MANUFACTURE OF THE COOLIDGE X-RAY TUBE

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IT was the privilege of the General Electric Company to entertain the members of THE AMERICAN ROENTGEN RAY SOCIETY and guests during the meeting at Saratoga Springs in September, 1919, and to show them by a trip through the laboratory and factory the various processes involved in the manufacture of the Coolidge *x*-ray tube. It is obviously impossible to convey by a written description the impressions gained by a personal inspection of this sort, but for the benefit of those who were unable to be present at that time, the following brief record is offered.

The Coolidge *x*-ray tube is now manufactured in two different types, Universal and Radiator. (For a description of these and their mode of operation, the reader is referred to various publications which have been issued during recent years.[1])

The process of manufacture of this tube may be divided into the following steps:

1. Preparation of the Metal Parts.
2. Assembly of the *X*-Ray Tube.
3. Exhaust of the Assembled Tube.
4. Testing *X*-Ray Tubes.

I. PREPARATION OF THE METAL PARTS.

TUNGSTON.—Wrought tungsten is one of the essential metals entering into the construction of the anode and cathode of all of the above types of Coolidge tube. The complicated process required for the production of this metal was evolved in the Research Laboratory in connection with the incandescent lamp development. The steps involved are as follows:

(a) *Purification of Tungstic Oxide.* Commercially pure tungstic oxide powder is dissolved in strong aqueous ammonia, and the solution is filtered. Pure tungstic oxide is then very carefully precipitated from this solution by the addition of hydrochloric acid. This yellow precipitate is filtered, very thoroughly washed, dried in oven at about 300°C., and finally sifted through 40 mesh sieves. A very high degree of purity is required in the oxide in order that the tungsten metal produced from it may be workable in the later stages of the process.

(b) *Reduction of Tungstic Oxide.*—The purified tungstic oxide is reduced to tungsten metal powder by means of hydrogen in a battery of specially designed reduction furnace (Fig. 1). These furnaces consist of electrically heated porcelain tubes in which a definite amount of the oxide is placed, and through which dried and purified hydrogen is passed at a definite rate. The temperature of the furnace is very gradually raised and maintained at a maximum until the reduction is complete. The metal is then allowed to cool in the atmosphere of hydrogen before removal from the furnace. The whole operation requires about twenty-two hours, and every step must be very carefully regulated in order that the resulting metal shall have the necessary characteristics.

(c) *Pressing Rods of Tungsten Powder.*—The resulting metallic powder is pressed into rods in the following manner (Fig. 2). A weighed amount of the dry tungsten powder is formed by hydraulic pressure in a specially designed mold into a rod 11 inches

[1] A Powerful Roentgen Ray Tube with a Pure Electron Discharge. *Physical Review*, Vol. 2, No. 6, December, 1913.

A New Radiator Type of Hot Cathode Roentgen Ray Tube. *General Electric Review*, January, 1918.

The Radiator Type of Tube. AM. J. ROENTGENOL., Vol. 6, No. 4, April, 1919.

Apparatus for Portable Radiography. *Journal of Roentgenology*, July, 1919.

Coolidge *X*-Ray Tube. Instruction Book 9136A, General Electric Company, April, 1919.

long, 1 inch wide and 1 inch thick. In the operation, a force of over 100,000 pounds is applied to the plunger of the mold. The pressed rod thus produced is too fragile to pick up, but is carefully transferred to a temporary support, consisting of molybdenum, the sister element of tungsten. On this support, the tungsten rod is heated three-quarters of an hour at about 1600°C. in an electrically heated tube furnace, and is protected from oxidation at this temperature by hydrogen gas, which is continually passing through the furnace. In this firing operation, the rod shrinks from 11 inches to 10½ inches in length and becomes strong enough to be handled.

