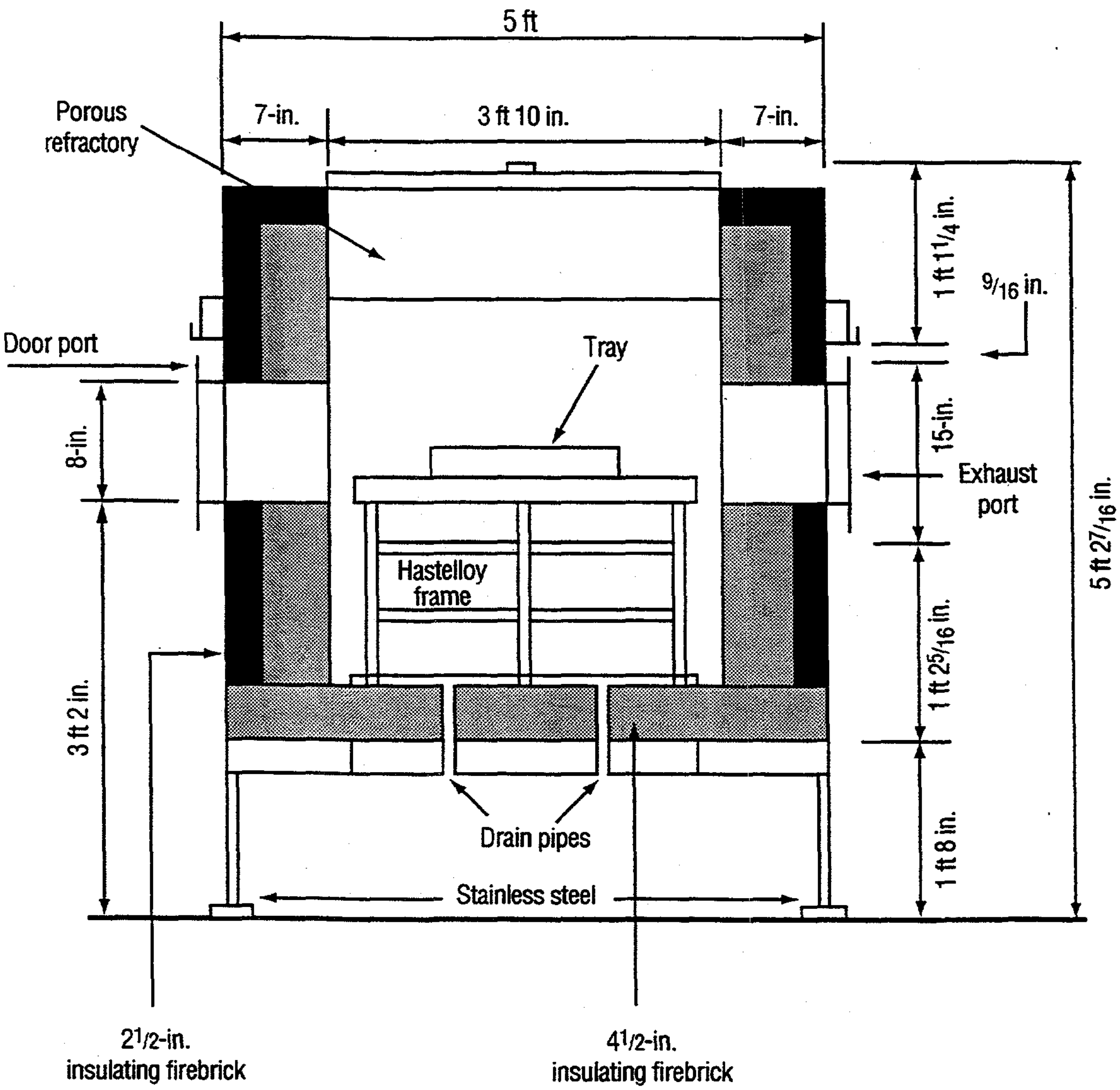

Fig. 1. Sectional elevation.

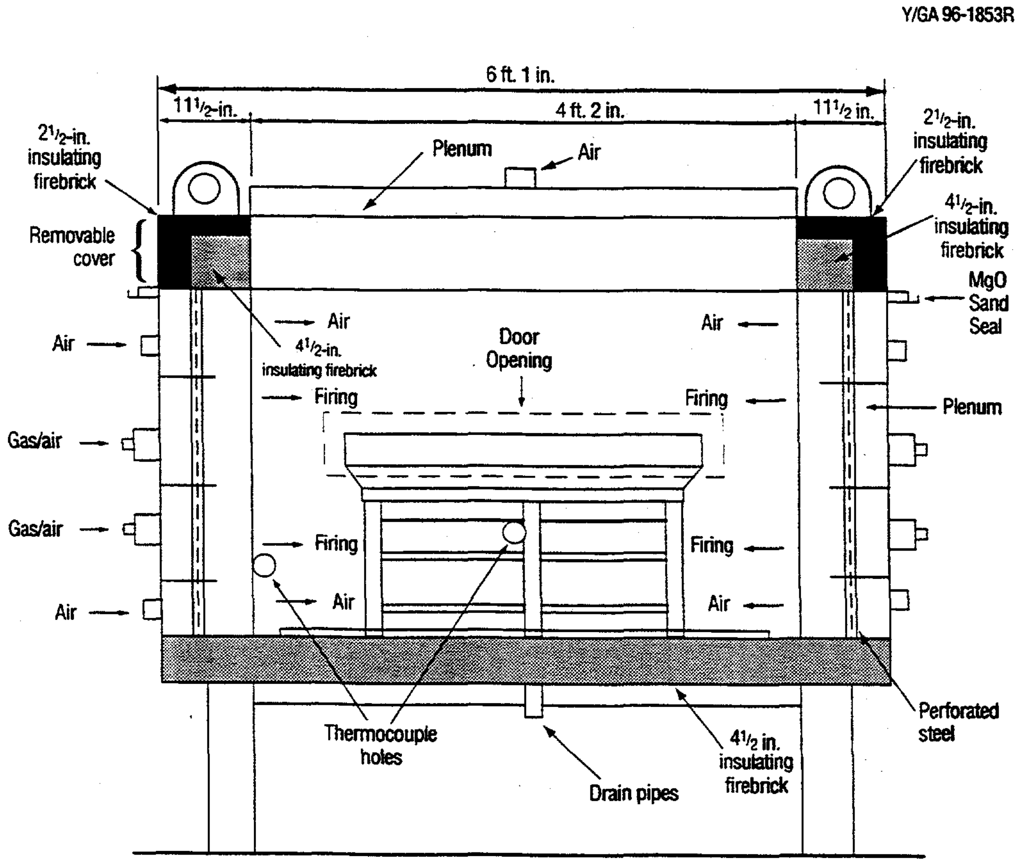

Fig. 2. Typical cross section.

Vendor information gives the composition of K30 IFB as shown in Table 1.[7] Mole percent was calculated using molecular weight and density values from a convenient reference. For species having more than one allotropic form, the density listed does not take abundance into consideration but is merely the mean of the density of individual allotropes. Equation (1) calculates the theoretical density (d_t) of the brick as 2.87 g/cc, and Eq. (2) calculates the porosity (p) as 71.5% using the actual density (d_a) of K30 IFB as 817 kg/m^3 (from vendor literature):

$$d_t = \frac{1}{\sum \left(\frac{\text{wt }\%_i}{100} \times \frac{1}{d_i} \right)} , \quad (1)$$

$$d_a = d_t(1-0.01p) , \quad (2)$$

where

$\text{wt}\%_I$ = weight percent of components ,
d_i = density of components .

BNZ 26 (BNZ Materials, Inc.) is also suitable for use in the furnace.[8]

Table 1. Composition of K30 firebrick

Species	Molecular weight (g/mole)	Density (g/cc)	Weight percent	Mole fraction (x)	$\frac{wt\%}{100} \times \frac{1}{d}$
Alumina (Al_2O_3)	101.94	4.00	46.0	0.451	0.11500
Silica (SiO_2)	60.06	2.30	52.0	0.866	0.22600
Ferric oxide (Fe_2O_3)	159.70	5.12	0.9	0.006	0.00018
Titanium oxide (TiO_2)	79.90	4.08	2.0	0.025	0.00490
Calcium oxide (CaO)	56.08	3.32	0.5	0.009	0.00151
Magnesium oxide (MgO)	40.32	3.65	0.1	0.003	0.00027
Alkalies (Na_2O)	61.99	4.08	0.4	0.006	0.00098

BURNERS

The furnace has six burners—two pilots and four main burners—all of which use premixed natural gas/air. An opening in the north side and an opening in the south side of the shell are provided for insertion of Maxon WR 1-1/4 nozzle mixing burners. These burners serve as their own fuel/air mixing devices, are equipped with electric ignitors,[9] and are designated as pilot burners because they provide the pilot flames for the main burners. The burners also provide the flame supervisory system for the furnace.

Once ignited, the pilot burners fire continuously until deactivated, delivering a significant portion of the heat consumed in the furnace. Cooling air enters the furnace near each pilot burner and diffuses through porous refractory material that surrounds the burner. The porous refractory material provides support for the burner block, insulation between the burner and the furnace shell, and separation between the pilot burners and the main burners.

The main burners are part of the furnace construction. Premixed natural gas/air enters two reservoirs on the north side and two reservoirs on the south side of the furnace, each of which feeds a plenum. The two plenums on each side of the furnace are located subjacent to each other. One cooling air plenum on each side surrounds the two natural gas/air plenums and the refractory-filled pilot burner section.

The cooling air plenums and the natural gas/air plenums do not communicate. A single perforated steel plate forms the inside walls (see Figs. 3 and 4) of all the plenums on each side of the furnace. A wall of porous refractory adjoins the perforated steel wall but is not sealed to it. The gases exiting the plenums through the perforated wall spread through the minute gap formed where the perforated wall and the porous refractory meet and diffuse through the porous refractory.[3, 4]

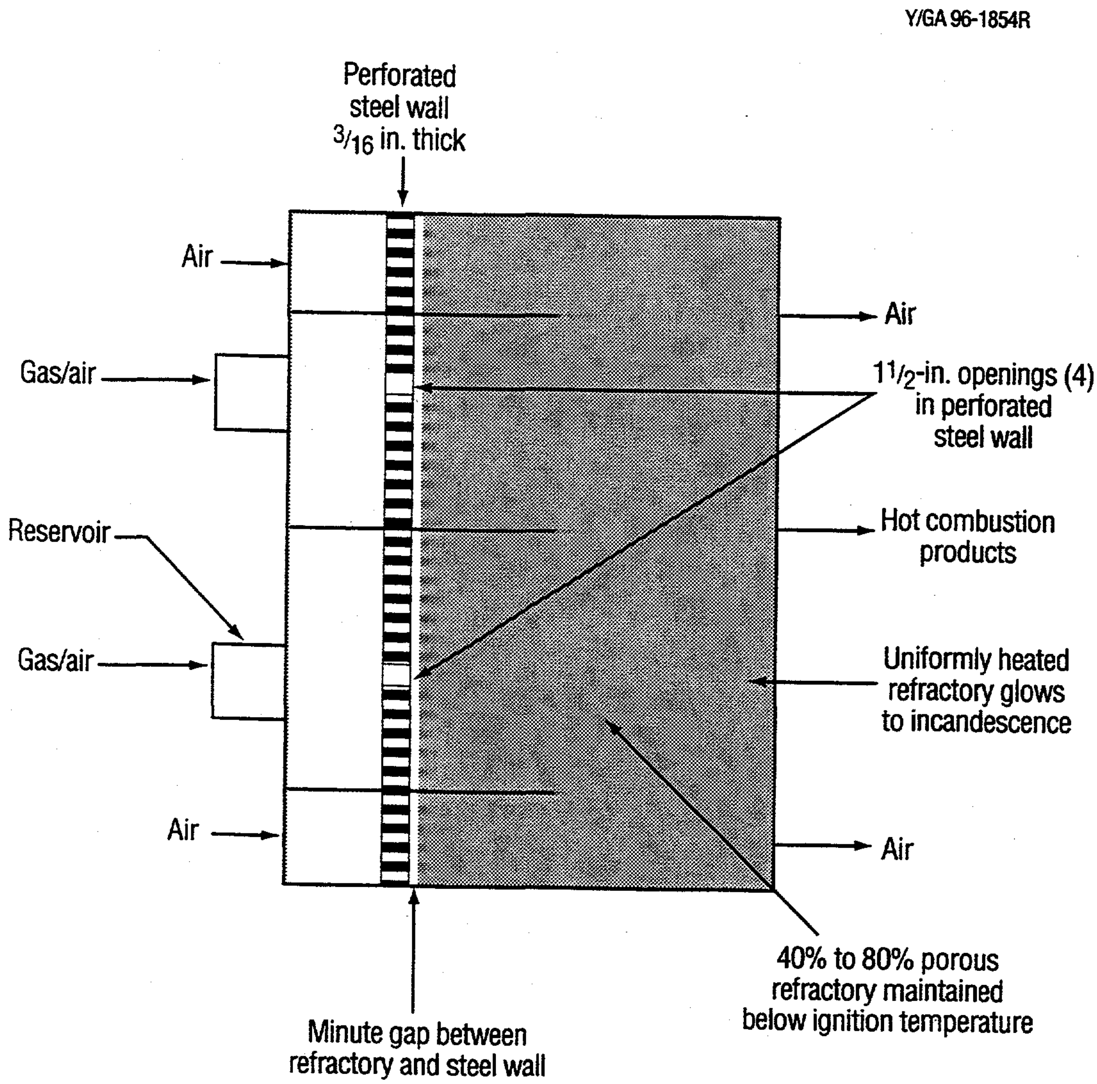

Fig. 3. Furnace wall construction, side view.

