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PERFORMANCE OF A THERMIONIC CONVERTER MODULE UTILIZING EMITTER AND COLLECTOR HEAT PIPES

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SUMMARY

A thermionic-converter module simulating a configuration for an out-of-core thermionic nuclear reactor has been designed, fabricated, and tested. The module consists of three cylindrical thermionic converters. The tungsten emitter of the converter is heated by a tungsten, lithium heat pipe. The emitter heat pipes are immersed in a furnace, insulated by MULTI-FOIL thermal insulation, and heated by tungsten radiation filaments. The collector consists of tungsten oxide vapor deposited on niobium, 1%-zirconium alloy. The interelectrode spacing is 0.30 mm. The active area of the emitters is 115 cm^2 and the diameter is 19 mm. The collector heat is rejected by radiation from a niobium, 1%-zirconium heat pipe utilizing a potassium working fluid.

The performance of each thermionic converter was characterized before assembly into the module. An electrically heated, water-cooled collector heat rejection system replaced the collector heat pipe for these tests. Dynamic voltage, current curves were taken using a 60-Hz sweep and computerized data acquisition over a range of emitter (1300 to 1850 K), collector (700 to 855 K), and cesium-reservoir (around optimum power) temperatures. An output power of 215 W was observed at an emitter temperature of 1750 K and a collector temperature of 855 K, for a two diode module. With a three diode module, an output power of 270 W was observed at an average emitter temperature of 1800 K and a collector temperature of 875 K.

INTRODUCTION

Heat pipe heated, heat pipe cooled, cylindrical thermionic modules best typify existing state-of-the-art technology in a prototypic configuration. (Ref. 1) These modules could be used for a wide range of space power applications, such as nuclear electric propulsion, space solar thermionics, and space isotopic power systems. Heat pipes used for emitter heating and collector cooling result in a light-weight system, the elimination of mechanical coolant pumping, the reduction of energy losses, increased reliability, and a closed redundant system. The modular design simplifies fabrication and testing, results in better quality control and lower overall costs, and allows easier scaling of power output to suit a particular application. Also, this design minimizes single-point failure on the total system and allows for possible converter repair or replacement if necessary.

The present design calls for three diodes in each module with a series or a parallel electrical connection during testing. Three diodes give a redundancy, which improves the data statistics. The nominal operating temperatures were set at 1800 K for the emitter and 825 K for the collector, with a power output of 2.5 W/cm^2. Performance mapping covered an emitter operating range of 1600 to 1800 K, whereas the collector was operated above 800 K to minimize the weight of the radiator.

Reliable, efficient, durable electric generation systems with high power-to-weight ratios are essential for future space missions, particularly those with requirements approaching the MW level. These power system requirements can be satisfied by these thermionic modules. In addition, the advantages of thermionic energy converters are simplicity, light weight, small volume, negligible mechanical stresses, no moving parts, modularity for space safety, high power densities, and high temperatures that allow low-mass radiators. Thermionic converters are also adaptable to other sources of thermal energy of nuclear, solar, or chemical origin.

DESIGN AND DESCRIPTION OF THERMIONIC CONVERTER MODULE

The thermionic converter module consists of three cylindrical diodes assembled as shown in Figure 1. A photograph of the assembled module is shown in Figure 2. The design operating parameters for this module are as follows:

Emitter	1800 K nominal	1900 K max.
Collector	825 K nominal	875 K max.
Cesium Reservoir	550 to 600 K	

The expected minimum efficiency at the nominal temperatures is 12 percent with a total output power of 250 W.

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An enlarged cross section of a thermionic converter is shown in Figure 3. Each diode is heated by a CVD (chemical vapor deposition) or arc-cast, vacuum-extruded tungsten heat pipe (19 mm o.d. x 222 mm long). The $35\text{-}cm^2$ tungsten emitter is an integral part of the condenser end of the pipe. A tungsten wire mesh wick is held against the inside of the pipe by a tungsten spring. Lithium is the working fluid.

The collector for each diode is constructed of niobium, 1%-zirconium alloy, and the surface is coated with tungsten oxide. Each collector is cooled by a niobium, 1%-zirconium heat pipe (70 mm o.d. x 515 mm long), as shown in Figure 4. The collector and collector heat pipe are two separate units assembled using a tapered conical joint at the lower end of the heat pipe. Using molybdenum mesh as a wick, the collector heat pipe radiates the reject heat to a water-cooled jacket. A multiple screen wick artery system is used for the liquid return. Potassium is the working fluid. The spacing between the collector and emitter is 0.3 mm at operating temperatures.

Each diode has its own cesium reservoir located at the open end of the collector. The temperature of the reservoir is controlled by a nichrome heater and water cooling.

The emitter and collector are electrically isolated by a ceramic metal insulator and floating end locator, as shown in Figure 3. Both use Al_2O_3 for insulation. Electrical connections are made at the end of the emitter and collector using molybdenum and copper straps, respectively, as shown in Figure 5. The outboard ends of these electrical leads are water cooled. A water-cooled copper bus is used to connect the diodes in series or parallel.

The three diodes are mounted on a common plate, as shown in Figure 6. (It should be noted that the heat pipe collector radiators have not been attached yet.) Each diode is electrically isolated from this plate with alumina insulators.

For the test module, tungsten filament heaters are used to radiatively heat the three emitter heat pipes. The heaters and the heat pipes are enclosed in a MULTI-FOIL insulated furnace to minimize heat losses and to provide a constant temperature source. The furnace is shown at the bottom of Figure 7. The heaters simulate a thermal energy source such as a reactor.

The copper radiation receiver used for testing the module has water-cooled walls coated with chromium oxide with an emissivity of 0.7. The vacuum in this chamber was below 10^{-5} torr at operating temperature.

Because the design is modular, each converter, with its various components (emitter heat pipe, collector heat pipe, and diode), can be individually tested. Any component found faulty may be repaired or replaced before final assembly. In addition, each diode can be performance-mapped individually over a wide range of conditions. This capability means that, even though the module is targeted to operate at 1800 K emitter temperature and 825 K collector temperature, it will be possible to predict accurately the module performance over a wide range of temperatures.

CONVERTER FABRICATION TECHNIQUES

Each heat pipe converter consists of three major components; the emitter-heat pipe assembly, the collector assembly, and the collector heat pipe. The components are fabricated separately, then the emitter and collector assemblies are combined to complete a converter. The collector heat pipes were not used until the three-converter module was constructed. Details of the fabrication techniques for these components and a description of the initial converter construction are given below.