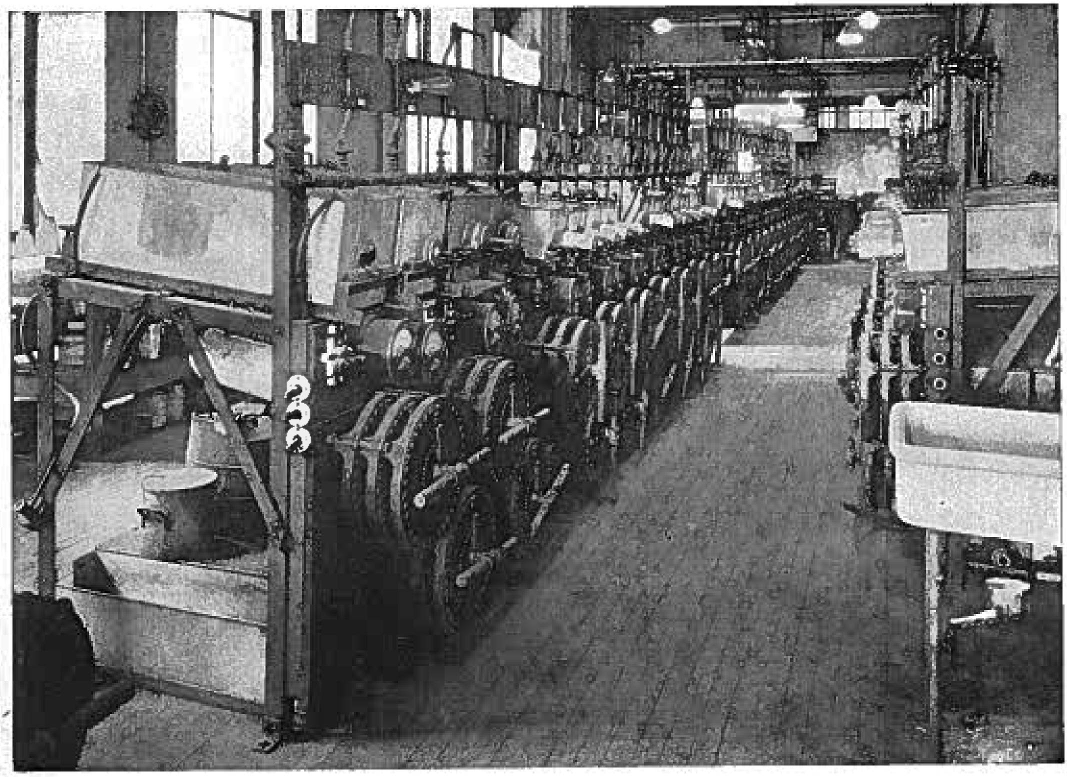

FIG. 1. FURNACES FOR REDUCING TUNGSTIC OXIDE.

(d) *High Temperature Sintering of Tungsten Rods.*—A tungsten rod pressed and fired as just described is next clamped in an upright position in a so-called "treating bottle" in which it is heated close to its melting point for about an hour by the passage of a current of 10,000 amperes at 6 volts (60 KW). (Fig. 3.) In this "treating bottle" the rod is protected from oxidation by a steadily maintained current of hydrogen gas. The interesting features of the treating bottle are the upper water-cooled clamp, the heavy copper lower clamp swimming in a water-cooled pool of mercury which leaves the rod free to shrink, and the mercury seal which prevents air from reaching the interior of the bottle.

As it comes from the "treating bottle," the tungsten rod is very dense, is brittle when cold, and gives a fracture resembling steel.

(e) *Hot Swaging of Large Tungsten Rods.*—Tungsten cannot be worked mechanically while cold. It is so hard that it cannot be machined by sharp edge tools, but has to be brought into desired shapes by high temperature hammering or cold grinding.