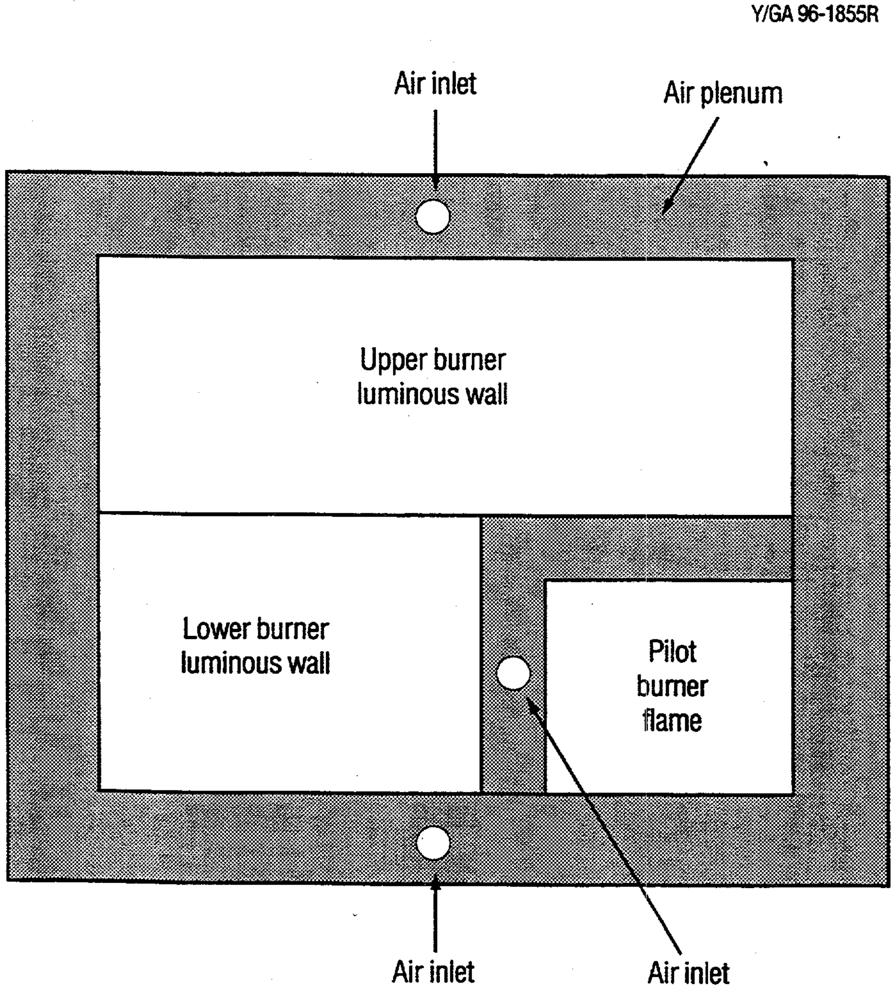

Fig. 4. Furnace wall construction, front view

Although the patents suggest that passageways should be drilled or formed in the porous refractory to ensure a uniform distribution of gases through the refractory wall, Figs. 1 and 2 do not indicate that any such passageways exist in the Room 29 furnace. At the inner surface of the porous refractory wall, the natural gas/air mixture is ignited and burns with a short flame over the entire wall, causing the wall to become luminous. The cooling air, diffusing through the porous refractory, prevents overheating of the firing sections and provides convective heat transfer to the furnace during the initial stages of operation. The main burners are fired intermittently to control the temperature of the furnace.

HOODS

Hood 66 has three parts: the furnace loading hood (Fig. 5), the pan cooling hood (Fig. 6), and the pan unloading glove box (Fig. 5). The furnace loading hood provides contamination control when material in transport containers is transferred to muffle pans or when the furnace door is open. A port behind the furnace loading hood connects to the furnace door port. The ports are sealed with an asbestos gasket (see Fig. 7) and immobilized with bolts. Both ports are wrapped with coils for water

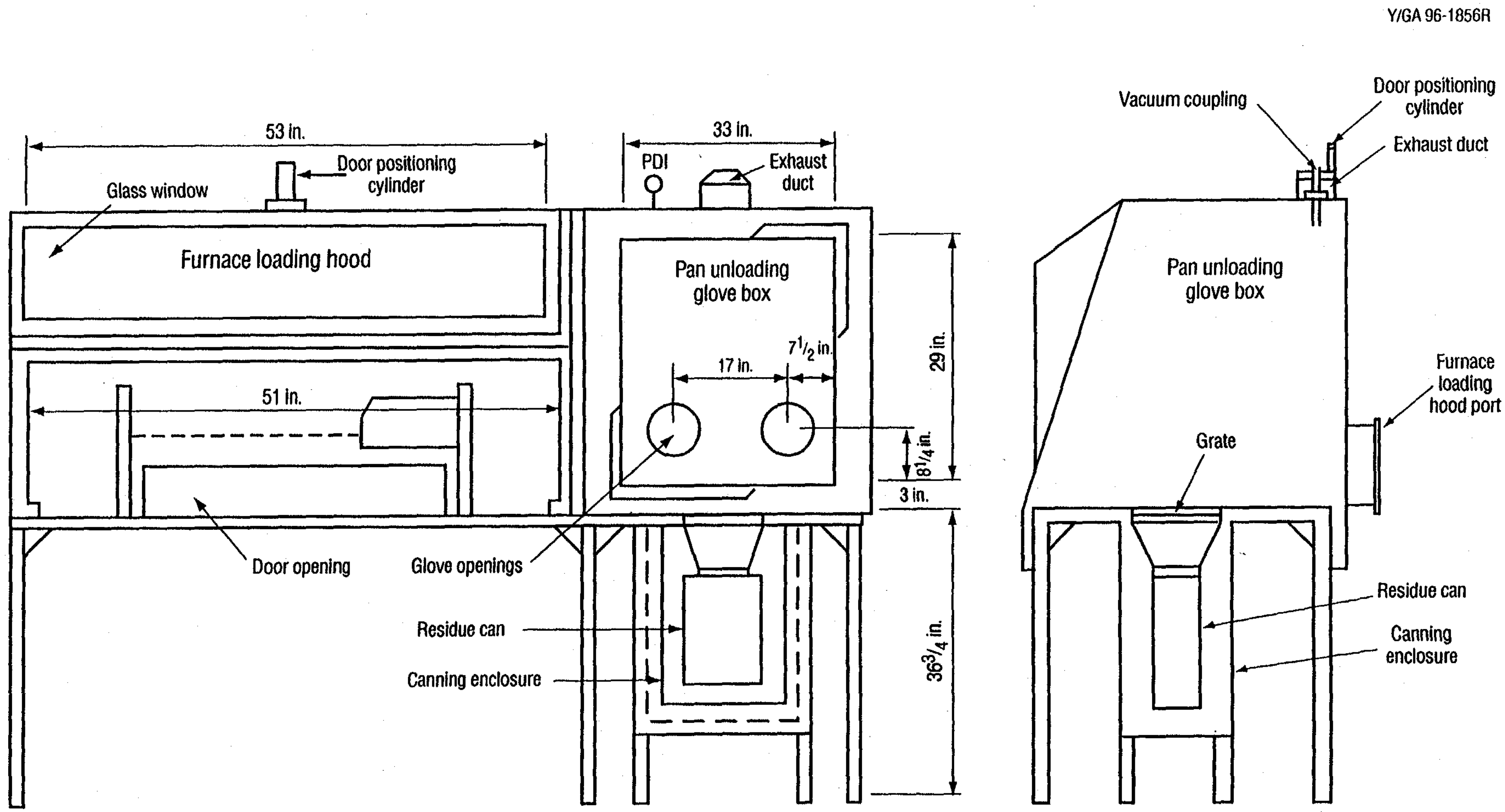

Fig. 5. Furnace loading hood and other details.

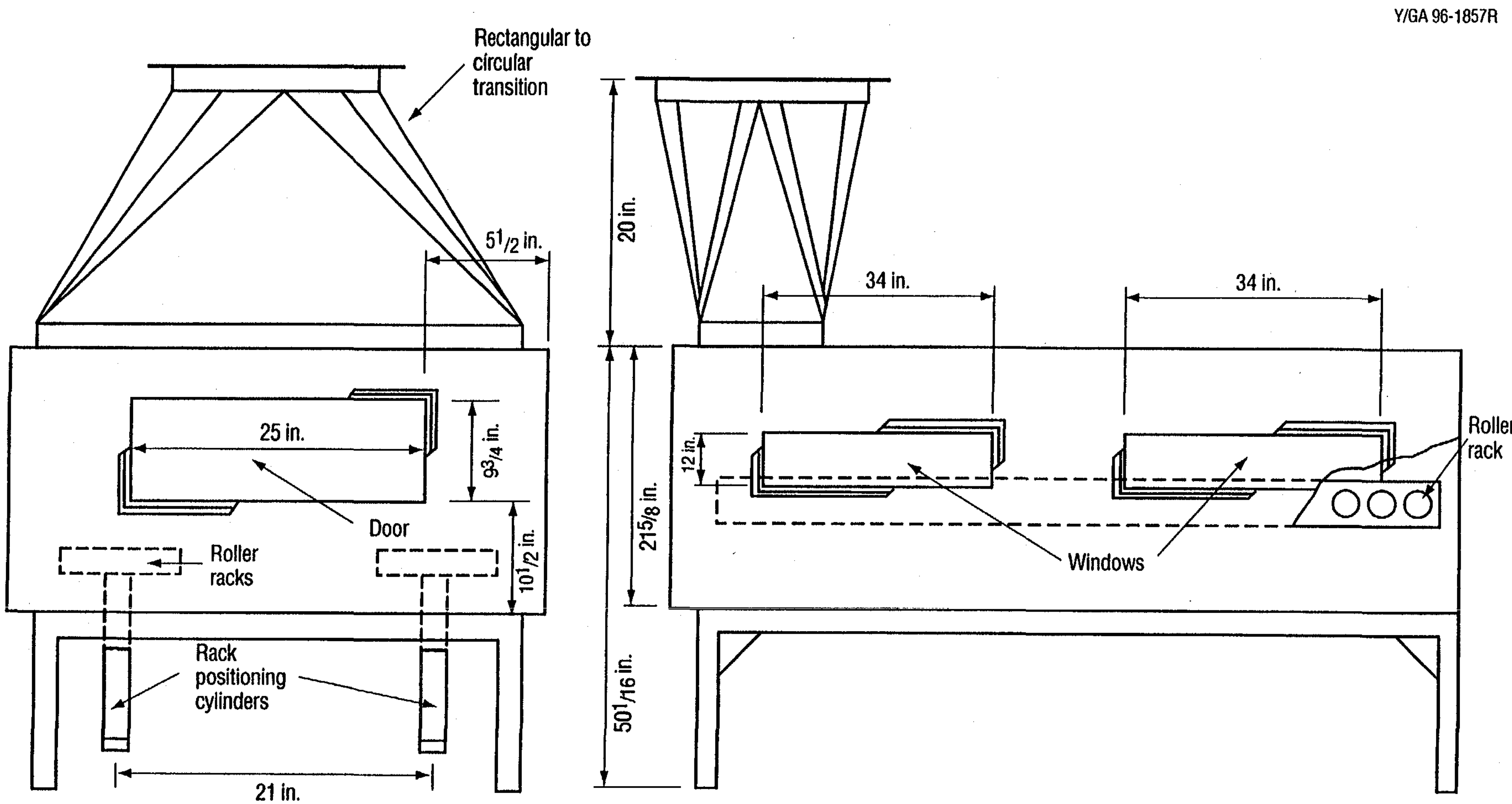

Fig. 6. Cooling hood details.

