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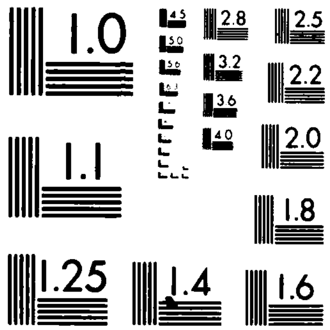

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A HOT GAS SOURCE FOR CONVECTIVE IGNITION STUDIES OF ENERGETIC MATERIALS

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Mark A. DeWilde

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August 1986

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A novel hot gas source is described that possesses the capability of producing a continuous laminar flow of hot gas at temperatures from ambient to 900°C. Details of construction are given and a short description of intended application is provided.

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The author wishes to acknowledge Mr. Wade Scott for taking the pitot tube measurements in the table.

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I. INTRODUCTION

In order to understand the ignition of propellant grains in a charge within a gun, it is desirable to study how the evolved hot gases that permeate the bed and flow over the individual grains cause ignition of those grains. The temperatures of these gases range from ambient, to the adiabatic flame temperatures characteristic of the propellant in use. The composition of the gases ranges from that of air, to mixtures of partial combustion products with air. The flows may be either laminar or turbulent. The difficulties of designing an apparatus to simulate all such conditions, led to the chosen regime, that of the early stages of bed ignition. In these stages, temperatures range from ambient to approximately 1000°C, flows are laminar, or just starting to break up into turbulence, and the gases are essentially air, or oxygen depleted air. The apparatus described produces these conditions.

II. DESIGN, CONSTRUCTION, MATERIALS*

The design of the active portion of the apparatus is shown in Figure 1. The system consists of five heat exchangers and six ceramic insulated heating elements, alternately stacked. The heat exchangers are plumbed in series as is shown in the figure. The entire assembly is placed in an insulating container to minimize heat loss and maximize ultimate attainable temperature. Figure 2 illustrates the design of one of the heat exchangers. The material chosen for construction was type 304 stainless steel, mainly for reasons of being on hand, although monel would be the material of choice for units subsequent to the original test model. Each exchanger consists of a single plate with long holes drilled through the length at equal spacings. To interconnect these drilled gas passages into a single path, channels are milled into the end of the plate between adjacent holes. Finally, small plates are welded over the channels to complete the closure of the gas passage. The total path length through each exchanger is 46 inches. Note that inlet and outlet are on the same end of the heat exchangers block. The heating elements (used for reasons of being on hand) were from the Lindberg Furnace Company, Model 7217100400C, rated at 625 watts 60 volts. The wiring of these elements is shown in Figure 3. The insulating material is four inches of standard insulating firebrick from the Babcock-Wilcox Company. The entire assembly is placed in a sheet metal box that is centered inside of another slotted sheet metal box, four to five inches larger in each dimension. This outer box provides ventilation around the inner box, and prevents any hot surfaces from being accessible by the user. An in-house fabricated heated nozzle is put on the outlet of the gas source, and serves to enlarge and laminarize the exiting flow. This nozzle is shown in Figure 4. A standard laboratory combustion tube furnace, one inch inside diameter, overall length of four to five inches is placed over the nozzle. The function of this tube furnace is to eliminate the cooling by the nozzle of the hot gas exiting the furnace. Initially, insulating material around the nozzle was tried, but due to the low heat capacity of air, and the high temperature differentials

*The use of manufacturer's names and model numbers is not be be construed as an endorsement by the US Government. They are provided as a reference to the types of equipment used, and any equal product can be substituted.