Emitter Assembly Fabrication

The emitter of the thermionic converter is heated by radiation using a heat pipe that is integral with the emitter. The heat pipe allows the heat source to be remote from the emitter surface. The specifications call for high temperature capability for a tungsten emitter surface; thus, the whole emitter-heat pipe assembly was fabricated from a single tungsten tube. In order to simplify the welding of the end caps, the crystal structure of the tungsten was closely controlled. The desirable elongated crystal structure can be obtained by extruding an arc-vacuum-cast tungsten billet, and making the tube from the extrusion by electrical discharge machining. (This technique was used to fabricate the emitter for Converter No. 185.) Alternatively, the tube can be formed by CVD on a mandrel, which is later dissolved. (All other converters were fabricated by the CVD method.)

Two end caps are attached to the tungsten tube by electron beam welding. One end cap has a projection used to center the emitter in the collector assembly; the other end cap is equipped with a thin-walled tungsten tube. A tungsten wick and wick retainer are inserted prior to welding the second end cap. The moly-rhenium emitter sleeve assembly is welded on at this point. The distillation of the lithium is performed in a vacuum system. The lithium distillation container is terminated in a thin-hollow tungsten needle that is inserted into the tungsten tube of the heat pipe. The slip fit of these two tubes permits the heat pipe to be outgassed prior to the distillation of the lithium. The lithium can contains a U trap so that only the lithium can enter the heat pipe, and

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the impurities (mainly oxides) remain in the can. Heaters are provided on the lithium can, the heat pipe, the heat pipe filling neck, and the tungsten fill tubes. By suitably varying the temperatures in the system, the lithium can be distilled through the can into the heat pipe, or alternately from the heat pipe back into the can. The can is charged with an excess of lithium to allow for some loss into the bell jar during the distillation process.

At any point during the distillation process the heat pipe can be checked to determine if it has been charged with the proper amount of lithium. This is accomplished by operating the heat pipe in the usual mode and checking for uniform temperature along its length. Lithium may then be removed or added as needed by varying the temperature gradient between the lithium can and the heat pipe.

The final closure of the heat pipe is accomplished once proper heat pipe operation has been observed. A current (~700 amp) is passed through the concentric fill tubes causing them to melt and form a leaktight tungsten bead at the end of the full tube. The heat pipe emitter assembly prior to charging with lithium is shown in Figure 8. The completed heat pipe, under test, is shown in Figure 9.

Collector Assembly Fabrication

The collector assembly consists of collectors, emitter centering ceramic, collector guarding ceramics, collector-emitter ceramic insulator, and cesium reservoir. The collector body is fabricated from niobium 1%-zirconium alloy. The centering, guard, and insulator ceramics are alumina. The collector guarding ceramics are metallized and brazed to the collector body to ensure good thermal contact. The leadthrough assembly and the centering ceramics likewise are metallized and brazed to the leadthrough flanges and collector end cap, respectively. This subassembly is shown in Figure 10. These are then assembled to the collector body by electron beam welding.

The tungsten oxide collector surface is prepared in a separate operation. The desired tungsten oxide is formed by resistance heating a tungsten rod in a 1-atm oxygen pressure at 823 K. The resulting oxide is evaporated to a collector in vacuum. During the evaporation, the tungsten rod is slowly heated over a period of an hour to 1753 K while the collector surface is kept at 823 K using an electrical heater. Then the collector is removed and installed in an ion-pumped system where the oxide is soaked into the collector at 773 K for six hours. The collector is removed and an additional layer of tungsten oxide is deposited in the manner described. Then a second vacuum firing is carried out at 473 K for two hours.

Collector Heat Pipe Fabrication

The collector heat pipe is made from niobium 1%-zirconium alloy. The working fluid is potassium. Due to the unavailability of proper size tubing, the heat pipes are fabricated by rolling and electron beam welding sheets. After the first rolling operation the edges of the sheet are trimmed so that, upon welding and rerolling, the desired tube size is obtained without further machining. Microgrooves are machined on the heat pipe surface to increase its apparent emissivity. The tube is then cleaned and annealed. The wicks and arteries are inserted, the end caps are welded on, and the charging and evacuation tubes are attached.

The heat pipe is mounted on the charging stand, connected to the pumps, and outgassed using electrical resistance heaters. Then the potassium capsule is cracked, the evacuation tube pinched, and the potassium distilled into the heat pipe. Temporary pinch-offs are made on the charging and evacuation tubes. The heat pipe is removed from the vacuum system, and the final electron beam pinch-offs on the niobium 1%-zirconium tubes are made. As an additional precaution, pinch-off protector caps are electron beam welded over the pinch-offs. The space between the pinch-off and the protective caps is evacuated prior to welding.

Upon fabrication, each heat pipe is instrumented with thermocouples and mounted in a water-cooled shield. An electron bombardment filament is inserted in the collector cavity of the heat pipe to simulate the collector heat load. Each heat pipe is tested up to an 850 K radiator temperature. The heat radiated to the water-cooled shield is measured by noting the temperature rise and flow rate of the cooling water. The results are shown in Figure 11. Also shown in this figure is the apparent emissivity of the surface, based on the measured radiator surface temperature.

The effectiveness of this radiator configuration for removing heat from the thermionic converter is evaluated with the aid of the model of the converter (Ref. 2) using the measured electrode parameters as shown in Figure 12. This figure shows a curve of constant power output (2.5 W/cm^2) versus emitter temperature and current density. Also shown are the emitter temperatures at the current densities, where the heat rejected from the radiator corresponds to the collector temperature of 850 K (the temperature drop in the collector-to-heat pipe taper seat was determined experimentally). This figure shows that, above an emitter temperature of 1675 K, with the converter output equal to 2.5 W/cm^2, the collector radiator has excess capacity to reject heat. Therefore, when operating the converter at an 1800 K temperature, part of the radiator should be shielded to achieve optimum collector operating temperature.

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Converter Fabrication

The converter is completed by welding the collector assembly to the emitter assembly. The collector and emitter subassemblies are shown before final welding in Figure 13. After the final weld, the converter is mounted in a MULTI-FOIL furnace cavity. Next, the evacuation tube is fusion brazed, a cesium capsule inserted, and the converter attached to an ion pump. An outgassing heater (with water cooling) is mounted on the collector to facilitate outgassing. Each converter is outgassed at temperatures at or above expected operating conditions. The final pressure, with all surfaces hot, is better than 1×10^{-7} torr. After outgassing, the ion pump is pinched-off and the cesium distilled into the converter. Once the distillation is completed, the cesium capsule tube is pinched-off and the cesium driven back into the reservoir.