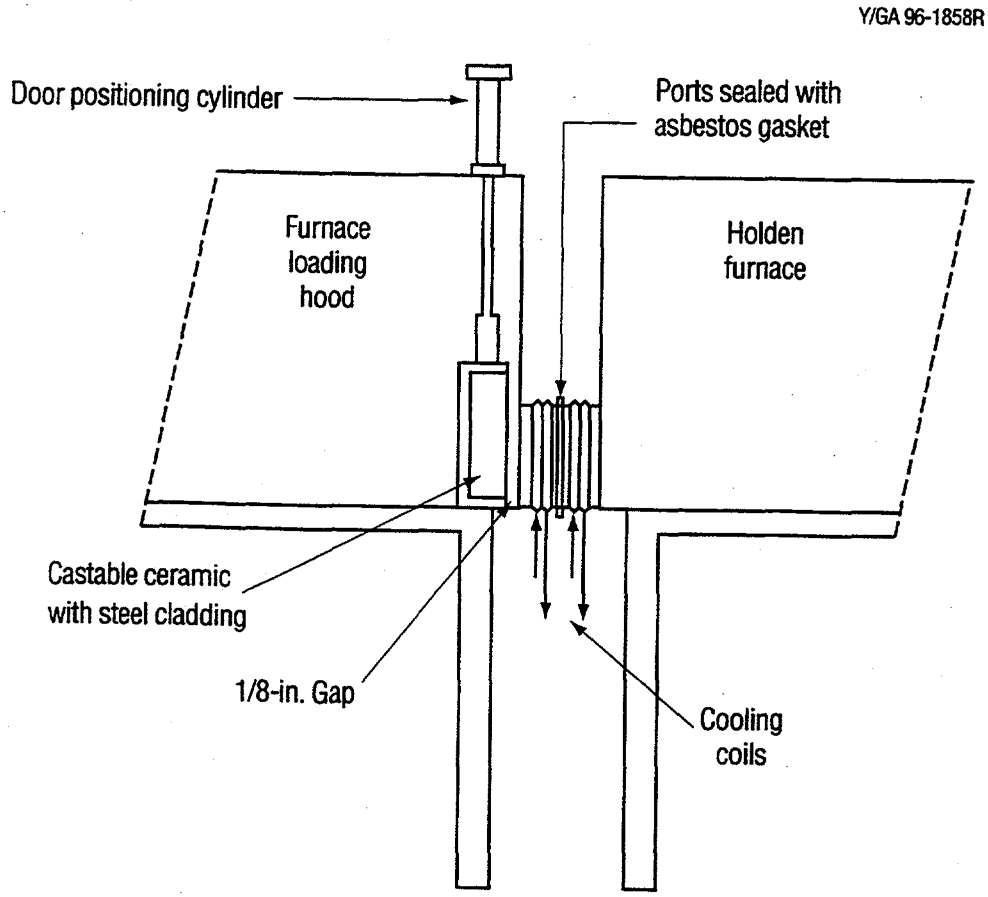

Fig. 7. Furnace door, ports, and cooling coils.

cooling, presumably to protect the seal. With the cooling coils in place, other gasket material should be suitable. The furnace door positioned in front of the hood port is made of castable refractory (according to available documentation, Stores No. 01-246-4900) surrounded by steel on three sides.[10] A designed 1/8-in. gap is left between the door and the port opening, perhaps to avoid damaging the exposed ceramic face. The door is raised and lowered by a 60- to 90-psig pneumatic positioning cylinder. The furnace loading hood is exhausted through the pan cooling hood.

Pans of dried or combusted material are stored in the pan cooling hood until they are cool enough for further handling. The pan cooling hood contains two roller racks, which can be raised or lowered by pneumatic positioning cylinders, to help slide the pans into and out of the hood. Drain holes are provided in the bottom of the pan cooling hood.

The pan unloading glove box adjoins the furnace loading hood; the opening between the hood and the glove box is fitted with a rubber curtain. Openings are provided in the pan unloading glove box for an exhaust duct, a differential pressure gauge, a vacuum coupling, and a port to a canning enclosure located directly beneath the glove box. The opening between the pan unloading glove box and the canning enclosure is covered by a grate. A drain hole is in the bottom of the canning enclosure. Cooled material is dumped in the pan unloading glove box and forced through the grate into a can positioned in the canning enclosure.

The exhaust duct from the glove box joins the duct from the pan cooling hood immediately upstream of the sail switch. Typically, the differential pressure in the hood is approximately –0.03 in. of water column (wc). DOE Order 6430.1A, *General Design Criteria*, Division 11, states that the minimum negative differential pressure in glove boxes or enclosures should be 0.3 in. wc.[11] DOE Order 6430.1A applies here even though the glove box is not a true enclosure for criticality analysis because the curtain between the furnace loading hood and the pan unloading glove box does not create a seal.[12]

An alternative method of unloading the material is to transport the material to cans in the gulping glove box using a dry vacuum system. Material is vacuumed out of a cooled muffle pan in the pan unloading glove box through a hose connected to the vacuum coupling. The gulping stream is not in service now.

NATURAL GAS TRAIN

The unit connects to a 15-psi natural gas supply line (Fig. 8). Regulators (Fisher Controls) immediately reduce the pressure in lines that feed both the main burners and the pilot burners to 6 to 10 in. of water. The regulators should function properly with a supply pressure of between 1 and 60 psi.[13] Gas flow to the main burners proceeds through a block-and-bleed valve arrangement using a North American safety shut-off valve as the primary block valve, an ASCO shut-off valve as the secondary blocking valve, and an ITT General Control solenoid valve as the bleed valve. A low-pressure switch set at 4 in. wc is located upstream, and a high-pressure switch set at 15 in. wc is located downstream of the primary blocking valve. The pipeline splits to the north and south sides of the furnace. On each side, before entering the burners, the gas flows through temperature control valves (TCVs), a limiting orifice (throttle) valve, a premixer, and a low-pressure switch set at 4 in. wc.

From the pilot gas regulator, gas flow to the pilot burners proceeds through a solenoid-operated shut-off valve before splitting to the north and south sides of the furnace. On either side, the gas flows through a limiting orifice valve, which is the means for making fine adjustments to the gas flow, before entering the nozzle of the Maxon burner. A small bleed line feeds a portion of the pilot gas stream into the combustion air stream, which then flows through the ignitor port. A small manual shut-off valve and a fine adjustment valve are in the bleed line.

The gas flow rates shown in Fig. 8 were calculated as discussed herein. Vendor literature for the North American safety shut-off valve indicates that flow capacity (*F*) can be calculated by Eq. (3):[14]

$$F = 1360\ C_V \left(\frac{P_1^2 - P_2^2}{2GT} \right)^{0.5} , \tag{3}$$

where

C_V = flow coefficient,
P_1 = inlet pressure (psia),
P_2 = outlet pressure (psia),
G = specific gravity,
T = temperature (R).

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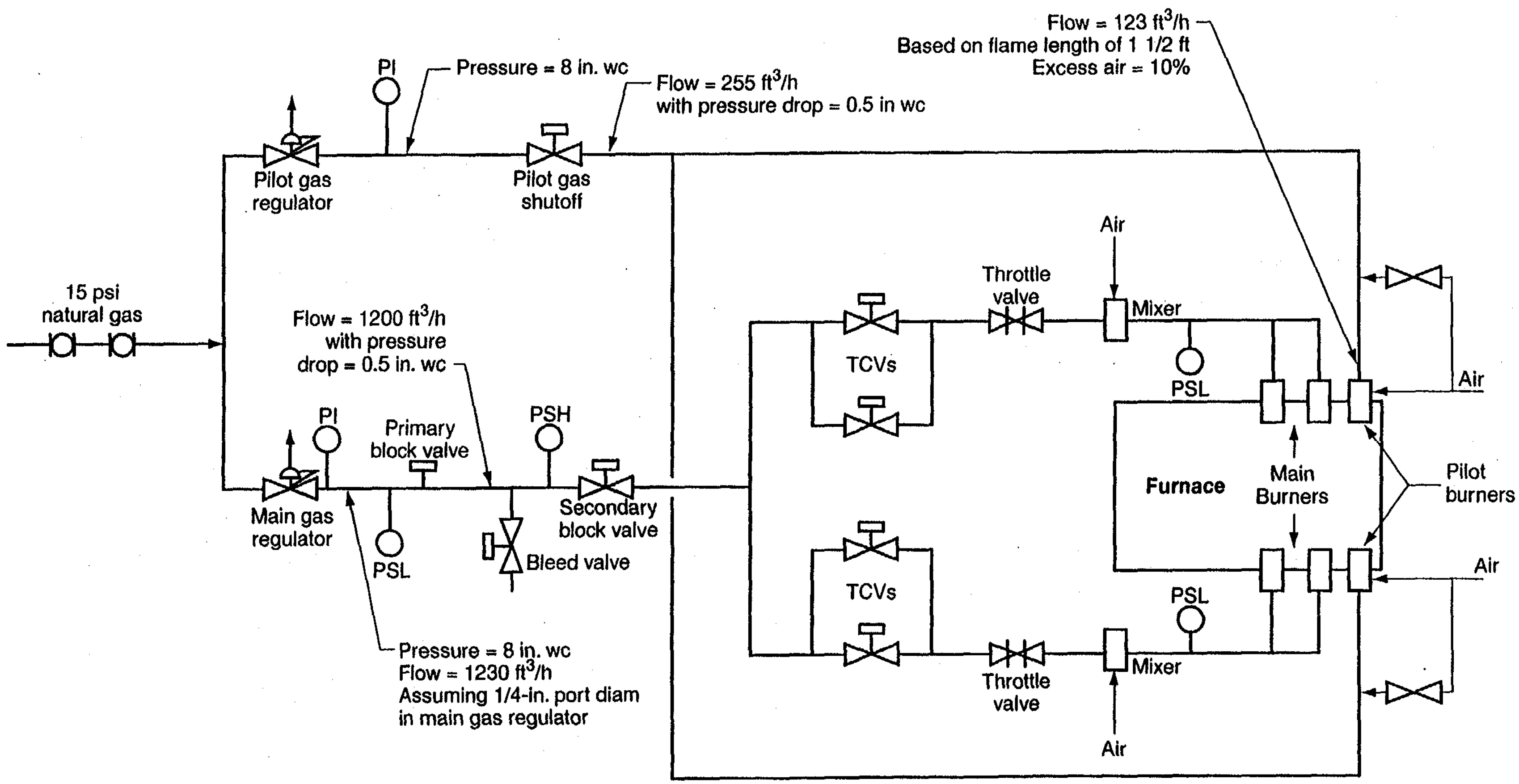

Fig. 8. Natural gas flow into the Holden furnace.

For a given set of conditions, Eq. (3) can be rearranged to Eq. (4):

$$F = C_V \, C_1 \left(P_1^2 - P_2^2\right)^{0.5} , \tag{4}$$

where $C_1 = 1360/(2GT)^{0.5}$.

Comparison of capacity data for recently manufactured North American safety shut-off valves with that for valves manufactured when the furnace was installed shows that capacities for the newer valves are two to three times higher than those for the older valves.[15] Using $F = 8900$ ft^3/h, $P_1 = 5$ psi, and $P_2 = 4$ psi as tabulated in the literature for the older valves, ($C_V C_1$) was calculated as 1435.95. Capacity for $P_1 = 8$ in. wc (15.076 psia) and $P_2 = 7.5$ in. wc (15.071 psia) was calculated as shown in Eq. (5):

$$\begin{aligned} F &= (1435.95)\,(15.076^2 - 15.052^2)^{0.5}, \\ F &= (1435.95)\,(227.28 - 226.58)^{0.5}, \\ F &= 1201.89 \text{ ft}^3\text{/h}. \end{aligned} \tag{5}$$

Similarly, capacity data for the Fisher regulator, upstream of the North American safety shut-off valve, can be used to determine the flow rate through this line. Available documentation indicates that the regulator is a model S100 with a range of 5.5 to 8.5 in. wc. To use the capacity tables in the vendor literature, one must also know the port diameter. Not only is the port diameter unknown to the author at this time but also the model number has not been field verified. Using the model number listed in available documentation and assigning a port diameter of 1/4 in., one can interpolate the capacity of natural gas from vendor data. The capacity is 1230 ft^3/h.[13]

For the 3/4-in. ITT General Control K30 valve on the pilot gas line, $C_V C_1$ (calculated using Eq. (4) and $F = 415$ at $P_1 = 5$ psi and a pressure drop of 1 in. wc, as indicated in the vendor literature believed to be valid at the time of furnace installation) is 305.15.[16] Using an inlet pressure of 8 in. wc and an outlet pressure of 7.5 in. wc, one calculates the flow rate of the pilot gas as 255.31 ft^3/h.

The pilot gas flow rate can also be estimated using vendor data for the Maxon burner, which show maximum and minimum capacities in terms of Btu/h for various input combustion air pressures.[9] The approximate diameter and length of flame expected for the given maximum power are also listed. There is no way of knowing where, between the maximum and minimum values, the Room 29 furnace is operating. However, the flame size versus the power data can be used to estimate the gas consumption based on observed flame length. According to theory, flame height is related to power level by Eq. (6).[17]

$$H = CP^{0.4} , \tag{6}$$

where

H = flame height (in.),
P = power level (Btu/h),
C = constant.

The constant, C, depends heavily on the amount of excess air used in the combustion process. Theory predicts that, for a given power, flame height increases as excess air increases. A plot of Eq. (6), using data for the WR-1 1/4 burner, is shown in Fig. 9. The data fit Eq. (7) with a correlation coefficient of 0.97.