The rough anode head for the Universal

tube is formed from a sintered tungsten rod in a swaging machine, which is a nicely controlled high speed hammer used in this case to reduce, by successive operations, the diameter of the tungsten rod. The rod is heated to about 1600° C. in an atmosphere of hydrogen gas in an electric furnace, and is then rapidly passed through the swaging machine. In this operation the diameter of the rod is reduced 10 per cent. The rod is then re-heated in the furnace and is ready for the next pair of swaging dies, which will again reduce its diameter by 10 per cent. When the rod is at the required diameter for the head of the anode, the end of the rod only is swaged down to form the taper and straight portion to which the molybdenum stem is attached. After rough grinding to approximate size and shape, the anode head and molybdenum stem are swaged together. The assembly is completed by the addition of an iron collar and a thin metal tube and the finished anode is then polished and very carefully cleaned.

(f) *Tungsten Wire for Cathode Filaments.*—The tungsten wire used in making the filament for the cathode is produced in a similar manner, the rod being reduced in size in the swaging machine until it may be hot drawn to the required size of wire through diamond dies.

MOLYBDENUM.—Wrought molybdenum is very much like wrought tungsten, but differs from it in that it can be machined while cold. Also for a given amount of mechanical working, it is stronger than wrought tungsten. Various parts of the cathode and anode structures are made from it. Its preparation is similar to that of wrought tungsten.

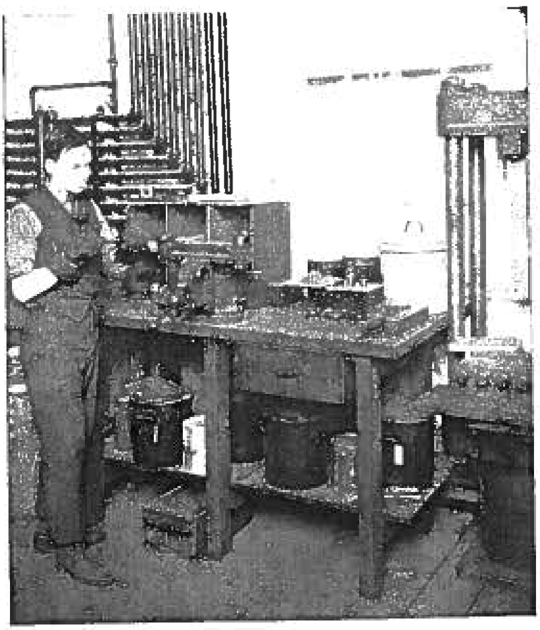

FIG. 2. MOLD AND HYDRAULIC PRESS FOR MAKING RODS FROM TUNGSTEN AND MOLYBDENUM POWDER. The operator is removing a rod from the mold after pressing in the hydraulic press at the right.

FIG. 3. TREATING BOTTLE AND TRANSFORMER FOR SINTERING TUNGSTEN AND MOLYBDENUM RODS. The operator is lowering the bottle over the rod which is held in place by the heavy copper clamp.

COPPER-BACKED TUNGSTEN ANODES.—The anodes for radiator type tubes are made by casting specially purified (boronized) copper around a carefully cleaned tungsten disc in a vacuum.[2] Copper and tungsten do

[2] COOLIDGE. Metallic Tungsten and Some of Its Applications. *Trans. Am. Inst. Elect. Engrs.*, 31 (1), 1219-28, 1912.

not alloy with one another, but under the conditions employed, the melted copper wets the tungsten and adheres firmly to it when it solidifies. This process assures good thermal conductivity between the tungsten and the copper. The finished anode heads are electrically welded to a rod of copper which is to extend out through the anode arm of the tube and support the radiator. The platinum or alloy sleeve by means of which the seal between anode and glass is made is silver-soldered to the copper rod.