EMITTER HEATING FURNACE MEASUREMENTS

The three emitter heat pipes of each module are heated by a common radiation source. The radiation filaments and the three emitter heat pipes are enclosed in a MULTI-FOIL insulated furnace. The design of the furnace is based on a standard 152.4-mm diameter 152.4-mm high furnace, and it is insulated with MULTI-FOIL vacuum insulation consisting of 30 layers of tungsten foil and 30 layers of molybdenum foil. The foil spacing is maintained by zirconia particles. The cover of the furnace is modified by providing three holes to permit the insertion of the module emitter heat pipes. Three hairpin shaped tungsten filaments are used as the heat source. The furnace is enclosed in a water-cooled jacket. The filaments are attached to water-cooled leads that are suitably insulated from the furnace.

The characteristics of the furnace are measured with a water-cooled calorimeter, which is installed in the furnace as shown in Figure 14. The furnace temperature is determined by an optical pyrometer sighting on a blackbody hole in a molybdenum target at the bottom of the furnace. The power output of the furnace to the water-cooled load is determined by measuring the water flow rate using a graduated cylinder and a stopwatch. The water inlet and outlet temperatures are determined by test thermometers graduated at 0.1 K intervals. The furnace losses, mainly conduction losses through the tungsten filaments, are determined by subtracting the output from the input. The results are shown in Figure 15. The major losses at the higher temperatures are due to radiation, as may be ascertained by plotting the fourth root of the power versus temperature.

The losses due to conduction down the filment are expected to be linear with temperature. These losses are estimated by running the furnace with the water-cooled load removed and the opening in the furnace

covered by a MULTI-FOIL shield. If the value of the MULTI-FOIL losses (Ref. 3) is subtracted from the total loss, the filament loss may be estimated. For example, with the furnace temperature at 1900 K, the total losses are 4.0 kW. The MULTI-FOIL loss at this temperature is calculated as 0.2 kW, resulting in a filament loss of 3.8 kW. This shows that the filament loss is the most significant.

ELECTRICAL CHARACTERIZATION OF CONVERTERS

Description of Data Acquisition System

A block diagram of the data acquisition system is shown in Figure 16. Two stations can be accommodated at one time, with two additional stations plug selectable. During testing, the converter operating conditions are set manually on temperature controllers individual to each diode element.

Converter testing is carried out by sweeping the converter voltage over its range from a transformer driven by the ac powerline. The raw data include mV thermocouple values as well as the digitized current and voltage points.

The I-V curve is continuously monitored on an oscilloscope. The sweep voltage and current shunt are selected to produce an acceptable curve on the oscilloscope. When the proper conditions have been attained, the data system is switched to the test station and given a trace command. The I-V curve will be traced repetitively with the pen up. If the curve is satisfactory, the operator plots the curve with the pen down.

The computerized data acquisition system is particularly advantageous in testing the three-converter module. The I-V curves for the individual converters as well as the entire module can be readily obtained and recorded on the chart. When the converters are operated in series, individual voltage taps are provided to determine the output voltage at the emitter sleeve. Additional taps are provided to measure the voltage drop of the converter in interconnecting leads.

Performance of Variable-Spacing Converter with Planar Electrodes

This planar variable-spacing converter employs an electropolished tungsten emitter and a tungsten oxide collector. The converter was constructed to evaluate the techniques required to use tungsten oxides with niobium substrates. The collector is made of niobium 1%-zirconium, with two vapor depositions of tungsten oxide. Initially, tungst oxide was vapor deposited onto the substrate, which was then heated   acuum to 775 K for 6.5 hours in order to diffuse the oxide layer into the substrate. This bake was followed by another vapor

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deposition of tungsten oxide and a predegas vacuum heat treatment to 475 K.

Initial power data did not indicate the presence of oxygen typical of tungsten oxide converters. The performance was stable and emitter saturation currents were no greater than those for non-oxygenated tungsten emitters. However, operation of the converter for several days with the collector at 750 K and in 0.25 torr of cesium increased the saturation currents by a factor of about three, which indicated that oxygen was dispensed slowly from the collector. After the performance stabilized, the collector was heated to 800 K, and once again an increase in emitter current was observed over a period of a few days. At this point the converter had sufficient oxygen to operate at a high emitter temperature and still maintain a 1-mm spacing. The converter was operated at T_E = 1600 K, T_C = 800 K, T_R = 528 K, and d = 1 mm, with a barrier index of 2.05 eV. The power output was 2.7 W/cm^2 at 8 amp/cm^2.

Figure 17 shows a typical cesium family for this converter illustrating oxygenated performance with the converter operating at a 1-mm spacing. Figure 18 shows a cesium family at a 0.5-mm spacing.

This converter was life tested for slightly more than 2200 hours at the following conditions: T_E = 1600 K, T_C = 850 K, T_R = 528 K and d = 1 mm. Figure 19 shows the converter performance during the life test.

After 2200 hours of operation this converter was shut down in order to check the emitter thermocouples for degradation effects. The emitter temperature was measured optically through the bell jar with a pyrometer just prior to the shutdown. Losses due to deposits on the bell jar were included in this measurement. Subsequent calibration of the bell jar showed the emitter temperature to be 30° high, which at 1700 K would result in a positive 50-mV shift in the I-V curve (see Figure 19).

At this time the converter was moved to a dc life-test station. However, shortly after moving the converter, a power failure in the building caused the emitter power supply to shut down. The emitter cooled down while the collector remained at 850 K for several hours, which apparently caused an irreversible loss of oxygen in the converter. This converter operated for more than 2200 hours with a barrier index of 2.05 eV and a power output of 2.6 W/cm^2 at 0.3 V.

Performance of Cylindrical Heat Pipe Converters

Each converter was individually activated, aged, and tested prior to construction of the module. The performance of a tungsten oxide converter improves with time. It is important to construct the module from three fully activated converters. This activating and aging process is described below.

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Initially the converter was operated with the collector at a low temperature, typically 700 to 750 K. During this aging period, the emitter temperature was held between 1400 and 1500 K. The cesium pressure ranged between 0.5 and 2 torr. This aging process lasted approximately 100 hours. It is believed that during this period the initially insulating tungsten oxide collector becomes more conducting. The I-V characteristic becomes less resistive in appearance as the active area of the collector increases. This change in collector resistivity is shown in Figure 20. Curve 1 shows initial performance, and curve 2 shows the converter performance after 100 hours. Once the collector was activated, its temperature was raised 50 to 100 degrees in order to dispense oxygen to the emitter. At a collector temperature of 800 K, 50 hours of operation may be needed to provide enough oxygen for enhanced performance. At collector temperatures of 850 K or greater, the process takes considerably less time. Curve 3 in Figure 20 shows the oxygen-enhanced performance.