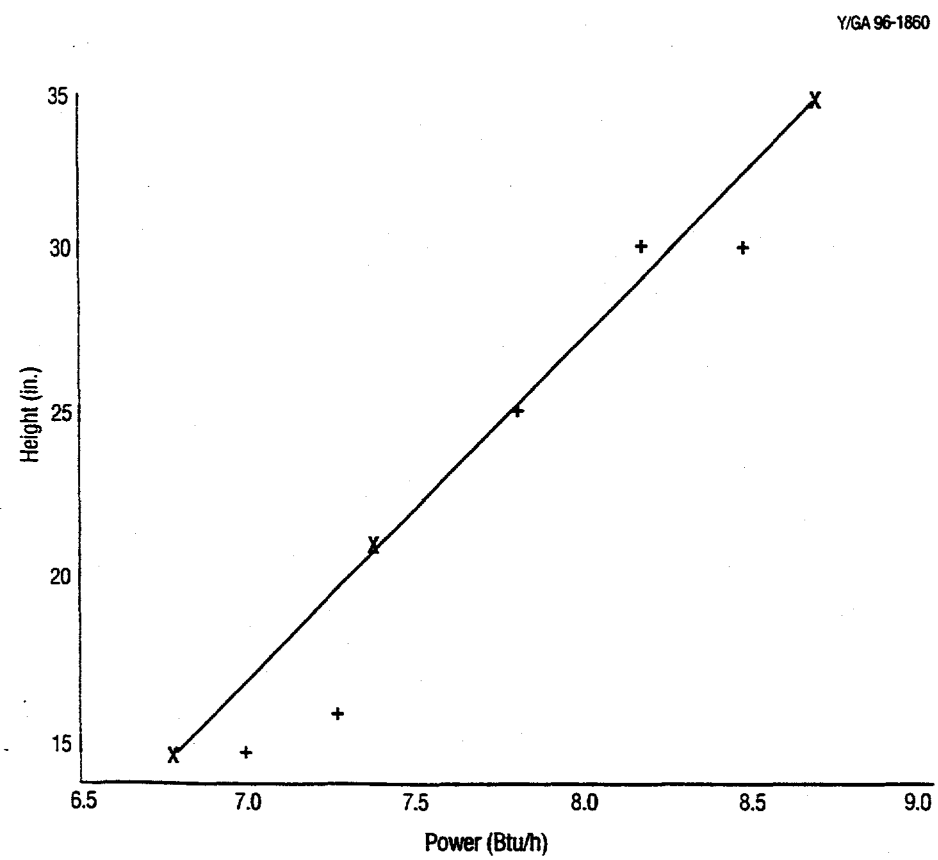

Fig. 9. Relationship between capacity and flame height of Maxon WR-1 1/4 burner.

$$H = 10.116\, P^{0.4} - 54.05\,. \tag{7}$$

A flame length of approximately 18 in. has been observed during furnace operation, although opportunities for observations have been limited. According to Eq. (7), the burner delivers 135,000 Btu/h. Natural gas contains essentially 1000 Btu/scf; therefore, the gas flow rate is calculated as 135 ft^3/h. Data given in the vendor literature are assumed to correspond to an excess air factor of 1.

Examination of literature data indicates that the relationship between C and the excess air factor (f) is essentially linear.[17] For a given flame height, the greater the excess air factor, the lower the power level of the flame. If one assumes an excess air factor of 1.1 (10% excess air), the flame power is 123,000 Btu/h. The gas flow rate for each Maxon burner is 123 scf/h. The total flow rate is 246 ft^3/h, which agrees closely with that calculated from the flow capacity of the pilot gas solenoid valve.

COMBUSTION AND FURNACE AIR

Combustion air and furnace purging and cooling air are provided by a North American Premix turbo blower. The blower uses a 5-hp motor to pull in air from Room 29 through a filter and deliver 43,800 scf/h of air at 16 oz/in.^{2} (25 in. wc) through a 6-in. header to the furnace.[18] Figure 10 shows the operating curves. A low-pressure switch set at 17.5 in. wc is located in the header. Combustion

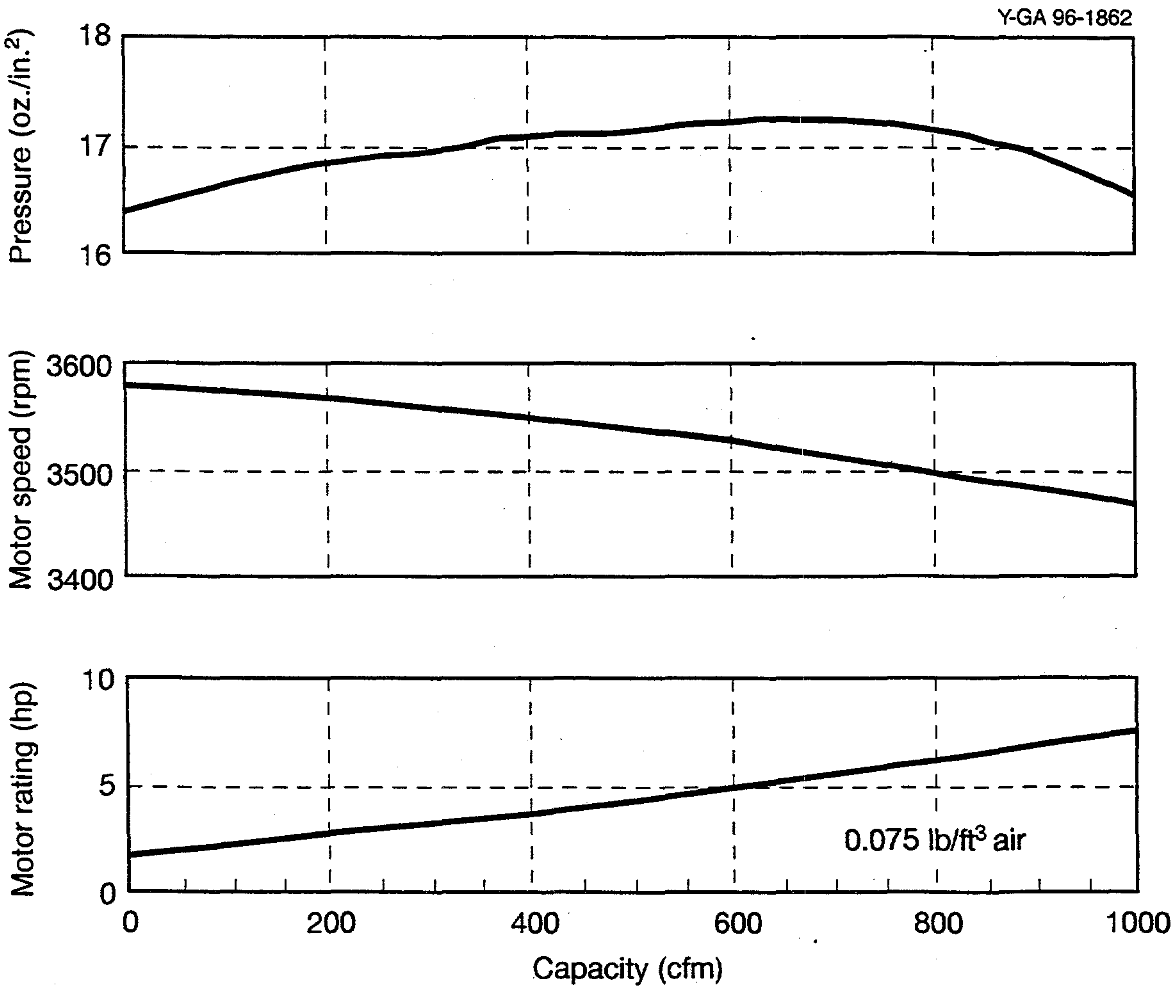

Fig. 10. Characteristic operating curves for North American Mfg. Co. No. 316-D1-5 turbo blower with 21 3/4-in.-diam impeller.

air lines to the premixers and the pilot burners exit the header. Furnace purge and cooling air lines exit the header and enter both the furnace cover and the north and south sides near the main burners and near the pilot burners.

The airflow distribution, shown in Fig. 11, was calculated by Eqs. (8) through (12), which assume that the airflow distribution is proportional to the smallest diameter of lines exiting the header. Pressure drops along the header, through the lines, and across the mixers and burners are not considered. Available documentation does not list the air orifice diameter of the Maxon LG 200' mixers used on the Room 29 furnace. Maxon literature lists the largest orifice diameter as 1.25 in., which is used in the calculation.[19] All combustion air going to the pilot burners is channeled through the Maxon burner pilot ports. Although the Maxon literature does not state the diameter of the pilot port, the diameter appears to taper from 0.5 in. to 0.25 in.

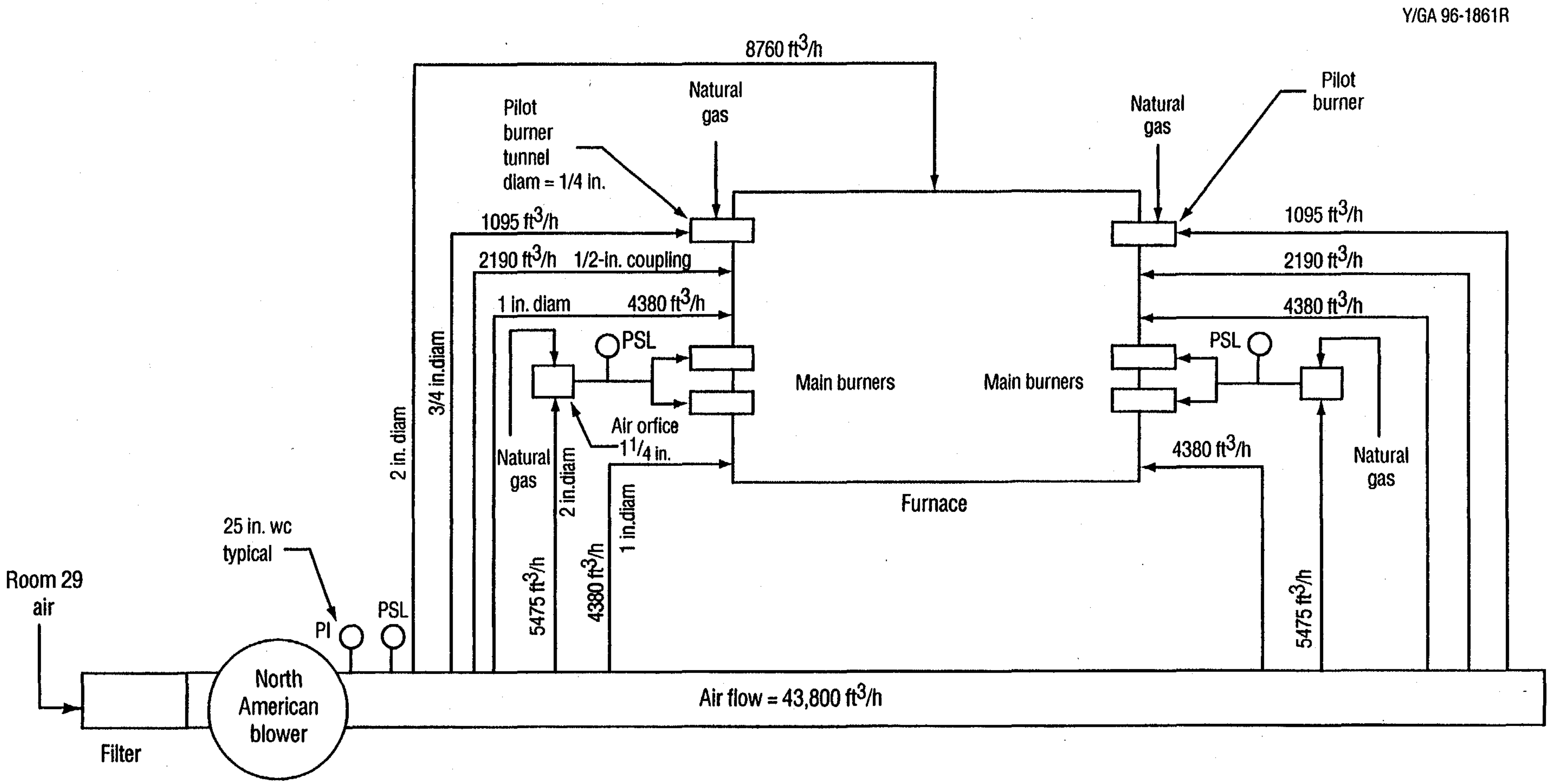

Fig. 11. Holden furnace air flow.

$$1a + 2b + 2c + 4d + 2e = 43{,}800, \quad (8)$$
$$a = 2d, \quad (9)$$
$$b = 1.25d, \quad (10)$$
$$c = 0.5d, \quad (11)$$
$$e = 0.25d, \quad (12)$$

where

a = airflow (scf/h) through a 2.0-in. line going to the cover,
b = airflow (scf/h) through a 1.25-in. orifice diameter in mixers,
c = airflow (scf/h) through 0.5-in. cooling air lines near the pilot burners,
d = airflow (scf/h) through 1.0-in. cooling air lines near the main burners,
e = airflow (scf/h) through a 0.25-in. pilot port diameter .

Solving simultaneously gives the following results: $a = 8760$, $b = 5475$, $c = 2190$, $d = 4380$, and $e = 1095$.

The total airflow to all six burners is 13,140 scf/h, or 2628 scf/h oxygen, using the mole fraction of oxygen in air as 0.2. According to Eq. (13), stoichiometric combustion requires 1314 scf/h methane:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O \ . \quad (13)$$

Given that the assumption of 10% excess air is correct, the calculations of Fig. 8 suggest that approximately 16,000 scf/h air should be delivered to the burners. The air flow rate in Fig. 8 agrees with the flow rate calculated by Eqs. (8) through (12) within approximately 18%.

EXHAUST SYSTEM

The air supplied by the blower would in itself create a forced draft; however, because exhaust fan EF-120 (formerly AJ-701) creates a slight vacuum (-0.50 to -0.25 in. wc) in the chamber during operation, the furnace exhaust operates primarily as an induced draft. The airflows shown in Fig. 12 are taken directly from drawing H2E-117517.[20] When the exhaust blower is operating with the combustion blower off (implying a nonfiring state because the furnace cannot be fired without operation of the combustion blower) and the furnace door closed, the pressure in the chamber is typically -1.5 in. wc. The furnace exhaust port connects to a rectangular-to-circular transition requiring an asbestos gasket as a seal. The transition connects to a 10-in.-diam exhaust duct, which expands to a 14-in.-diam duct; the change from a 10-in-diam to a 14-in.-diam duct resulted from rework of the exhaust system. The entire exhaust duct is wrapped by a water cooling coil.