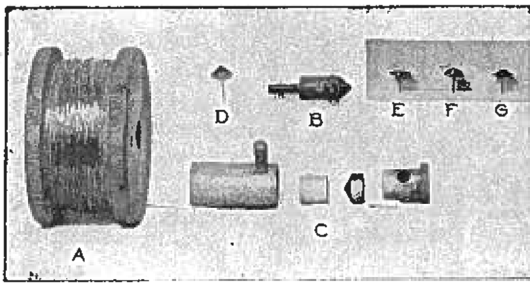

FIG. 4. VARIOUS STEPS IN THE FORMING OF FILAMENTS FOR CATHODES. *A*, spool of tungsten wire; *B*, Mandrel with filament wound on it; *C*, form (unassembled) for high firing of filament; *D*, low fired filament; *E*, fine focus filament after firing in form; *F*, medium focus filament; *G*, broad focus filament.

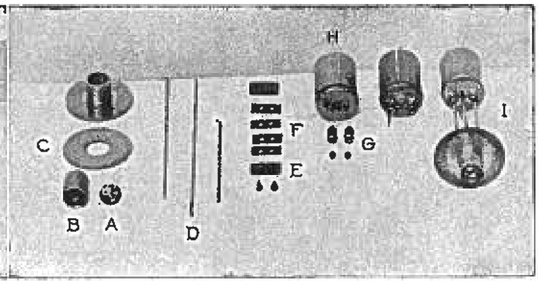

FIG. 5. PARTS OF CATHODE OF UNIVERSAL TYPE TUBE AND VARIOUS STAGES OF ASSEMBLY. *A*, filament; *B*, molybdenum tube; *C*, molybdenum disc; *D*, leads; *E*, metal clamp; *F*, mica washers; *G*, bushings; *H*, support tube; *I*, assembly.

CATHODE ASSEMBLY.

(a) *Preparation of Cathode Spirals.* For all cathode filaments, tungsten wire of 0.0085 inch diameter is used. The first operation in making a filament spiral is the winding of the wire on a conical mandrel of special tungsten steel. Before the spiral is removed from its mandrel, it is given an anneal in hydrogen in an electric furnace. Conical spirals thus prepared are next clamped in molybdenum forms and heated in an electric furnace to a temperature of 1600°C. in an atmosphere of hydrogen gas. This forming of spirals is carried out to give three different shapes of filament which are necessary to produce the various sizes of focal spot (Fig. 4).

(b) *Assembly of Cathodes.*—The assembly of the cathode calls for very delicate manipulative work. As shown in Fig. 5, many of the parts are small; and in order to obtain the desired size and distribution of energy over the focal spot, the relative positions and shapes of these various parts must be nicely regulated. The tungsten terminals of the spirals in assembled cathodes are welded in place by arcing in hydrogen gas. One weld is made on the cathode cup and the other on the metal leading-in wire. This operation is carried out in an inverted glass bell jar through which is passing a stream of hydrogen.

VACUUM FIRING OF METAL PARTS.—All metal parts before being mounted in an *x*-ray tube are fired in a quartz tube vacuum furnace at 900°C. for about an hour, and are allowed to cool down in a vacuum so as to prevent oxidation (Fig. 6). The purpose of this firing is to render the parts perfectly clean and to remove partially the occluded gases and thus reduce the time required in the exhaust of the tube.

2. ASSEMBLY OF *x*-RAY TUBE.

The bulbs and glass parts used in the tube are blown in molds at the glass factory and are therefore of uniform shape and quality.

The operation of assembling these glass parts and the metal parts prepared as above is carried on by girls with the help of glass-blowing machines, one of which is shown in Fig. 7. These are essentially lathes in which the two glass parts to be joined are clamped in separate chucks which are geared together so as to rotate at the same speed. Fires are provided for melting the glass, and compressed air, controlled by valves, for blowing.