After the collector was activated and the emitter saturation current indicated oxygen enhancement, the converter performance was optimized by varying the collector and cesium reservoir temperatures. The tungsten oxide collectors typically optimized at 800 to 850 K. The cesium pressure optimized between 0.5 and 2 torr, depending on the emitter temperature and the amount of oxygen enhancement. Figure 21 shows the oxygen-enhanced performance of Converter No. 184. This particular converter optimized at a collector temperature of 800 K and a cesium pressure of 1 torr.

MODULE FABRICATION TECHNIQUES

After three converters were individually tested and showed favorable performance, they were assembled into a module. Figure 1 shows the final module configuration. Each converter was securely attached to the Inconel support plate with two threaded stainless rods. The rods were attached to the collector flange and electrically isolated from the plate with alumina ceramics (see Figure 6). The collector heat pipes were then mounted on the tapered collector assembly. The tops of the heat pipes were held in place by a locating plate that was supported by a rod in the center of the heat pipes. This locating plate was also electrically insulated from the heat pipes. The rod-and-plate structure was designed so as to limit any horizontal movement of the heat pipes, while allowing for considerable thermal expansion vertically. This structure is shown clearly in Figure 7. An Inconel sheath heater was wrapped around each heat pipe, allowing greater control of the collector temperature during initial testing. The heaters were also used in the final fabrication of the module when the collector heat pipe was bonded onto the collector assembly. In this step, the temperature of the heat pipe was raised to approximately 575 K while the collector was kept cold.

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The heat pipe was then able to expand thermally and slide down on the tapered collector. During converter operation, when the collector runs hotter than the heat pipe, the collector expands inside the taper thus ensuring good thermal contact.

The current leads for the emitter were made from 10 molybdenum straps and, for the collector, from 10 copper straps. Each strap was 0.25 mm thick and 38.1 mm wide. The total cross-sectional area of the leads was 0.97 cm^2 and the length was 101.6 mm. The three converters were connected in series with a water-cooled copper bus as shown in Figure 1. Later, additional copper straps were added to further reduce voltage drops in the interconnecting leads.

Each converter had its own voltage taps that were connected to extra current straps provided for this purpose. In addition, there was a voltage tap tied directly to the emitter of one converter, which was to measure emitter sleeve losses. The voltage drop in the interconnecting leads was also measured by separate taps.

The three converters had separate cesium reservoirs that were independently and automatically controlled. The separate reservoirs allowed for maximum flexibility in obtaining optimum converter performance.

A water-cooled copper radiation jacket surrounding the three collector heat pipes was added after initial testing of the module. The jacket was needed to keep the bell jar cool and the vacuum below 1×10^{-5} torr when the module was in full operation.

ELECTRICAL CHARACTERIZATION OF THE MODULE

One of the primary concerns in the testing of the module was to determine whether the three emitter heat pipes would be compatible in the furnace. If the three emitters did not operate at roughly the same temperatures for a given furnace power, there would be problems in optimizing the converter performance. Initially, with the emitters operating at 1400 K, there was less than a 100° variation among the three converters. However, when the module was operated at higher emitter temperatures (typically 1700 K), it was discovered that the emitter heat pipe in Converter C (see Figure 22 for converter location and designation) ran more than 200° cooler than those in Converters A and B. With their performance optimized at T_E = 1750 K, Converters A and B each had power outputs in excess of 100 W. Converter C, however, was operating in the negative power region and, subsequently, lowered the total output power of the module below what it would have been with A and B alone. In order to obtain reasonable power output from Converter emitter C, it would have been necessary to run Converter emitters A and B hotter than 1900 K. This temperature was

close to exceeding the maximum temperature allowed by the design. Converter C was simply not compatible with Converters A and B. At this point, it was decided to short out or bypass Converter C, thus allowing the performance of A and B to be optimized without losing output voltage to C. Figure 23 shows the optimized performance of Converters A and B at T_E = 1750 K.

The optimized operating conditions of both converters were almost identical with Converter B having a slightly higher collection temperature. Converter A showed the best overall performance with a barrier index of 2.1 eV. The combined performance of Converters A and B is given by curve A+B+Lead Loss in Figure 23. The lead loss represents the voltage drop in the interconnecting lead between the two converters. This voltage drop is plotted versus current density in Figure 23. The curve A+B+B'+Lead Loss represents the projected performance of a three-converter module. The power output of B' was taken to be identical to that of Converter B. The lead loss was twice that of the two-converter case. This projected performance indicates that the three-converter module quite readily obtains power outputs greater than 250 W at an emitter temperature of 1750 K.

Another converter (No. 195) was substituted in the module for the poorly performing Converter C. Again the performance of the module was measured at various emitter temperatures. An output power of 270 W was observed at an average emitter temperature of 1800 K. Figure 24 shows the performance of each converter as well as the total module performance. The maximum power point was at a current density of 6.4 amp/cm^2 and a voltage of 1.2.