The hood sections are also exhausted by EF-120. Filters and dampers are located in the ducts exhausting each hood. A Honeywell sail switch, set at 1000 ft/min, is located in the hood exhaust ductwork. The hood exhaust joins the furnace exhaust and passes through a flame arrestor before exiting Room 29 to pass through the EF-120 filter house, which contains roughing filters and high-efficiency particulate air (HEPA) filters. The exhaust exits through Stack 33. A dial thermometer is set in the duct to measure the temperature of exhaust gases before they exit Room 29.

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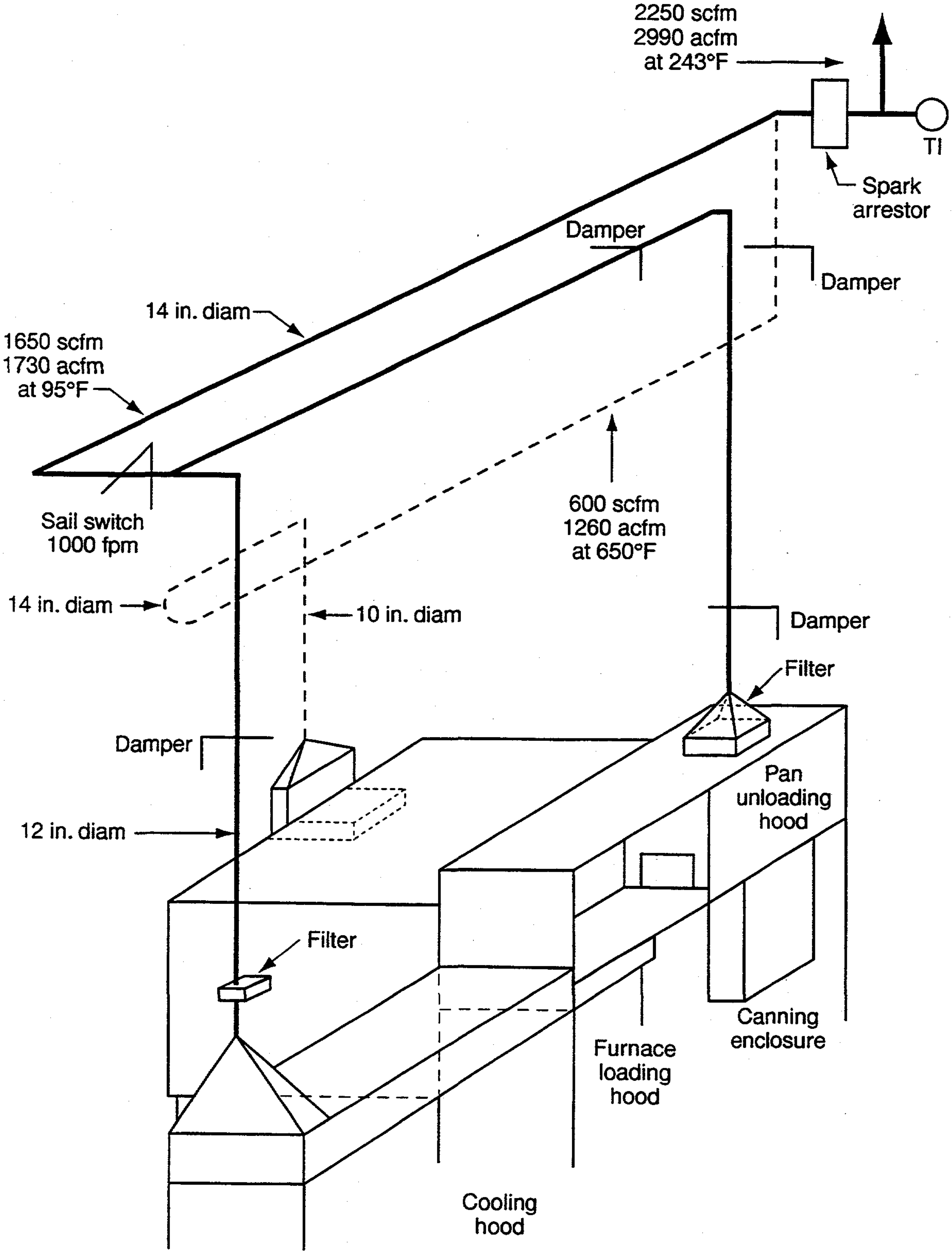

Fig. 12. Holden furnace exhaust.

PRIMARY PROCESS CONTROL SYSTEM

The temperature of the furnace is maintained by a simple on/off control loop. A thermocouple under the furnace tray is connected to a Barber-Colman (Wheelco) 471P temperature controller (Fig. 13). The controller operates a control valve on the north side and a control valve on the south side of the furnace. When the thermocouple senses high temperature, the valves are closed to prevent gas feed to the main burners. When the thermocouple senses low temperature, the valves are opened to allow gas flow and re-establish flame at the main burners.

ALTERNATE PROCESS CONTROL SYSTEM

If any part of the primary process control system is not functioning, an alternate system is available (see Fig. 13). Bypass control valves, parallel to the primary control valves, can be operated by a timer to maintain furnace temperature. Operators monitor the temperature changes and adjust timer settings until acceptable temperature gradients are established. The bypass valves will not open if the furnace over-temperature switch senses an over-temperature condition.

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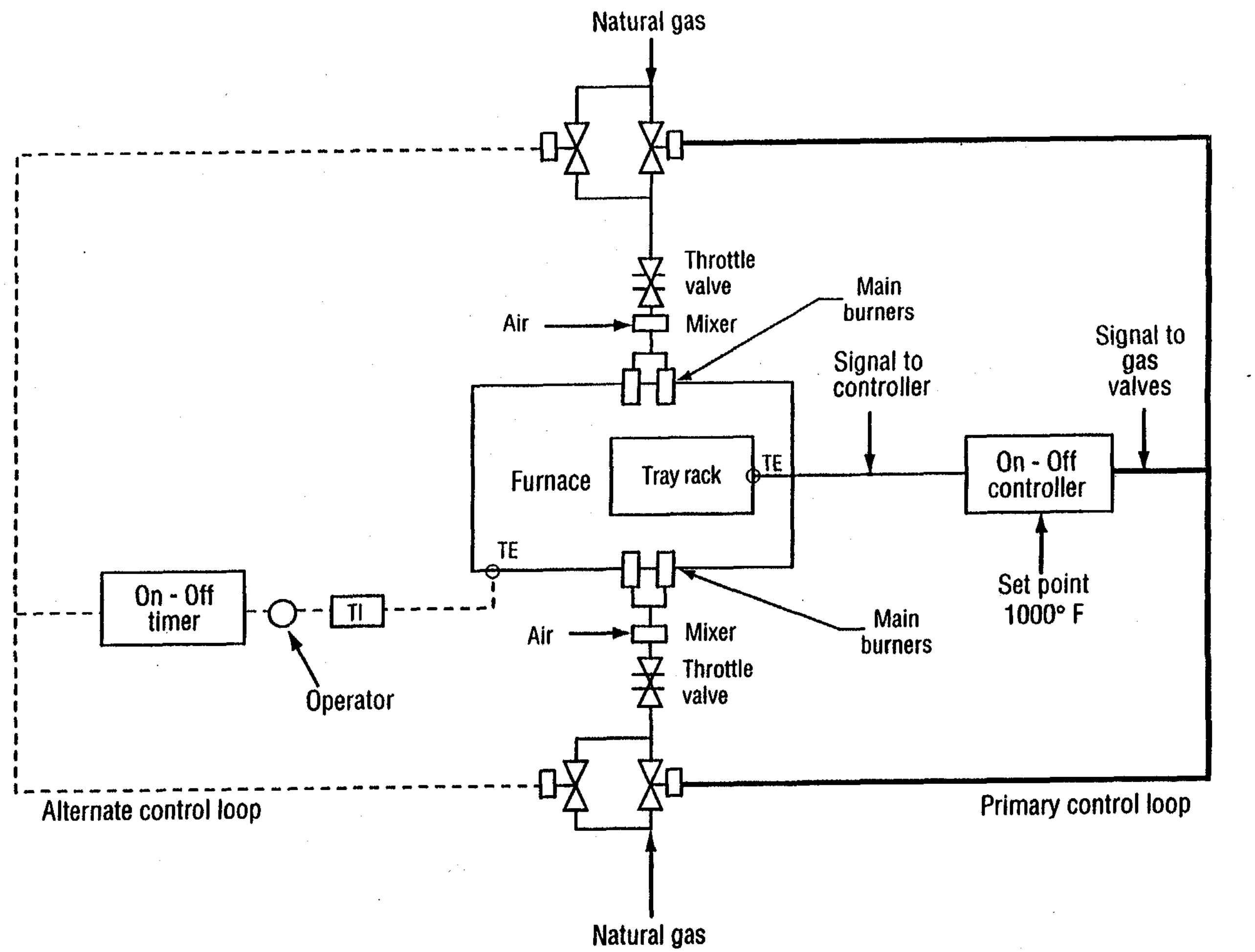

Fig. 13. Process control system.

SAFETY

The furnace is safe by design. DOE Order 6430.1A, Division 15, indicates that a number of interlocks or controls should be in place to prevent ignition of certain types of fired process equipment under unsafe conditions and to extinguish all burners if unsafe conditions arise after ignition. Although the requirements are not specifically for the Holden furnace, the suggested interlocks are in place and are shown in Figs. 14 and 15. The pilot burners cannot be ignited if there is

- inadequate cooling water flow [control relay (CR 9) to port coils or the exhaust duct],
- inadequate exhaust flow (CR 8, 1000 ft/min minimum),
- high wall temperature (CR 4, 1200°F maximum),
- an overload of the blower motor,
- inadequate blower air pressure (17.5 in. wc minimum),
- inadequate natural gas supply pressure (4 in. wc minimum),
- high natural gas supply pressure (15 in. wc maximum), and
- a purge timer switch that is not in place.

The purge timer is activated by the same switches that turn on the blower motor and is set so that the timer switch will close after 3.5 min of blower operation, which purges the furnace and plenums of combustible gases. After ignition, all of these interlocks must remain in place to keep the North American shut-off valve and the pilot gas shut-off valve open, which keeps the main burners and the pilot burners firing. Also, the pilot flames are monitored so that loss of flame at either pilot burner will extinguish all burners by closing the automatic shut-off valves. Loss of electrical power to the system will also shut off the burners.

The possibility of flame flashback is a recognized problem whenever a premix system is used.[21] The low premixed gas/air pressure switches, set at 4 in. wc, will close the North American shut-off valve to prevent flashback into the premixing pipe and tube. The low premix switches do not extinguish the pilot burners. According to the furnace patents, flashback in the plenums does not occur because the gas/air flow rate through the porous refractory and the use of cooling air around the burners keep the temperature in the plenums and the adjacent refractory below the ignition point of natural gas.[3]

The sail switch in the hood exhaust duct is the unit's design feature for safety; however, the Final Safety Analysis Report (FSAR) and the Operational Safety Requirements for the Y-12 Plant Chemical Processing Systems Buildings 9212 and 9206 (Y/MA-6290, Sects. 4.2.17 and 5.2.6) indicate that both the furnace purge cycle and the sail switch are required to mitigate the accumulation of explosive vapors.[22] Because of its location in the hood exhaust duct, the sail switch indicates nothing about the conditions in the furnace chamber. Closure of the switch verifies that air is flowing from the hood and that the exhaust fan is working, indirectly verifying that the furnace chamber is properly exhausted. If the chamber is properly exhausted, explosive vapors cannot build up, and explosions are prevented. The purge cycle more directly ensures the safety of the furnace by flushing out any lingering combustible gases before an ignition source is introduced. Also, the quantity of air

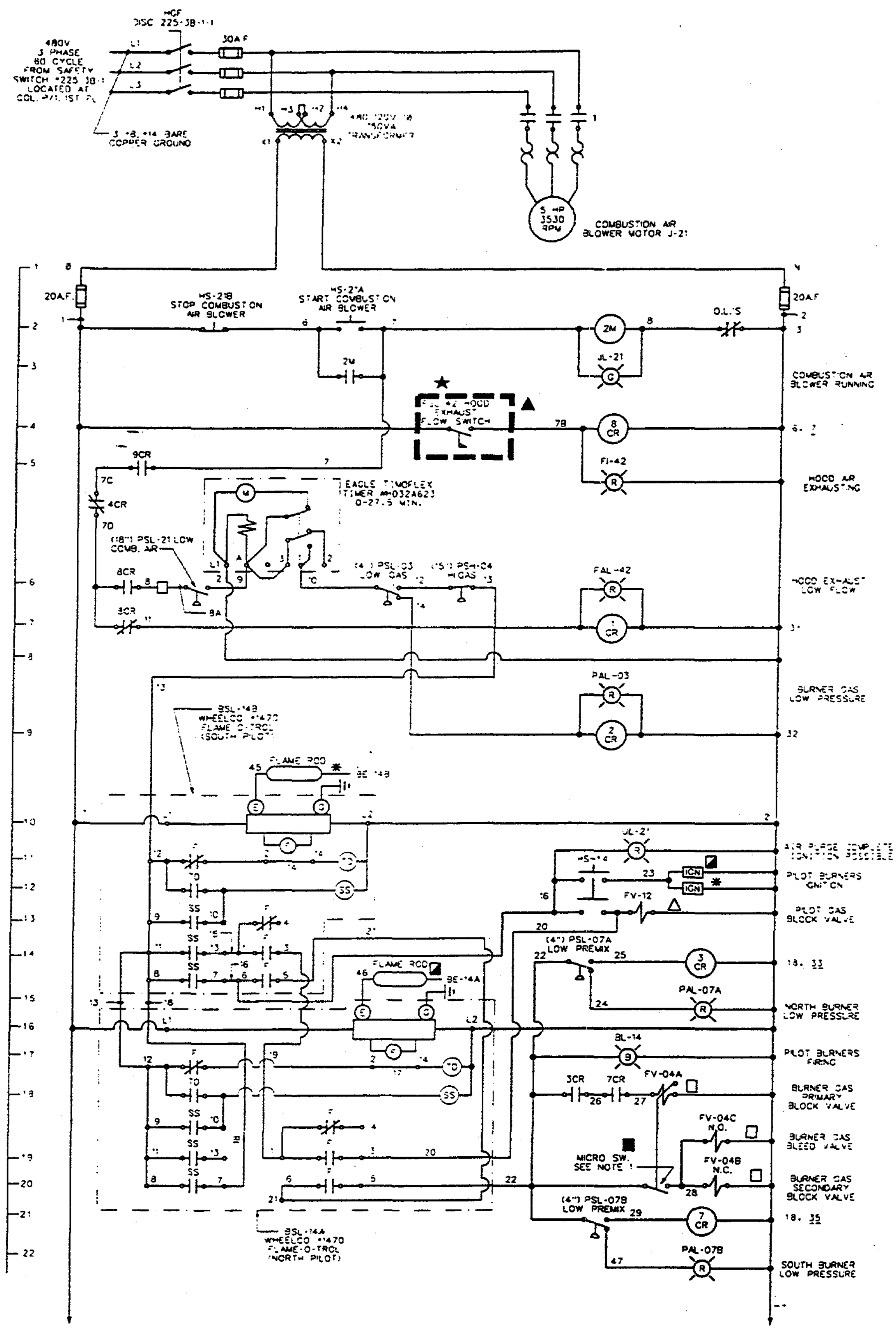

Fig. 14. Holden furnace control panel MCBD-141.