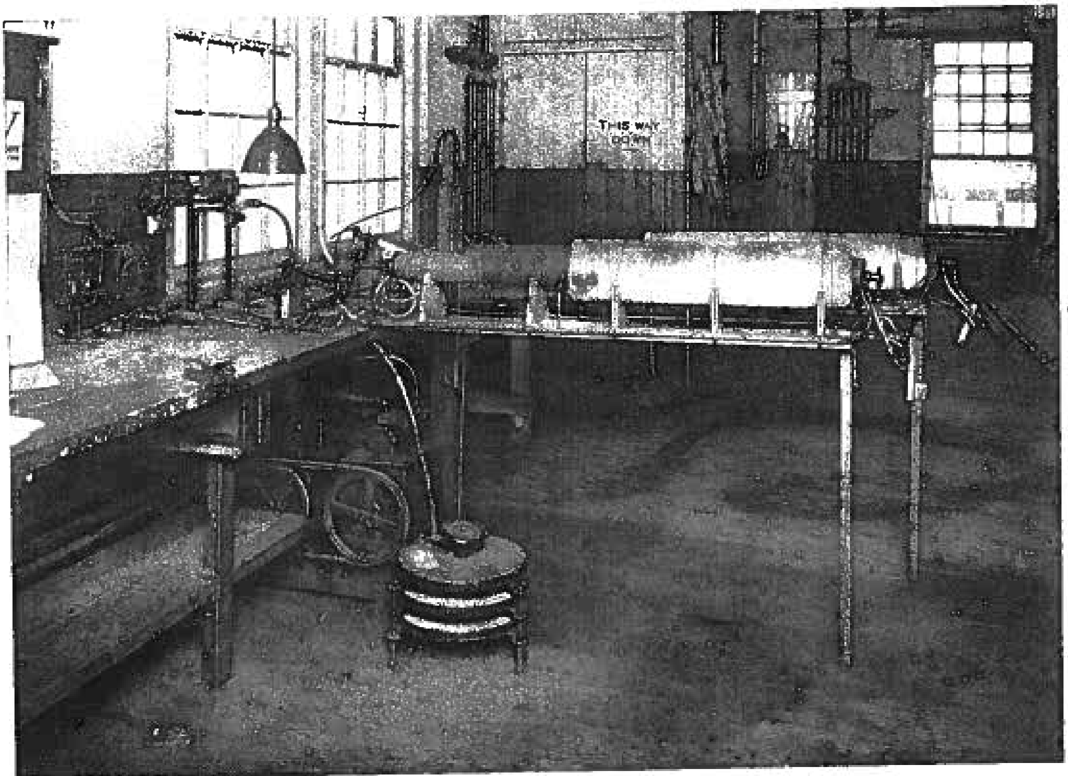

FIG. 6. VACUUM FURNACE USED FOR FIRING METAL PARTS OF X-RAY TUBES.

The various steps involved in the assembly of the tube are as follows:

a. Sealing on exhaust tube.
b. Sealing on cathode side arm.
c. Sealing in anode support tube.
d. Sealing in anode.
e. Sealing in cathode.

A separate machine is used for each of these operations, each one being slightly different from the others.

There are a few operations, especially in the assembly of the radiator type tubes, which require the services of skilled glass-blowers.

3. EXHAUST OF THE FINISHED TUBE.

The Coolidge x-ray tube requires a very high degree of vacuum for successful operation, approximately one ten-millionth of an atmosphere. In order to obtain this high vacuum, an elaborate exhaust system is necessary, as shown in Fig. 8. This consists of a series of three mechanical pumps, one condensation pump, and a trap surrounded by liquid air.

The x-ray tube to be exhausted is sealed directly to the glass tube coming from the liquid air trap. It is supported inside of a large oven, which is arranged with electric heaters for heating the tube during the first stage of the exhaust, and so constructed as to provide ample x-ray protection for the operators (Fig. 9).

The first operation in the exhaust consists of heating the tube to about 400°C. for three-quarters of an hour. This heating removes water-vapor, carbon dioxide and other gases from the glass and metal parts.