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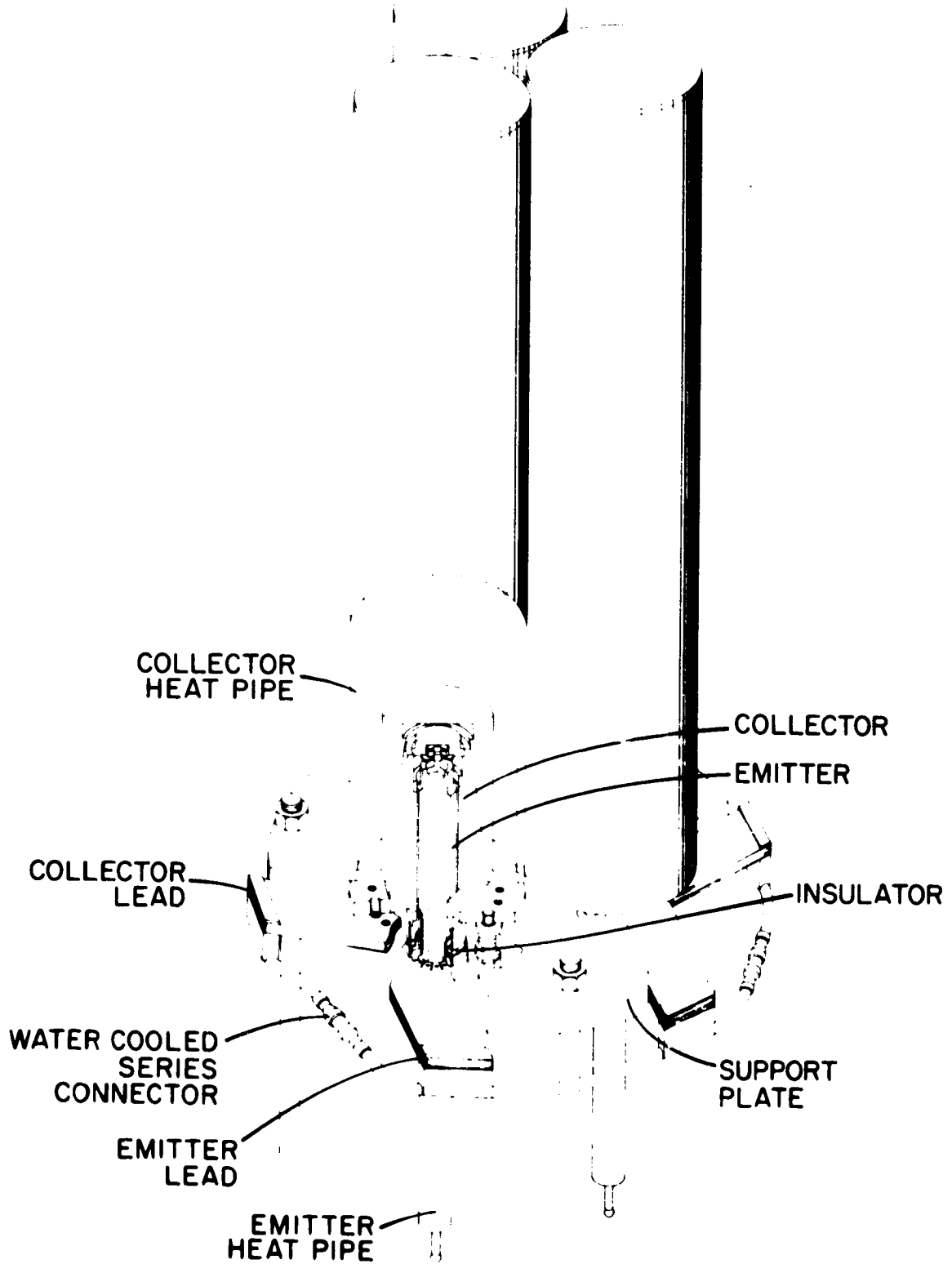
Figure 1. Cylindrical Converter Module
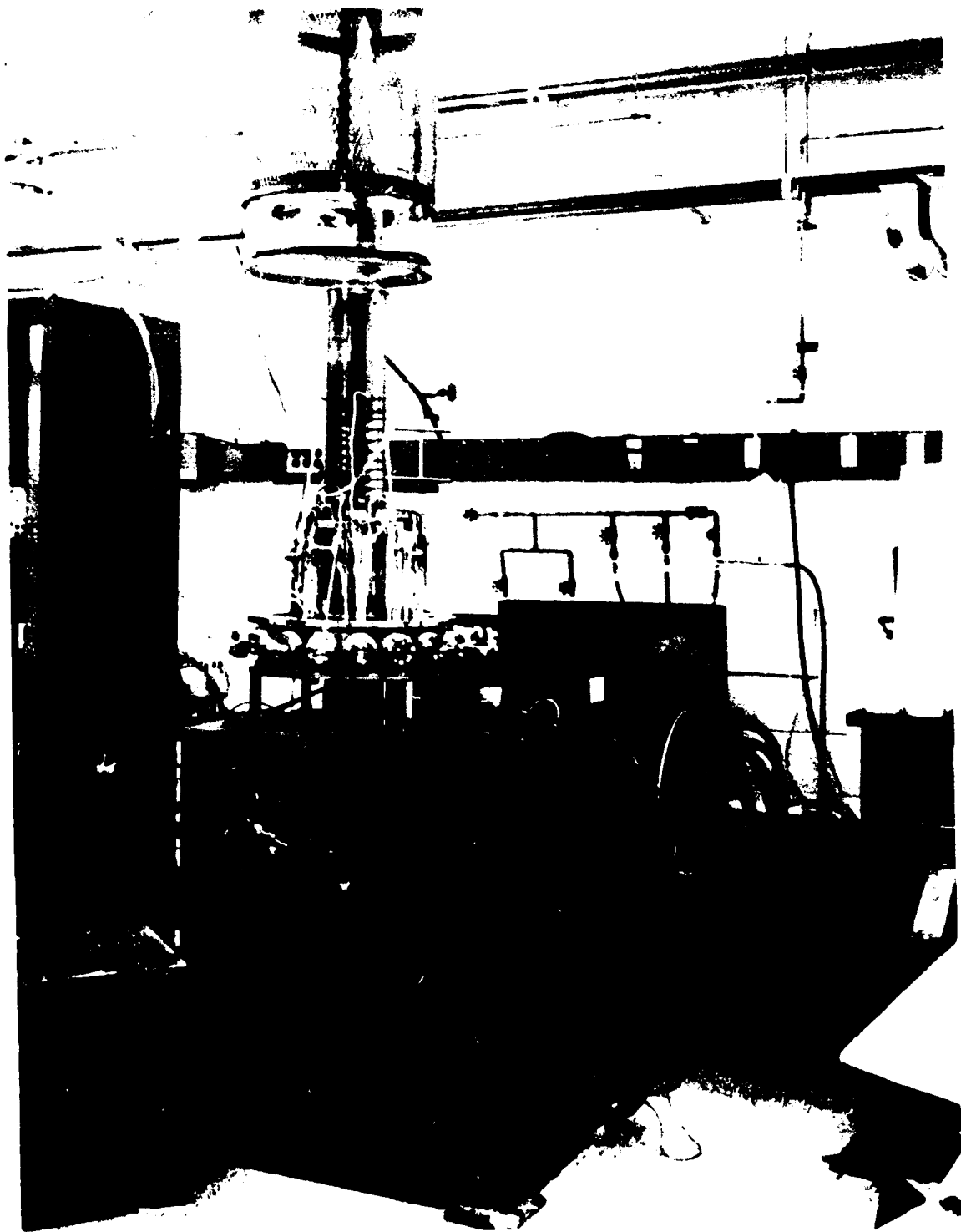