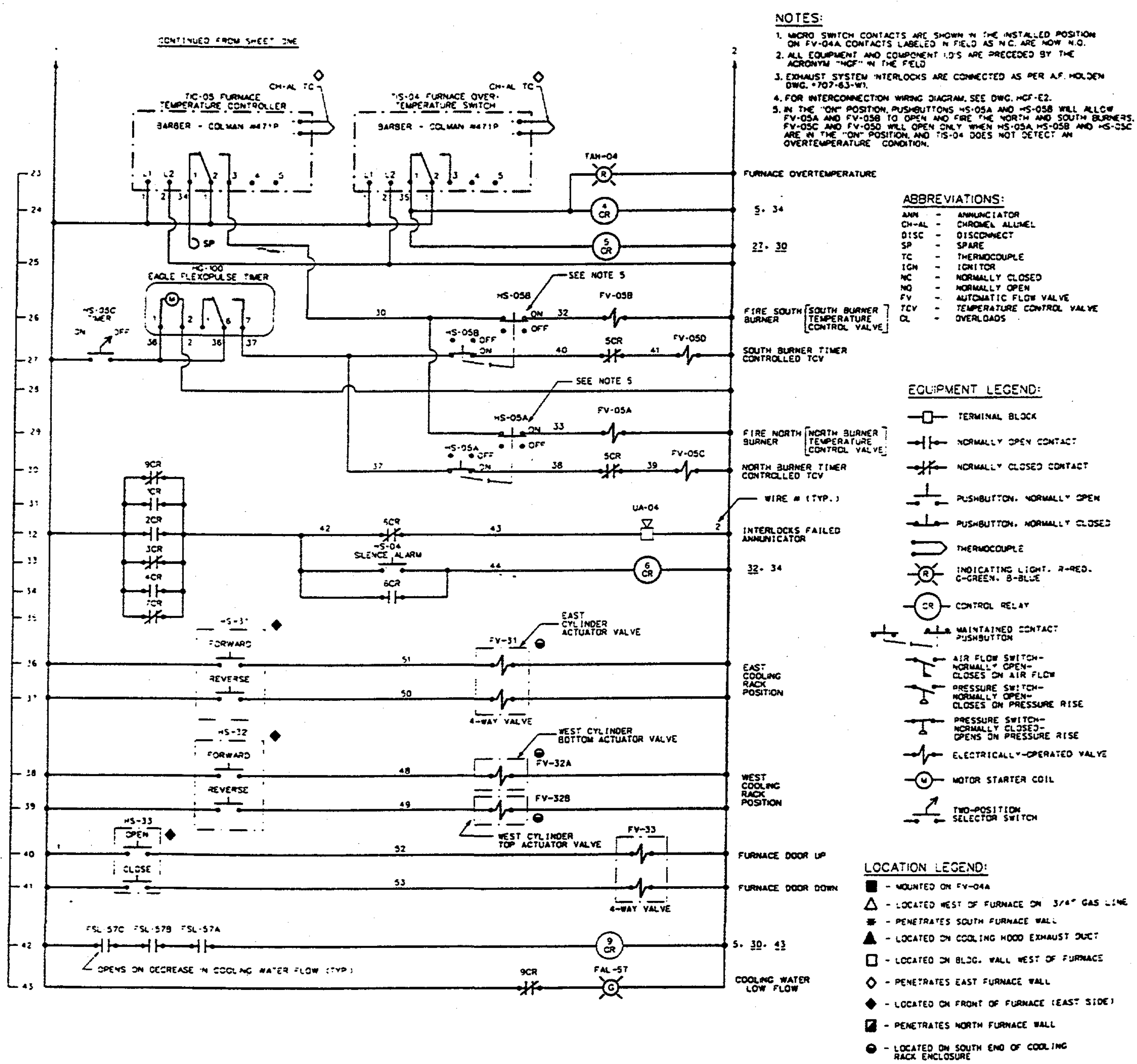

Fig. 14. (continued)

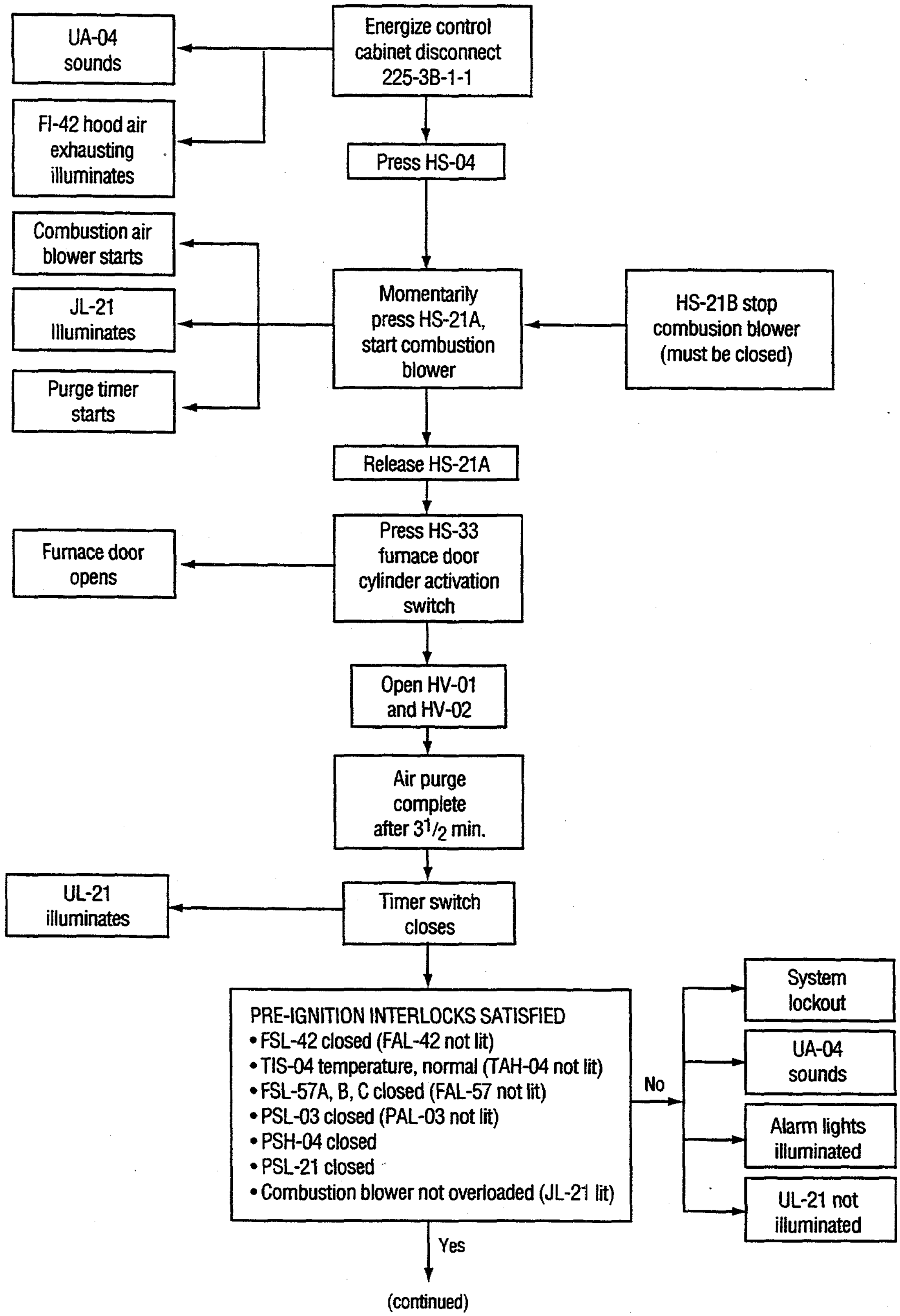

Fig. 15. Electrical schematic flow chart.

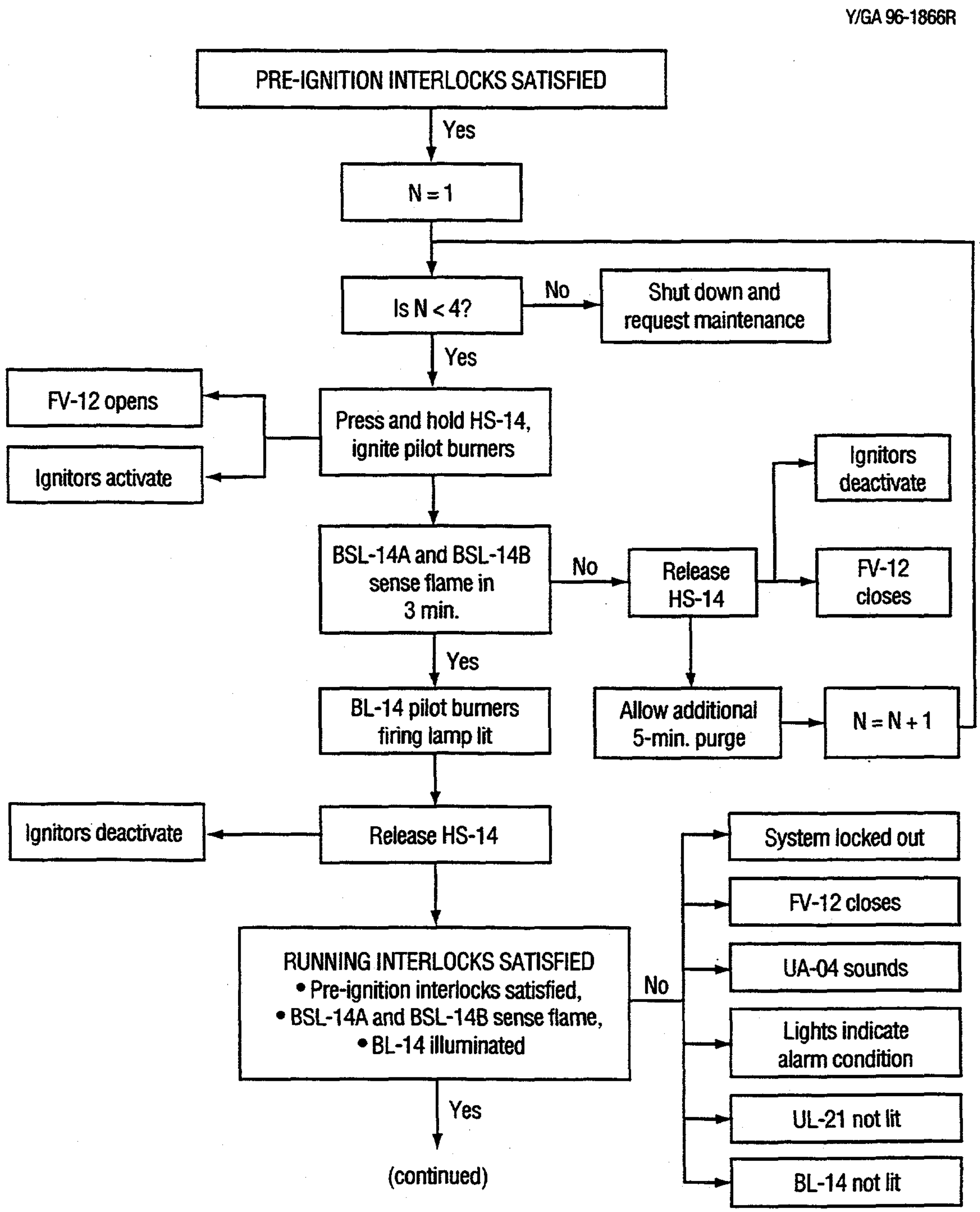

Fig. 15. (continued)