After cooling, the tube is connected to an x-ray machine and operated as an x-ray tube. For the early stages of the exhaust, a machine is used which is so arranged that it operates automatically, passing just enough current through the tube to drive out the gas at a rate at which it can be removed by the exhaust system. The final stages are carried out on a regular interrupterless machine, and the operation has to be very carefully regulated by trained operators. As the vacuum improves, the potential applied to the tube is constantly raised. The operation is continued until all signs of gas, that is, appreciable green fluorescence in the bulb, have disappeared and the tube is backing up a 10 inch parallel spark gap and the anode is at an intense white heat. The whole operation requires about one and a half to two hours' time.

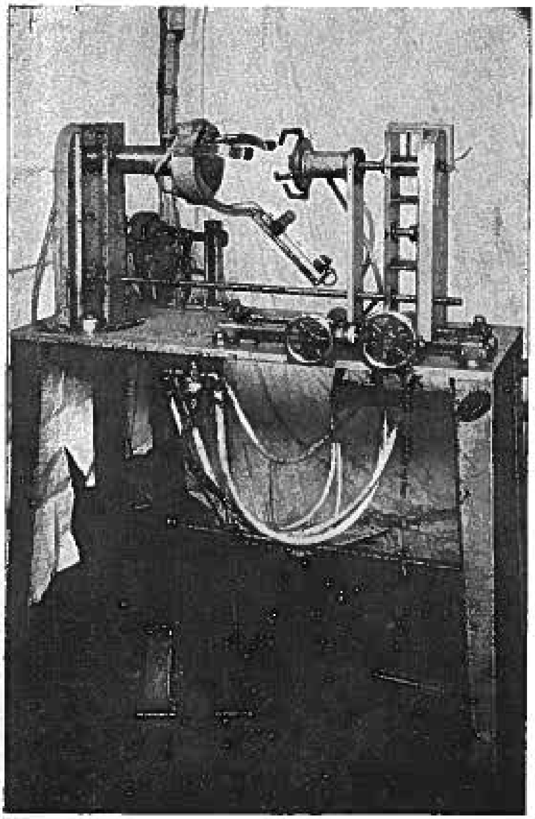

Fig. 7. Glass-Blowing Machine.

The above description applies to the exhaust of the Universal type of tube. The anode in the radiator types of tube cannot be heated as hot because of the low melting point of copper. The exhaust is carried out with the tubes connected to high tension transformers without mechanical rectifiers and requires a considerably longer time than the Universal type.

4. TESTING *x*-RAY TUBES.

A. Universal Type. *When the exhaust* of the tube is completed, it is sealed off from the exhaust system. After an interval of at least twenty-four hours, it is given a preliminary test. This consists of running at a six inch parallel spark gap with sufficient current through the tube to heat the anode to a white heat, and then increasing the gap to ten inches. Tubes which show appreciable green fluorescence in the bulb are rejected and must be re-exhausted. Tubes which pass the first test are provided with anode and cathode bases, and after a certain time-interval given a second test which is a duplicate of the first. A third test is made just before shipment.

B. Radiator Type. (a) *10 Milliampere Tube.*—The test of the radiator type tube differs considerably from that of the Universal type. The preliminary test of the 10 milliampere tube consists in running for two minutes with 5 milliamperes at 40 KV., one minute with 5 milliamperes at 50 KV., and one minute with 10 milliamperes at 60 KV.

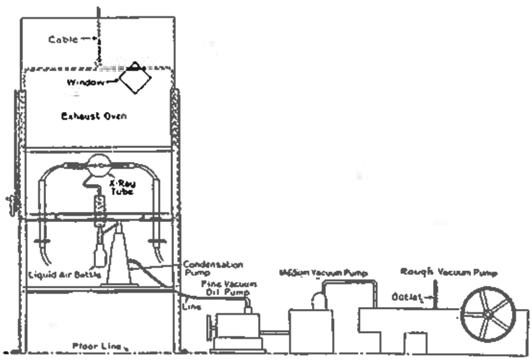

Fig. 8. Oven and Exhaust System for Exhausting *X*-Ray Tubes.