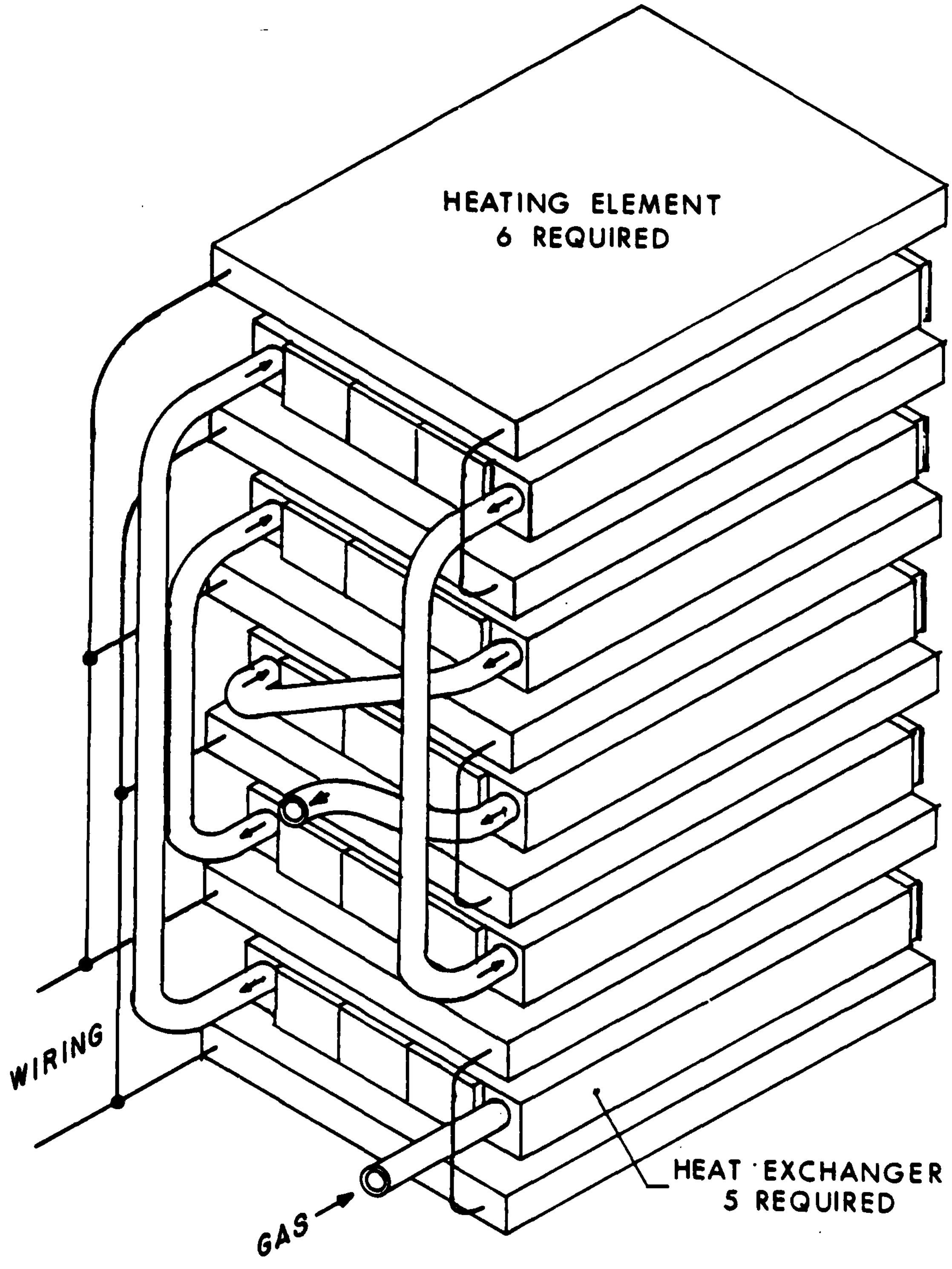

Figure 1. Working Elements of Gas Source

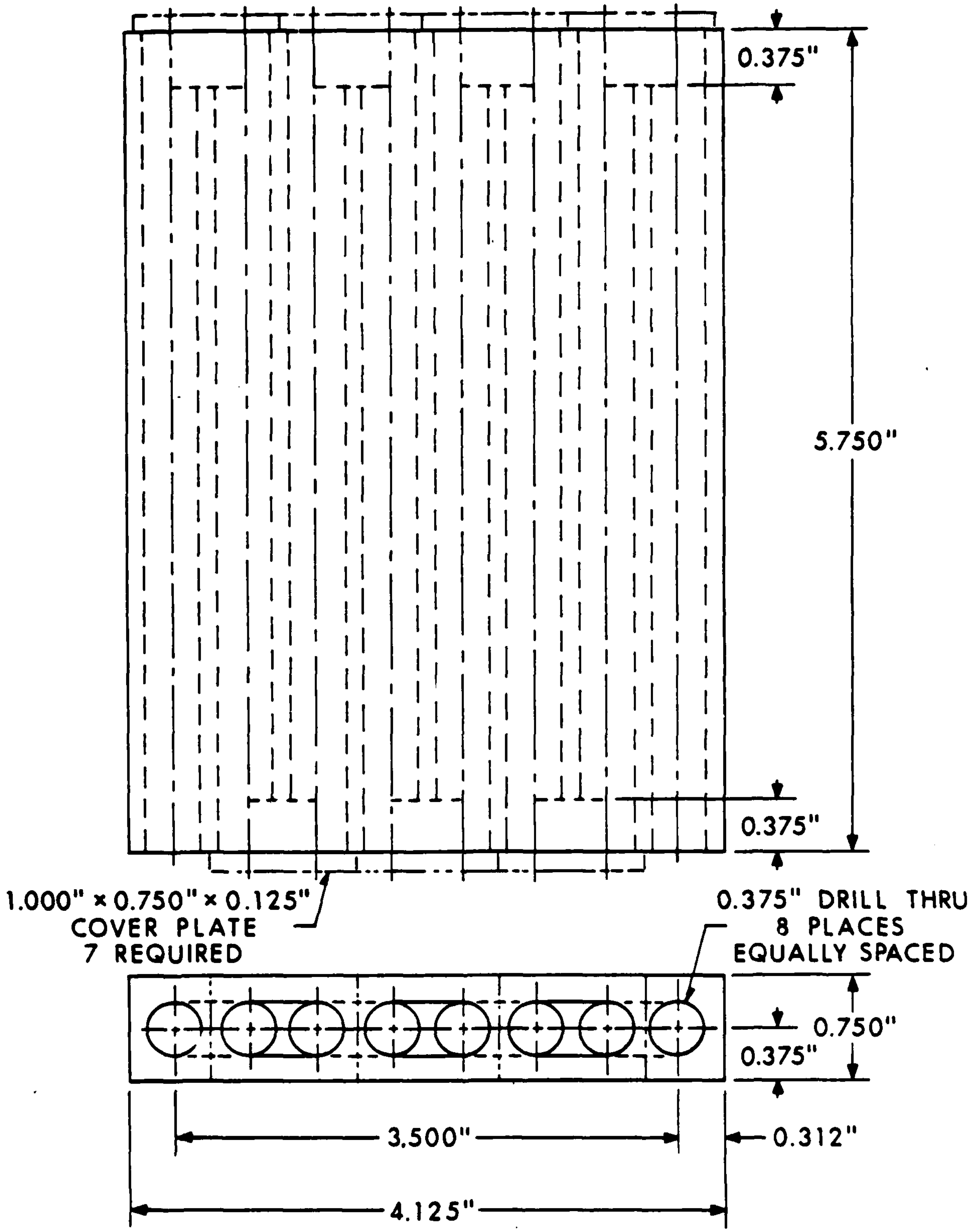

Figure 2. Design of Heat Exchangers

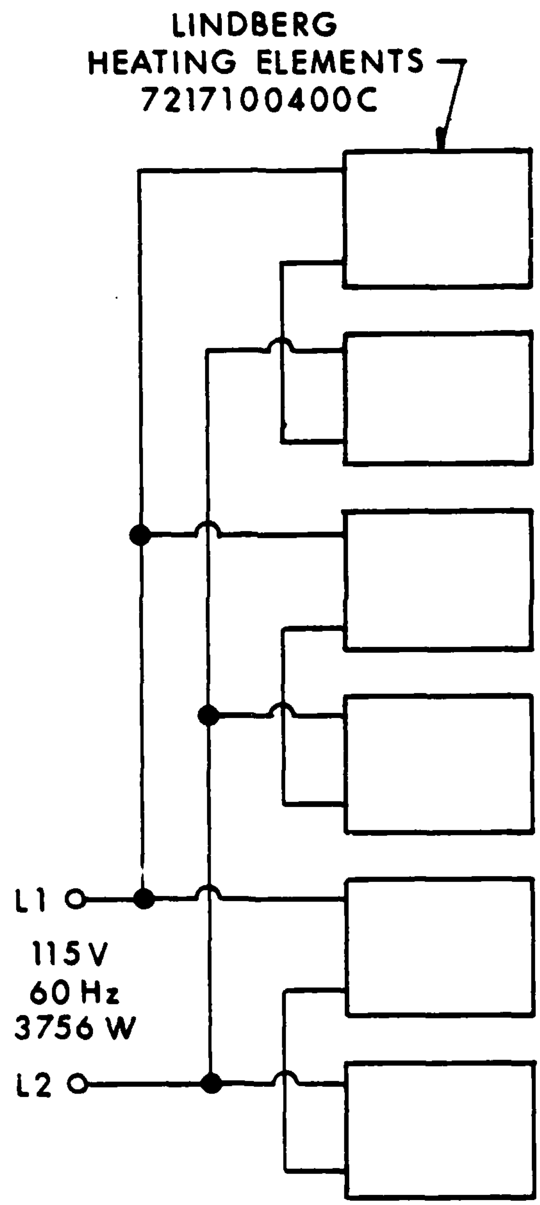

Figure 3. Wiring of Heating Elements

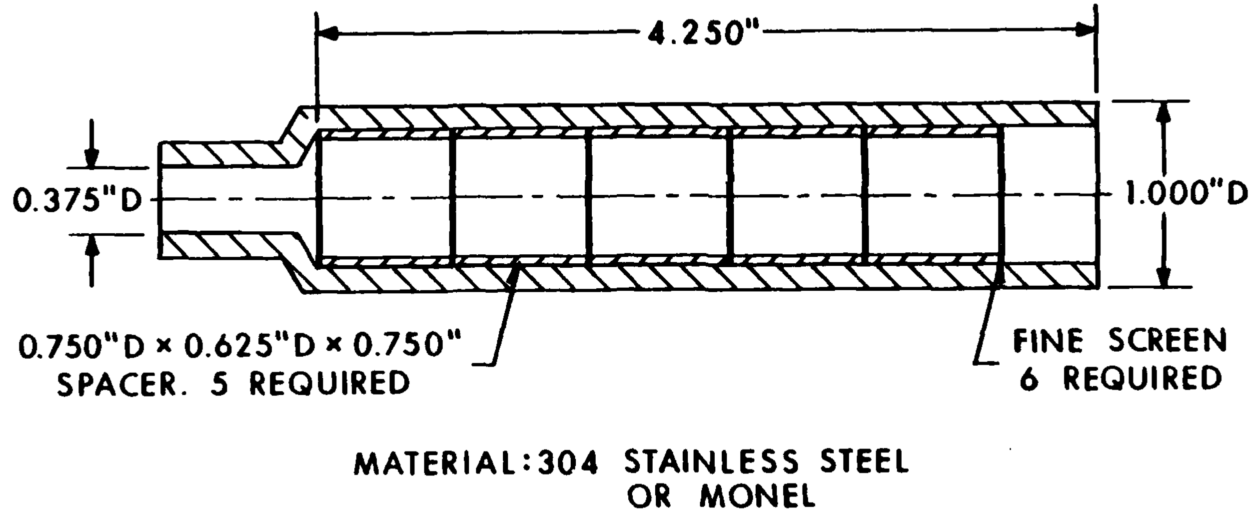

Figure 4. Outlet Laminarization Nozzle

involved, the nozzle always stabilized at a temperature considerably lower than that of the heat exchangers. The active heating method was adopted and solved the problem that the insulation did not. Figure 5 illustrates the completed furnace with the front insulation removed, and Figure 6, the external completed appearance. Not shown in the illustrations are temperature controllers for the heat exchangers and nozzle heaters. These are used to set the operating parameters desired.