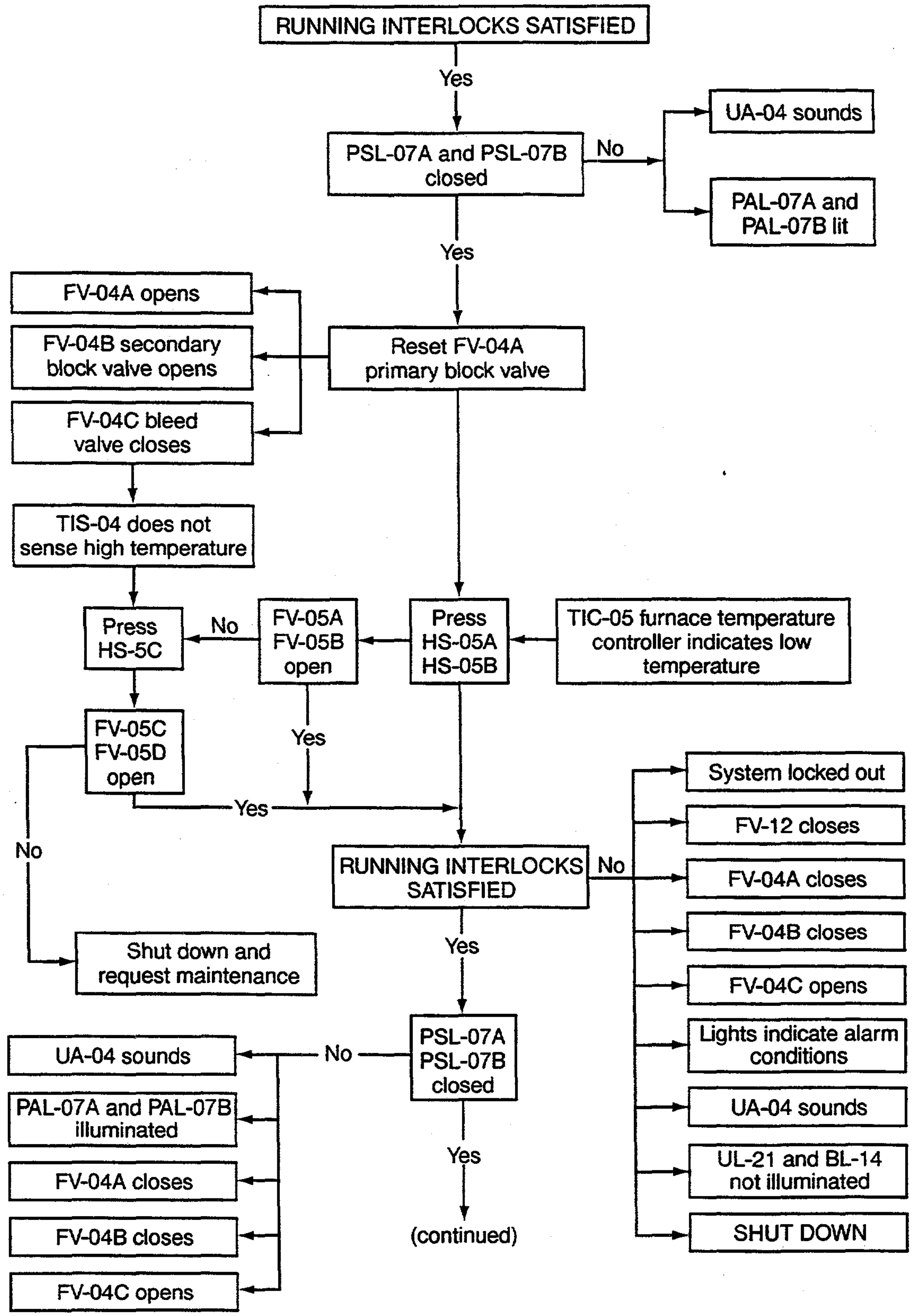

Fig. 15. (continued)

Y/GA 96-1868R

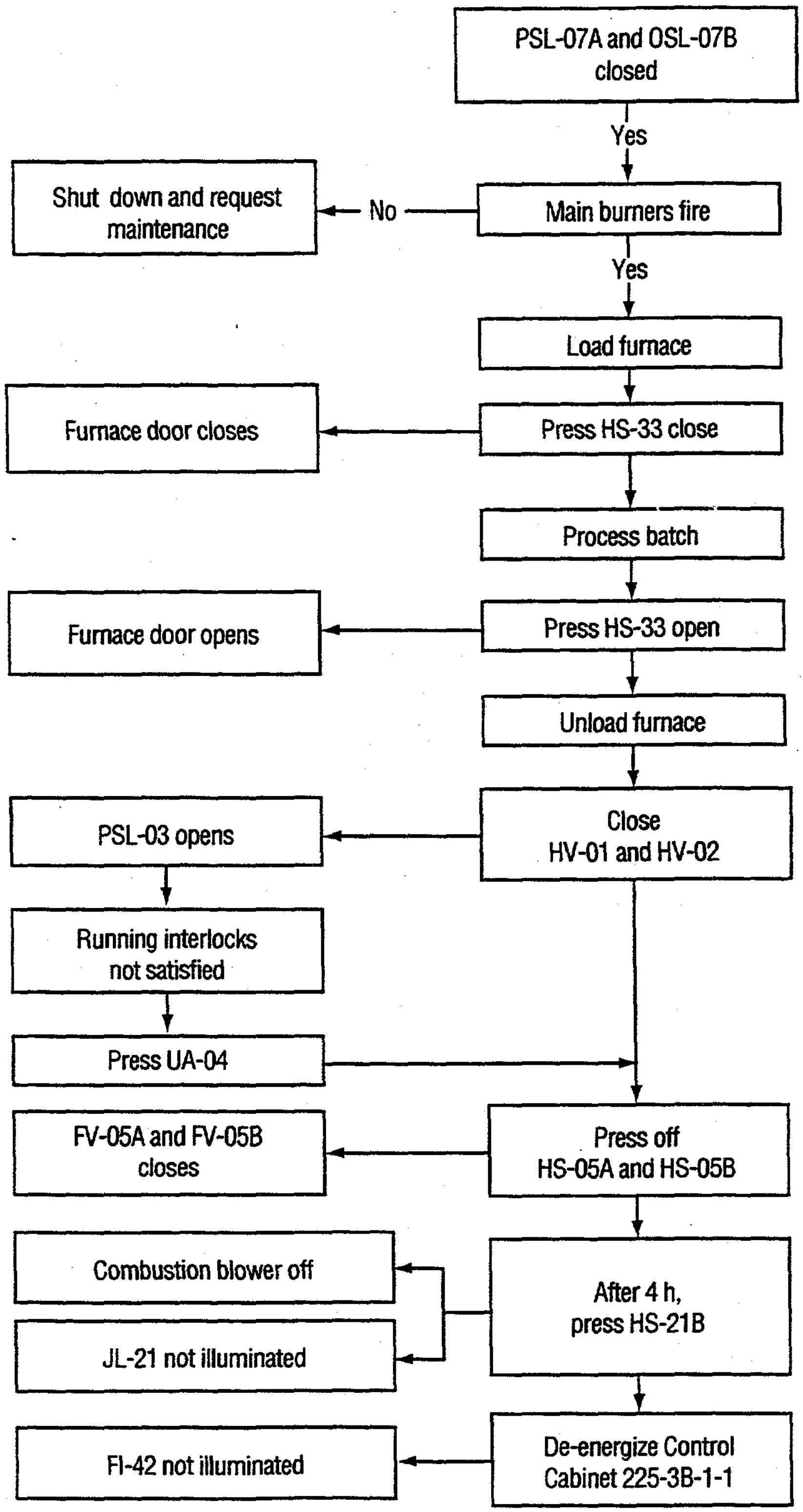

Fig. 15. (continued)

provided by the combustion blower during operation precludes the possibility of formation of an explosive mixture in the furnace chamber. (The lower flammability limit of methane in air is 4.3% by volume.)

The total flow rate of air into the chamber is 43,800 scf/h, and the flow rate of gas is 1456 scf/h; therefore, the steady state concentration of gas in the chamber is 3.32%, which is below the lower flammability limit. Equation (14) can be used to show that the concentration reaches steady state in 5 min.

$$C_g = \left(C_0 \frac{F_1}{F_1 + F_2} \right) \left[\exp \frac{-t(F_2 + F_1)}{V} \right] + \left(\frac{F_1}{F_2 + F_1} \right) , \tag{14}$$

where

C_g = concentration of gas,
C_0 = beginning concentration of gas = 0,
F_1 = flow rate of gas = 1456 ft^3/h,
F_2 = flow rate of air = 43,800 ft^3/h,
t = time (h),
V = volume of enclosure = 40.58 ft^3.

Figure 16 shows that a number of unlikely events would have to occur simultaneously before a combustible mixture could be created in the furnace chamber.[22]

The dimensions of the furnace chamber (with a length- or width-to-height ratio of close to 1) make the possibility of a detonation unlikely; therefore, any explosion would probably be the result of sudden ignition and overpressure of combustion gases.[23] According to the FSAR, the furnace should be able to withstand the effects of sudden ignition.[22] Only localized ripping, tearing, and minimal projectile damage would be expected to occur because the blast wave produced would be weak. There might be widespread danger to occupants of Room 29 and Building 9212 from airborne contamination.

If a fire were to start in the hood exhaust duct, a very slight possibility exists that a detonation could occur. Damage would be more extensive than damage from an overpressure explosion.[23] Flame-tube experiments show that induction lengths of 60 to 120 diameters are typically required for a deflagration of hydrocarbon fuel to transition into a detonation.[24, 25] The actual induction length depends on a number of variables. The pan cooling hood exhaust duct, from the hood to the west wall, has an L/D ratio of approximately 30. If the flame arrestor fails to function and the total enclosure is taken to include some of the ductwork between Room 29 and the EF-120 filter house, it begins to take on the appearance of an enclosure with a large L/D ratio. Because the diameter of the duct increases, the L/D ratio of the total enclosure is probably too small for a detonation to occur unless other variables (e.g., fuel/air ratio, preheat temperature, or turbulence) facilitated the transition to detonation. The bends in the duct would probably create turbulence in front of the combustion wave, which could shorten the induction length by 10% to 15%.[25] However, it is highly unlikely that natural gas could ever enter the exhaust duct and start a fire.

If, by some means, all of the natural gas supplied to the furnace failed to burn and entered the duct, the quantity of air pulled in through the hood would keep the gas/air mixture below the flammability limits. As was stated earlier, the lower flammability limits for methane in air is 4.3 vol %. The gas flow was determined to be 1456 scf/h (Fig. 8); therefore, the quantity of air needed to keep the gas/air mixture below the flammability limit has to be above 32,404 scf/h. (The total flow of methane and hood air would create a velocity of 721.3 ft/min in the 12-in.-diam duct at 95°F. The sail switch is set at 1000 ft/min, which provides a safe margin for this worst case scenario.)

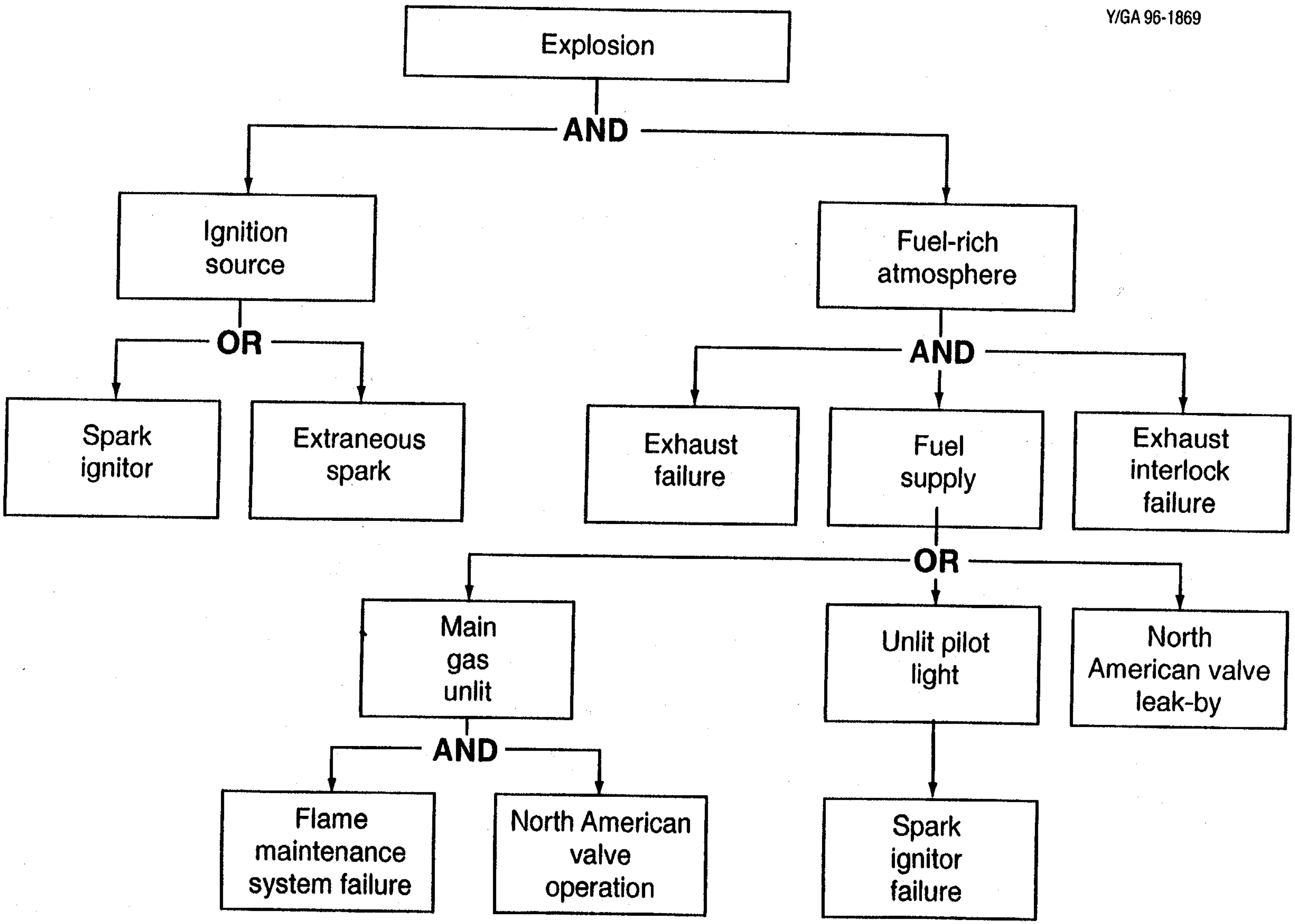

Fig. 16. Events required to create an explosion in the furnace chamber.