Figure 2.   Photograph of Cylindrical Converter Module in Test Stand,
Mounted on Vacuum System
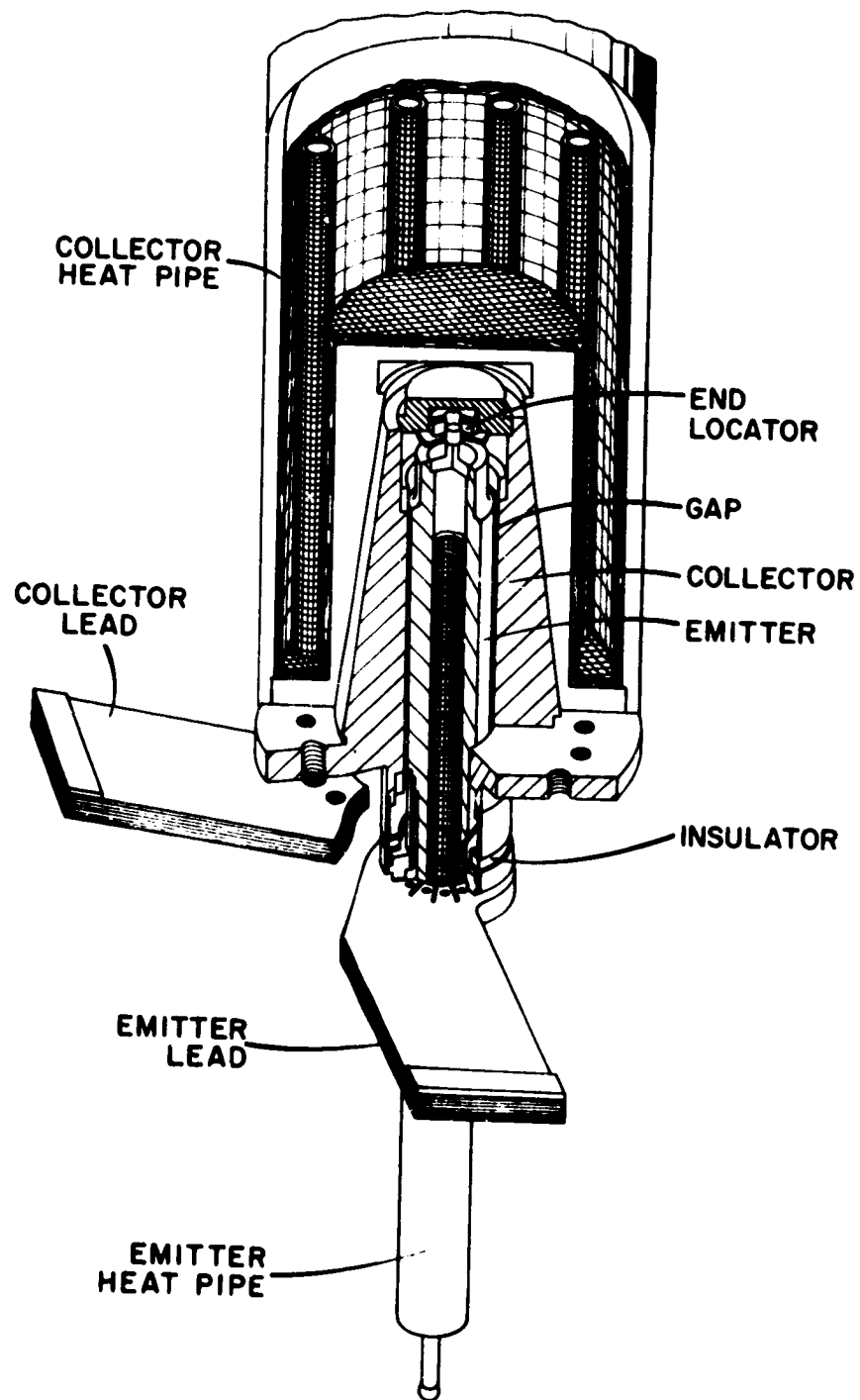
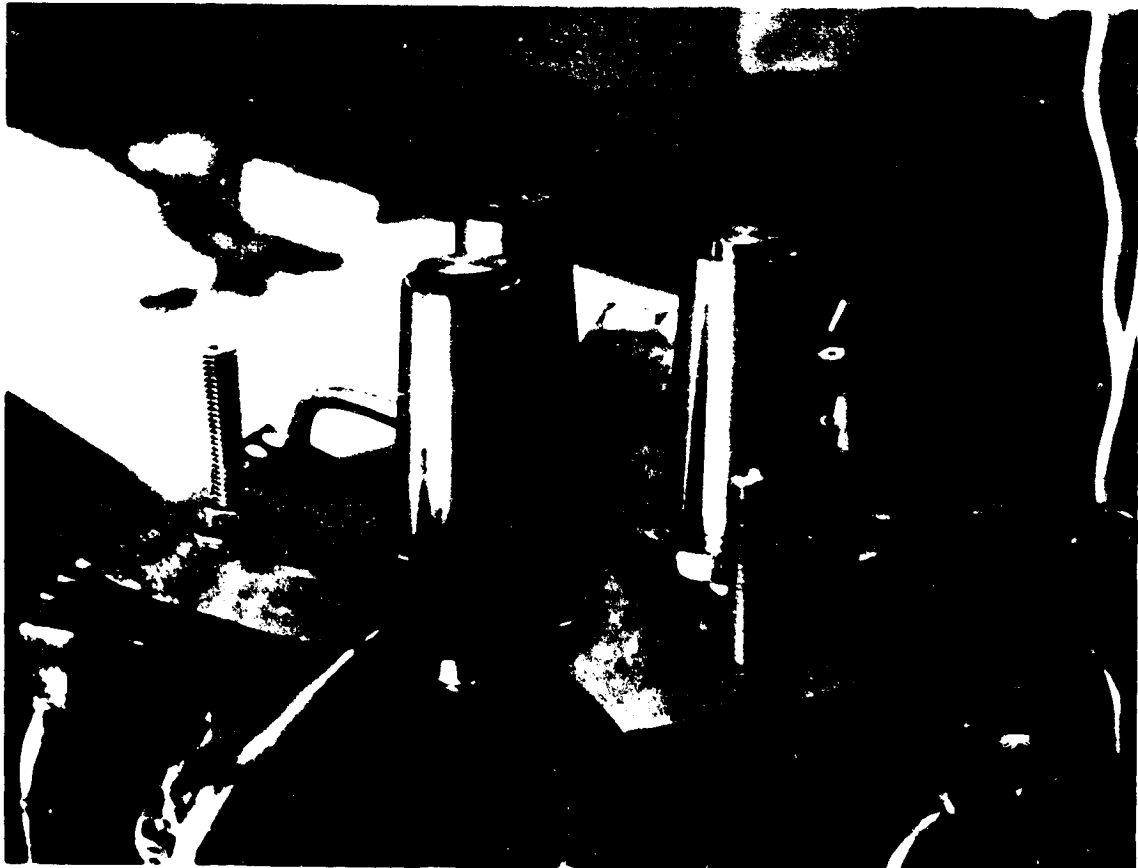Figure 3. Cutaway View of Cylindrical Converter