III. TYPICAL OPERATING PARAMETERS

In order to check the flow profile exiting the nozzle, pitot tube measurements were taken at 0.100 inch increments across the nozzle, at a distance of 0.4 inch from the end of the nozzle. Initial data as shown in the table for a supply pressure of 40 psi into the furnace, with air at ambient temperatures demonstrated a distinct dip in the flow profile at the center of the nozzle. This was found to be caused by depressions in the center of the screens, and was eliminated by more careful fabrication. After this improvement, the flow at the center became flat to within experimental error.

TABLE 1. PITOT TUBE MEASUREMENTS ACROSS NOZZLE

Position (inches)	Pitot Pressure (mm Hg.)
0.0	0.00
0.1	0.59
0.2	1.42
0.3	1.35
0.4	1.30
0.5	1.30
0.6	1.39
0.7	1.37
0.8	1.36
0.9	0.43
1.0	0.00

The typical operating temperatures used ranged from ambient to 1200°C for the heat exchangers, and ambient to 1000°C for the nozzle heater. Typically, the nozzle is held at the desired discharge temperature, and the heat exchangers at the same temperature for very slow gas flows, or up to 200°C warmer for higher flow rates. Figure 7 shows a shadowgraph of the gas exiting the gas source, and indicates the laminar nature at this flow rate for a distance downstream of the nozzle. The temperature of the gas for these measurements was 800°C. Thermocouple measurements at a distance of 0.5 inches from the nozzle indicate an operating temperature of 1000°C is attainable, although extended operation at this temperature considerably shortens the life of the heat exchangers When dry nitrogen gas was heated to 630°C and combustible materials placed in the gas flow, they could be made to pyrolyze, but not burn until withdrawn from the flow into the oxygen containing room air. If, however, gun propellants such as M-30 are placed in that same flow, vigorous ignition and burning with little smoke occurs, thus simulating the ignition of such materials in the oxygen-deficient gases in a gun tube. Further studies using this tool are in progress. It was found that once the