After basing and after a certain time-interval, the tube is given the second test, which consists of running continuously for two minutes at 10 milliamperes and 60 KV.

Tubes are rejected which show appreciable green fluorescence in the bulb.

During the two minute run, three pinhole camera focal-spot pictures of the tube are made on a dental film. Two of these are made with differently timed short exposures and show the distribution of the energy over the focal spot. The third is made with a longer exposure to show the total area of the focal spot. This third focal-spot picture is very carefully measured along two diameters, and if the size does not fall within certain very narrow limits, the tube is rejected.

(b) *30 Milliampere Tube.*—The preliminary test is the same as that for the 10 milliampere tube. The second test consists of a twenty-five second run with 30 milliamperes and 60 KV. Focal spot pictures are taken during this run.

(c) *Dental Tube.*—The first test is similar to that of the 10 milliampere tube except that the highest voltage used is 50 KV. The second test consists of a two minute run with 10 milliamperes at 50 KV., during which time focal spot pictures are made.

(d) *Portable Tube.*—The first and second tests consist of running the tube on the portable outfit for fifty-five-second shots with 10 milliamperes at 60 KV. with two-second intervals between consecutive shots.

Tubes are usually held in stock for several days after testing, and they are finally given a short test and are then crated for shipment.

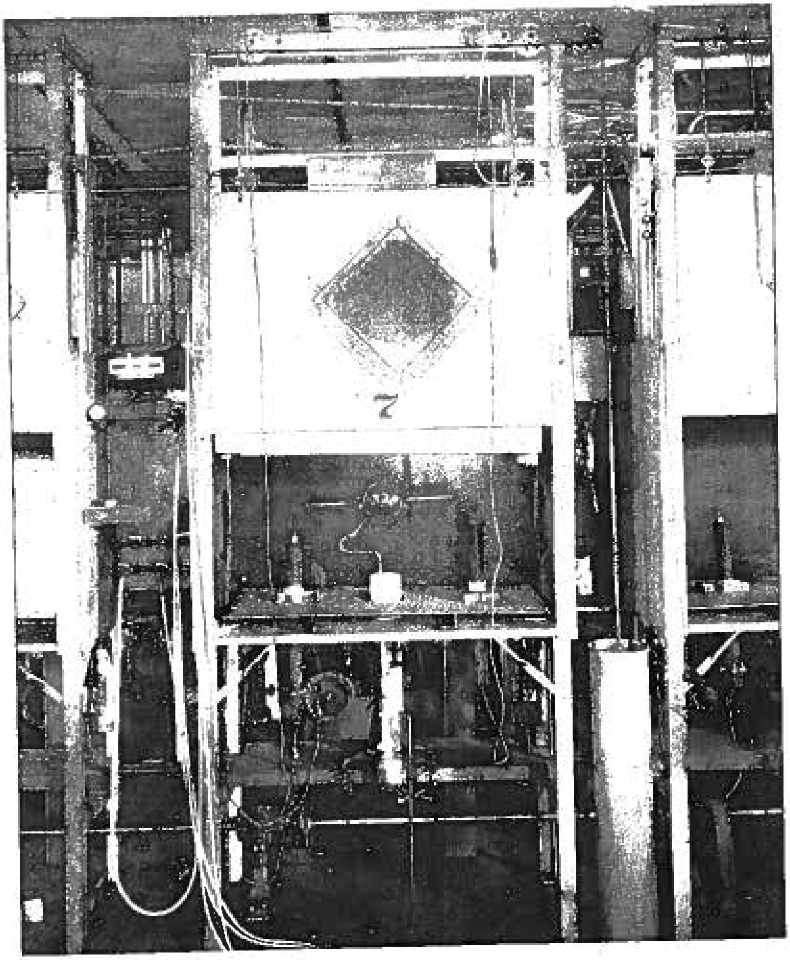

FIG. 9. EXHAUST OVEN FOR UNIVERSAL TYPE TUBE WITH TUBE IN POSITION.