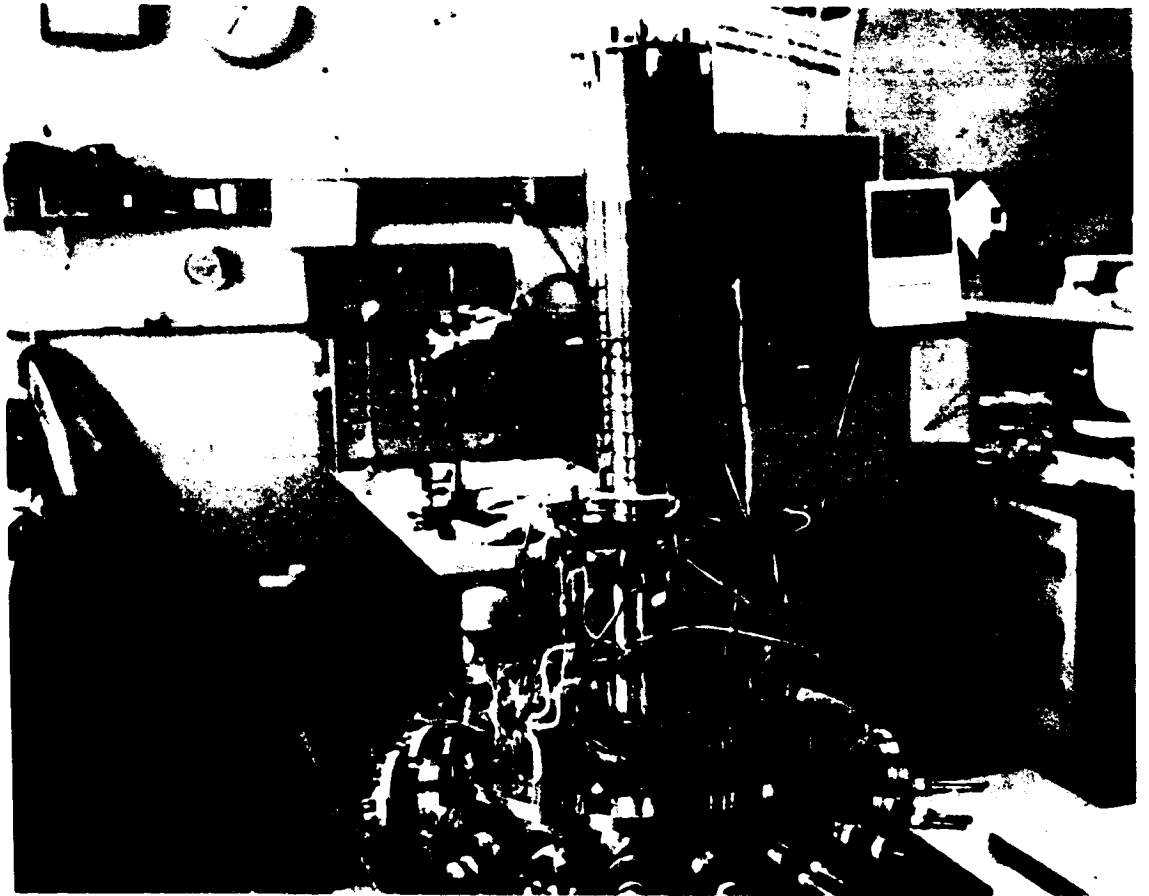
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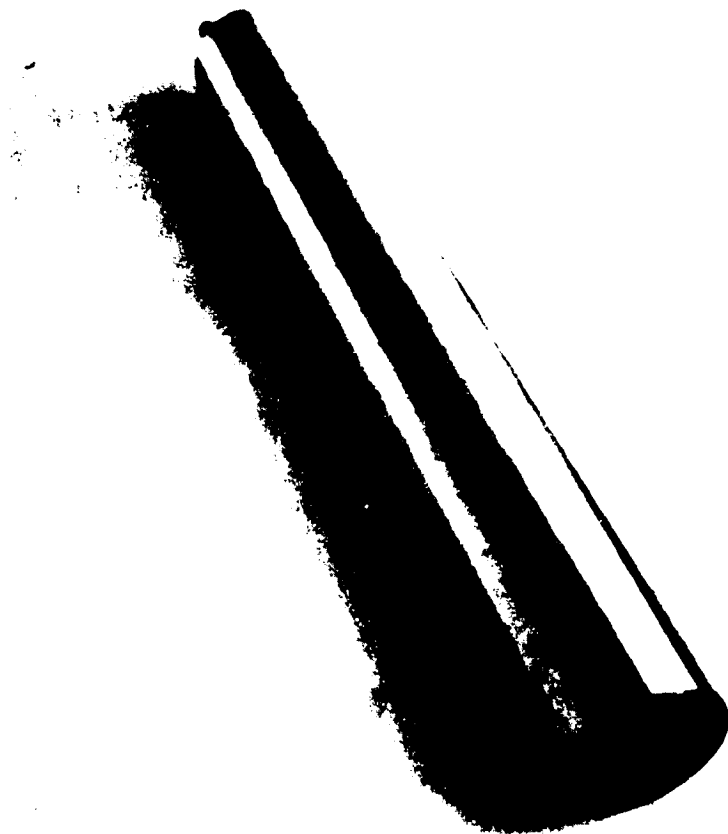
Figure 4. Photograph of Completed Collector Heat Pipe