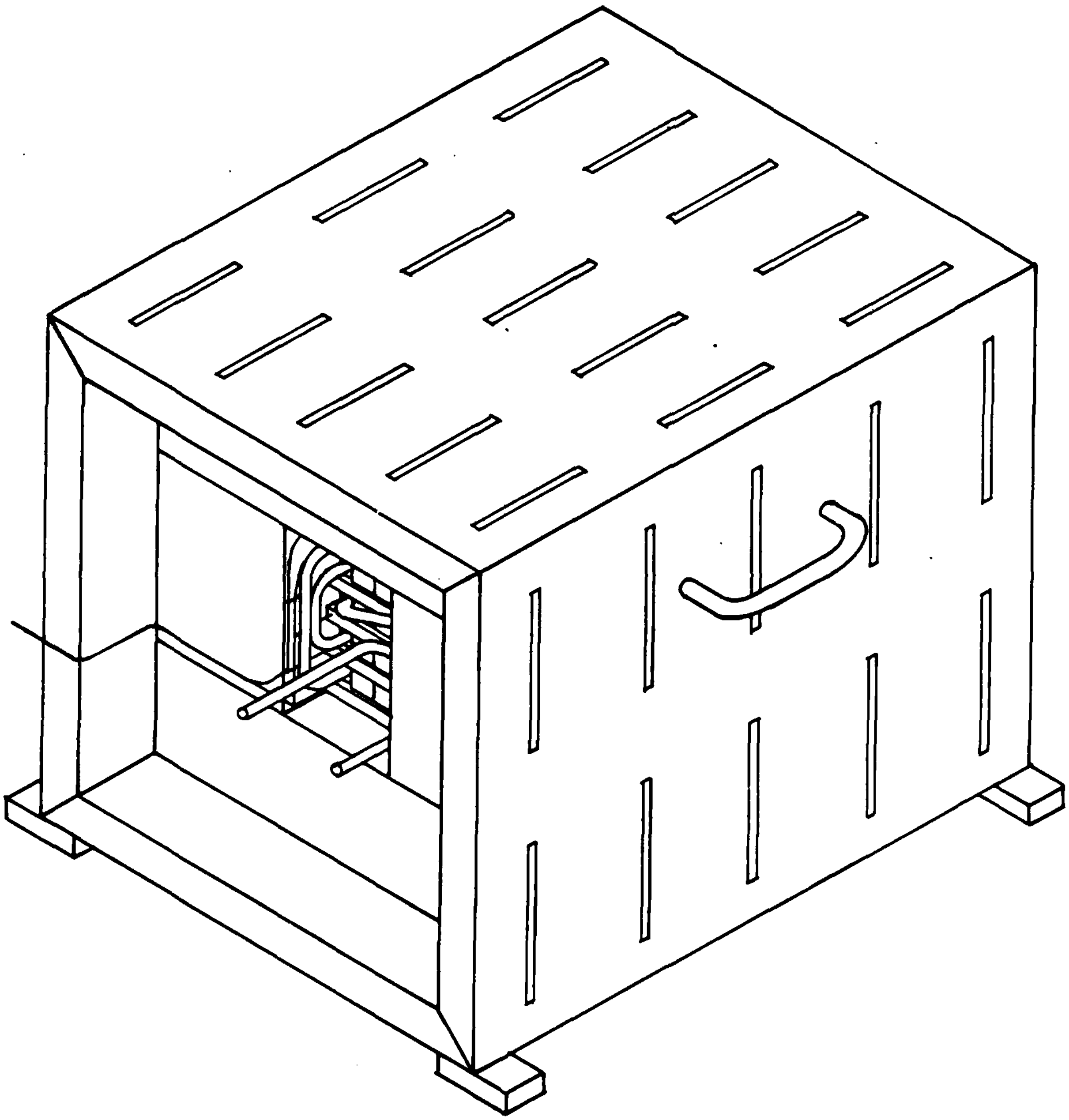

Figure 5. Gas Source Interior View

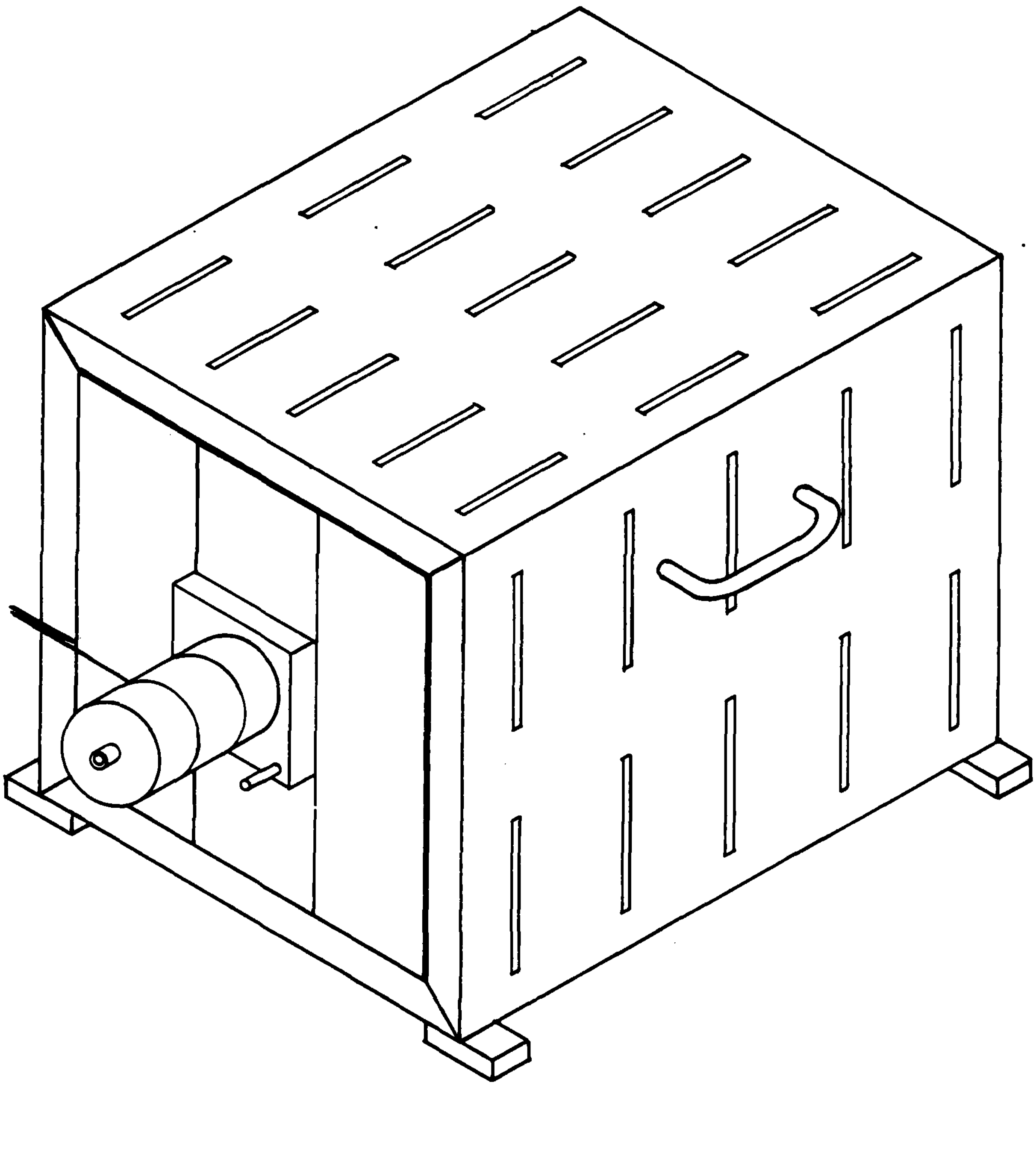

Figure 6. Completed Gas Source

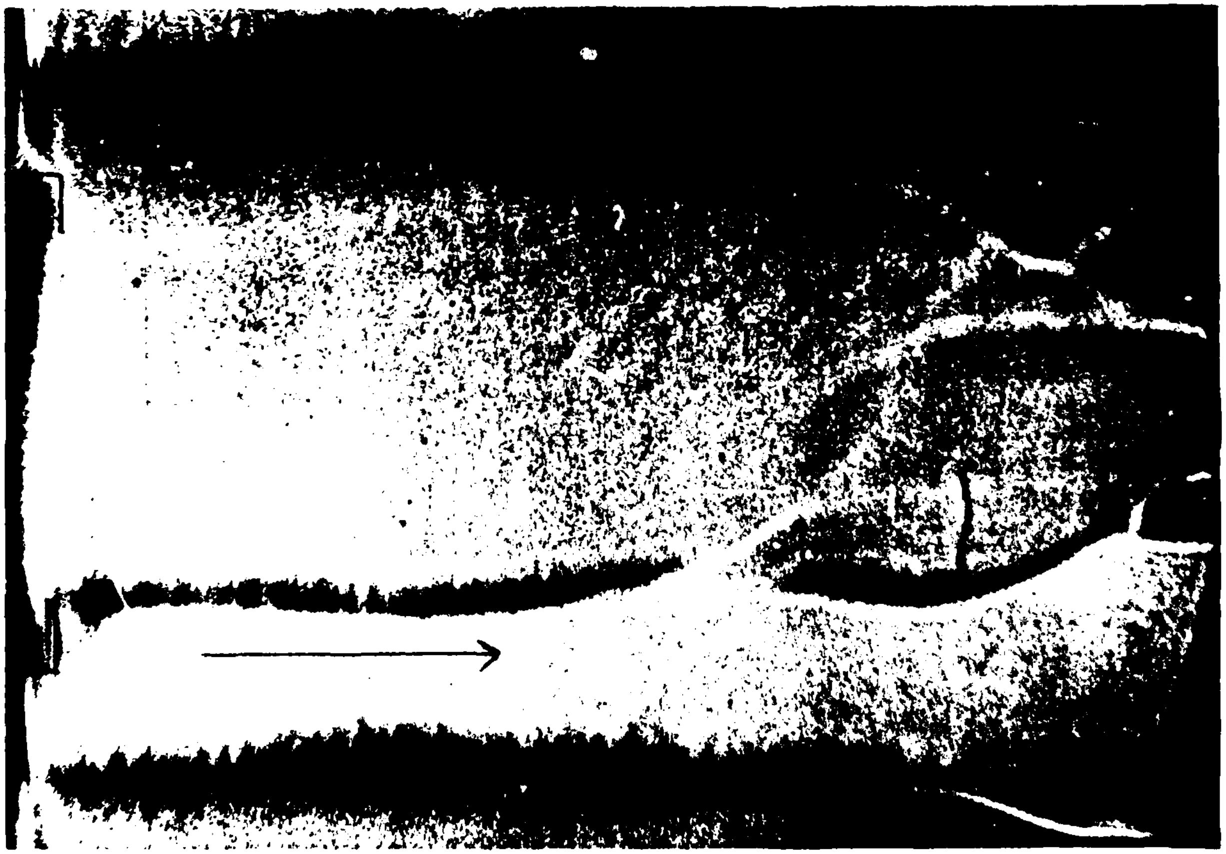

Figure 7. Shadowgraph of Flow

gas source has heated to the desired operating temperatures, the operation is steady state, i.e., there is extremely little drift in the outlet temperature over extended periods of time.

Warmup times for this furnace depend on temperature, and reach a maximum of two hours at 1000°C. The measurement times for thermal stability were 20 minutes, during which variations of ± 5 degrees were observed, caused by the on-off heating cycles of the temperature controller. The use of power proportioning rather than time proportioning controllers could be expected to lessen this variation. The specific heat of air at 1000°C