The volumetric flow rate of gases through the 12-in.-diam duct, at the flow-switch shut-down velocity of 1000 ft/min, would be 47,100 scf/h. From Fig. 12, typically, about 1650 scfm (99,000 scf/h) of air is pulled into the hoods. Therefore, under normal conditions, 110% more air is pulled into the hoods than the minimum required to prevent formation of a flammable mixture. (The flow rate shown in Fig. 12 might have been calculated from the dimensions of the hood face and a measured hood face velocity rather than the actual measurement at the sail switch position. The face of the furnace loading hood is 1122 in.^{2} With the hood face velocity at 200 ft/min, the calculated flow rate is 93,500 scf/h. The volumetric flow rate is 70,125 scf/h at a face velocity of 150 ft/min.)

Furnace safety could be improved by installation of a timed ignition system (trial for pilot) that resets the purge timer if ignition is not successful after a specified time period. Under current operating practice, this function is performed by the operator releasing the ignition button if the pilots do not light after 3 min and allowing an additional 5 min of purge before he attempts to re-ignite the furnace. Automatic trials for pilot systems usually reset the purge timer if ignition is unsuccessful after several seconds. The 3 min proposed by the procedure in preparation seems to be a reasonable time period for an operator to attempt ignition. Because of the large quantity of blower air delivered, a combustible mixture of natural gas and air should not be generated in the furnace chamber regardless of the amount of time the ignition button is depressed. From Fig. 8, the flow rate of gas through the pilot burners is 255 ft^3/h. On the basis of $F_I = 255$ in Eq. (14), the concentration of gas in the chamber should reach its steady state value of 0.58% in 30 s.

The circuitry connecting the sail switch and the automatic shut-off valves should be managed and maintained as a part of the system's safety design feature. Emergency back-up power supply for the combustion air blower or the exhaust fan should be considered to prevent the buildup of combustible gases if a power failure and an unlikely, simultaneous malfunction of the automatic shut-off valves occur. In addition to the flow switch in the hood exhaust duct, a flow switch should be installed in the furnace exhaust duct. A flow switch with an operating temperature limit of 400°F is available.[26] Furnace procedures allow a maximum temperature of 500°F in the exhaust duct. The switch parts that would be inside the duct are made of stainless steel and could survive the maximum duct temperature. The temperature outside and in the immediate vicinity of the duct probably does not exceed 400°F. The flow switch could be interlocked with the automatic shut-off valves or merely set up to sound an alarm if the flow rate drops below a minimum value.

Installation of an excess flow valve in the gas line entering Building 9212 would prevent the release of a large amount of gas if an explosion or other disaster occurred, rupturing the gas line. Similar precautions are taken for hydrogen lines entering the building. Installation of combustible gas monitors seems warranted. Installation of test connections in the gas train and the air lines would allow periodic certification of safety devices.

HEALTH AND ENVIRONMENTAL CONCERNS

Operation of the furnace has resulted in some incidents of high airborne uranium concentrations.[27] Investigators recommended that covers not be removed from any containers unless the containers are in the hoods. Current procedure allows covers to be removed from the transport pan outside of the hood. Investigators further recommended decreasing the face area of the hood to increase air velocity and perhaps eliminate some areas of relative stagnation within the hood. Increasing air velocity might also address another problem inherent in the use of exhaust hoods. Reportedly, positioning a worker in front of a hood can create back-eddy currents that could draw contaminants toward the worker.[28, 29] The effect is decreased as air velocity in increased. A change in operating procedures or a redesign of the hoods may be in order. Replacement of worn or missing gaskets throughout the unit should be beneficial. High-temperature gaskets are available as replacements for asbestos gaskets.

Use of premixed gas/air with a low percentage of excess air helps to ensure that fuel burns cleanly by lowering the flame temperature and limiting the amount of NO_x formed.[30] The slow burn rate of the trash in the muffle pans helps to ensure complete combustion and limited escape of volatiles through the exhaust. Most of the switches contain mercury; therefore, proper care should be taken during maintenance or disposal. Firebricks and castable refractory material typically contain crystalline silica, which is considered to be carcinogenic. K30 and BNZ-26 contain crystalline silica. Because the composition of the refractory in the furnace is undetermined, care should be taken to minimize exposure any time cracking of these materials leads to dusting. Patent 3,008,513 suggests that asbestos is used in the wall construction as expansion joints; however, available documentation does not indicate that asbestos is part of the wall construction of the Room 29 furnace.

PROCESS REQUIREMENTS

The furnace is operated on all shifts and operates more than 50% of the time. One operator is required to run the furnace.

The continuous-use temperatures of some materials on construction of the furnace are 1600° to 2800°F for firebrick, 2000°F for Hastelloy®, and 1600°F for stainless steel at 1 atm without significant creep.

Cooling water, required to prevent all three flow switches from shutting down the burners, is 1.4 gal/min, or 84 gal/h.[31] Typically, the cooling water is allowed to flow during periods of nonuse; therefore, the minimum cooling water required is 6000 gal/d.

Instrument air of 60 to 90 psi is required to operate cylinders that open and close the furnace door and that position racks in the pan cooling hood. The control cabinet requires a 480-V electrical supply.

Materials processed in the furnace include filter paper, small Dynel (polyvinyl chloride/acrylonitrile copolymer) filters, mop heads, solids from the ash leacher, general salvage residue, and clothing. Materials processed in the furnace are selected for their high moisture content; i.e., drying is a primary function of the furnace. The operating temperature of 1000°F is more than adequate for drying these materials in 1.5 to 2 h. Usually, the combustion of some portion of the material contained in the muffle pans is needed. Most of the materials that need to be burned are cellulosic, none of which approach the complexity of a piece of wood. Wood serves well as a limiting case; if conditions are sufficient for burning wood, the condition should be sufficient for the other materials. In a piece of wood, glowing combustion occurs in the char on the outer surface at temperatures as low as 1000°F.[17] Further into the piece of wood, pyrolysis occurs at temperatures between 400° and 1000°F. Flaming combustion occurs when escaping volatiles are ignited. With the high air flow in the furnace, sustaining a stable flame in the pan would be difficult. However, 80% of volatiles escaping from wood should be completely combusted at 1000°F.[32] The temperature of the furnace is sufficient to decompose cellulose, which begins to break down at 700°F.[17]

As was stated earlier, the natural gas requirements are calculated as 1456 scf/h, which is 1,456,000 Btu/h, or 67.71 lb/h given that methane contains 21,502 Btu/lb. The amount of combustion air required by the burners is 16,000 scf/h, assuming 10% excess air. The following calculations indicate that 737,268 Btu/h is required to heat the furnace, all the air is delivered by the blower, and the combustion products; therefore, the furnace operates at an efficiency of 51%.

The blower delivers air at 43,800 scf/h at 75°F, which is heated to 1000°F in the furnace. The heat required is

$$Q_a = M_a c_p (T_2 - T_1) \ , \tag{15}$$

where

Q_a = heat flow (Btu/h) into the air stream ,
M_a = mass flow rate (lb/h) ,
c_p = heat capacity (Btu/lb°F) ,
T_2 = final air temperature (°F) ,
T_1 = beginning air temperature (°F) .

The heat capacity for air at 500°F is 0.24 Btu/lb°F. The specific volume for air at 500 K is 30.72 ft³/lb. Using the values given, Q_a is 316,523.43 Btu/h. The heat required to maintain the furnace walls at 1000°F is estimated by Eq. (16):[32]

$$Q_f = 0.172\ A\ \sigma \left[\left(\frac{T_g + 460}{100} \right)^4 - \left(\frac{T_f + 460}{100} \right)^4 \right], \tag{16}$$

where

Q_f = heat flow to furnace walls (Btu/h),
A = area absorbing heat (ft^2) ,
σ = emissivity ,
T_f = furnace wall temperature (°F) ,
T_g = flame temperature (°F) .

Assignment of T_g as the flame temperature assumes that the temperature of the combustion products stays at the flame temperature throughout the furnace. In the Room 29 furnace, the temperature of the air and the combustion products probably equilibrate somewhere between the furnace temperature and the flame temperature. The assumptions used here make the calculations easier. Using A = 53 ft^2 (area of walls and tray rack) and σ = 0.64, and guessing that the flame temperature is 1400°F, Q_f is 433,198.9 Btu/h. The total heat required to heat the air and furnace, then, is 749.722.4 Btu/h.

Equation (17) can be used to check the guess of the flame temperature:[32]

$$T_g = T_o + \frac{Q_l}{W_1 c_1 + W_2 c_2} , \tag{17}$$

where

T_o = temperature of environment = 1000°F,
Q_l = lower heating value (Btu/h),
W_1 = mass of carbon dioxide (lb),
W_2 = mass of fraction of water(lb),
c_1 = heat capacity of carbon dioxide (Btu/lb°F),
c_2 = heat capacity of water (Btu/lb°F).

The lower heating value is the heat liberated by 1 lb of fuel during combustion and is 21,502 Btu/lb for methane. The quantity of methane required to deliver 749,722.4 Btu/h is 34.87 lb/h, or 984.7 gmol/h. The stoichiometric quantity of carbon dioxide is 984.79 gmol/h, or 95.71 lb/h; the water produced is 1969.59 gmol/h, or 78.25 lb/h. On the basis of c_l = 0.25 and c_2 = 0.47, both at 1000°F, the flame temperature is calculated as 1354°F; on the basis of using this temperature as T_g in Eq. (16), Q_f is 366,641.26 Btu/h.

The total heat is calculated from Eq. (18):

$$Q_t = Q_a + Q_f + Q_1 + Q_2 , \tag{18}$$

where

Q_1 = $m_1 c_1 (T_g - 1000)$,
Q_2 = $m_2 c_2 (T_g - 1000)$,
m_1 = mass flow rate of carbon dioxide (lb/h),
m_2 = mass flow rate of water (lb/h),
Q_a = 316,523.43 (Btu/h).

Q_l and Q account for the heat required to keep the combustion products at the flame temperature. Q_t is calculated as 704,656.03 Btu/h. With further iterations, the flame temperature is calculated to be 1377°F, and Q_t is calculated to be 737,268 Btu/h, which requires 34.3 lb/h of methane. As was stated earlier, this calculation represents an efficiency of 51% compared with data taken from Fig. 8.

As a check on the data from Fig. 8, the heat requirements of the Room 29 furnace can be estimated by comparison with the heat requirements of typical industrial furnaces. The literature shows energy requirements of typical gas-fired furnaces of various sizes, air flow rates, and beginning and final temperatures.[33] The example most like the Room 29 furnace shows that, for a furnace with a length of 48 in., a diameter of 12 in. (area = 12.6 ft^2), an air entrance diameter of 6 in., and an air exit diameter of 10 in., 520,000 Btu/h is required to heat 600 ft^3/min of air from 60° to 850°F.

Assume that the total heat is used to heat the air and the walls and that the heat required by the combustion products is negligible. The amount required to heat the air can be determined from Eq. (15) and is 222,322 Btu/h. Therefore, 297,668 Btu/h is required for the walls. For the Room 29 furnace, the area of the furnace walls is 41 ft^2, and 730 ft^3/min is delivered by the blower to be heated from 75° to 1000°F. If one corrects the literature data proportionally for air flow, a similar furnace would use 270,504 Btu/h to heat 730 ft^3 of air. If one corrects proportionally for area, a similar furnace would use 962,538 Btu/h to heat the walls. The total heat required for the Room 29 furnace is estimated as 1,296,388 Btu/h. No corrections were made for temperature because the Room 29 furnace may sometimes operate over the range shown in the literature. The estimate compares favorably with the data of Fig. 8.

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ACRONYMS AND ABBREVIATIONS

atm	atmosphere
Btu	British thermal unit
CR	control relay
DOE	U. S. Department of Energy
FSAR	Final Safety Analysis Report
HEPA	high-efficiency particulate air
IFB	insulating firebrick
L/D	length/diameter
$oz/in.^2$	ounces per square inch
PI	pressure indicator
PSH	pressure switch high
psi	pounds per square inch
psia	pounds per square inch, absolute
psig	pounds per square inch, gage
PSL	pressure switch low
scf	standard cubic foot
scf/h	standard cubic feet per hour
scfm	standard cubic feet per minute
TCV	temperature control valve
wc	inches of water column

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