is approximately 0.257 cal/gm. At the same temperature, the density is approximately 2.7×10^{-4} g/cc. This yields a heat capacity of 7.1×10^{-5} cal/cc-deg C. The lowest and highest linear flow velocity of the nozzle were measured to be 1 cm/sec to 7 m/sec. The amount of heat available to a one square cm. area object of infinitesimal thickness blocking the flow for each degree of cooling of the gas ranges then from 7.1×10^{-5} cal/sec to 520.7 cal/sec. Actual heat transfer to the object and cooling of the gas flow depends on shape, thermal conductivity of both gas and object, orientation, and numerous other factors. For the qualitative sorts of observations needed in the studies of propellant convective ignition* these considerations were not of prime importance.

IV. CLOSING COMMENTS

The hot gas source described in this report has proven to have applications other than those originally intended. One researcher has duplicated this device and uses it to provide a flow of hot gas for environmental control within a high pressure propellant strand burner. Since the flows produced are laminar and their temperatures can be measured directly with thermocouples, they provide a convenient way to calibrate and test optical thermometry techniques in this temperature regime. Although not used for this purpose to date, the source should provide an excellent heat source for measuring heat flows into small objects and could be useful in convective heating and heat flow measurements.

*Beyer, R.A., DeWilde, M.A., "Convective Heating of Energetic Materials," Ballistic Research Technical Report, BRL-TR-2701, December 1985.

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