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Figure 5. Photograph of Cylindrical Converter with Collector
Heat Pipe Attached (Emitter heat pipe is seen in
the foreground.)

Figure 6. Photograph Showing Cylindrical Module in Test Stand,
Prior to Assembly of Collector Heat Pipes

Figure 7. Photograph of Cylindrical Module with Collector Heat Pipes Attached

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Figure 8. Photograph of Completed Emitter Heat Pipe
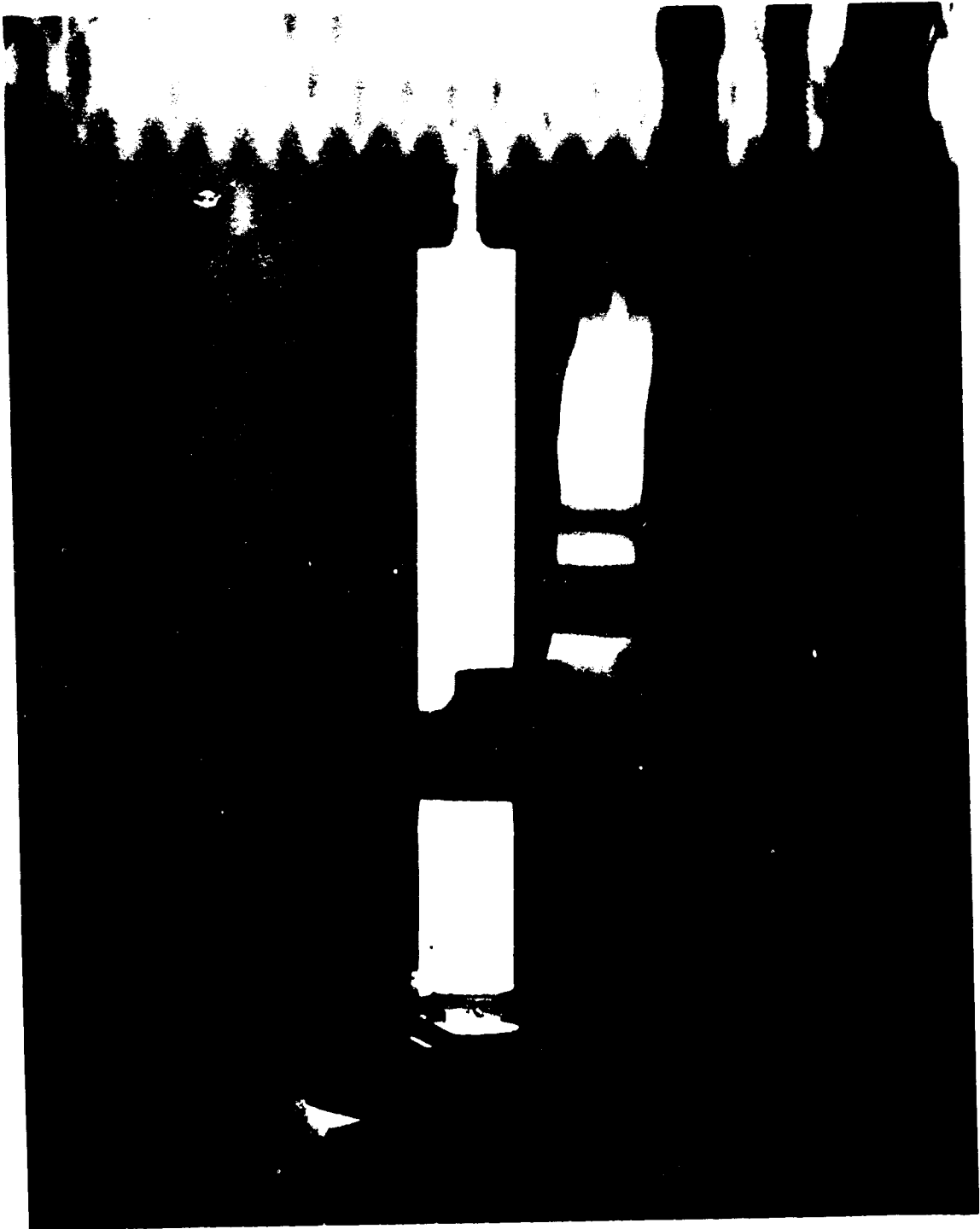
Figure 9. Photograph of Emitter Heat Pipe During Test

Figure 10. Photograph of Collector Subassembly

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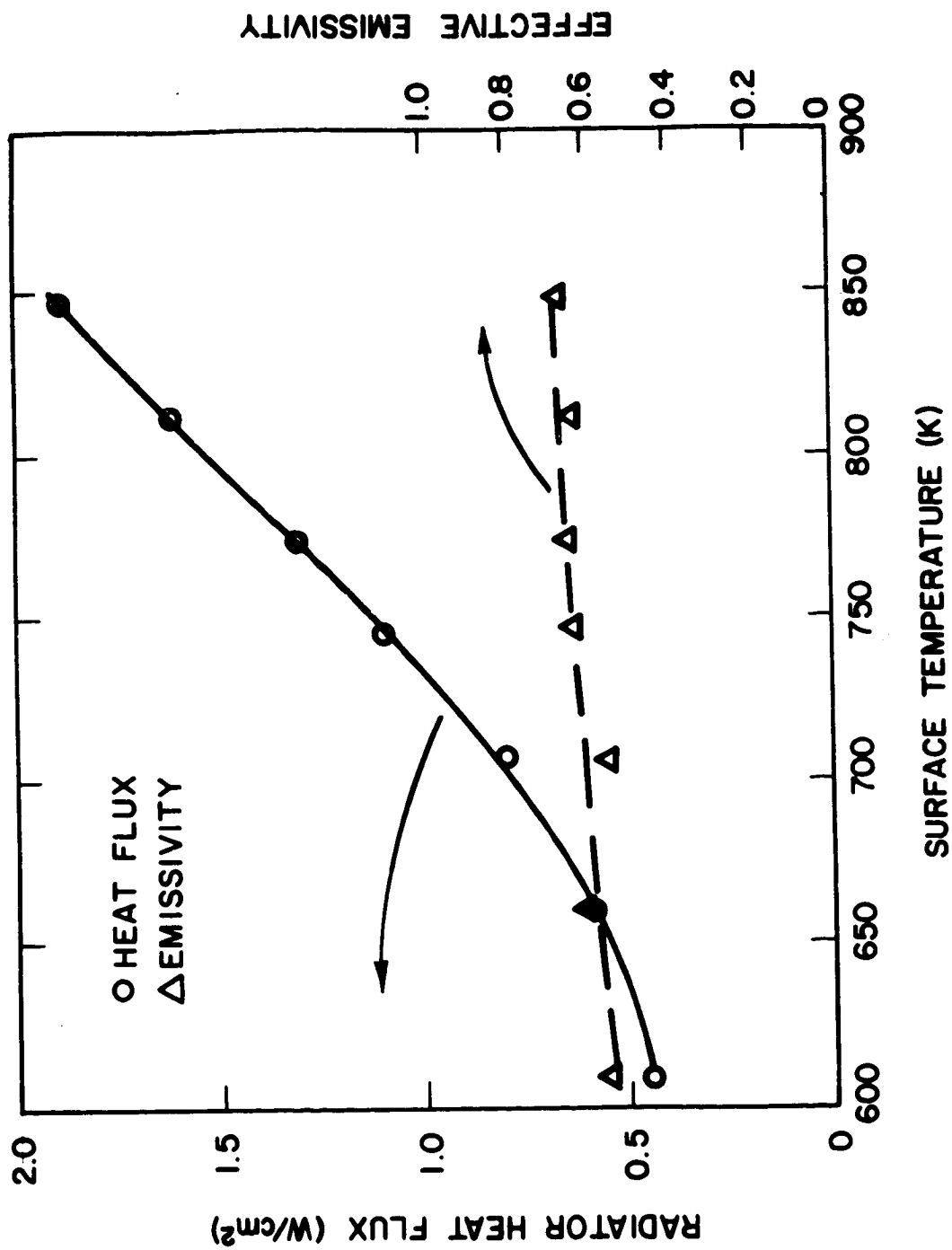
Figure 11. Heat Pipe Radiator Heat Flux Measurements

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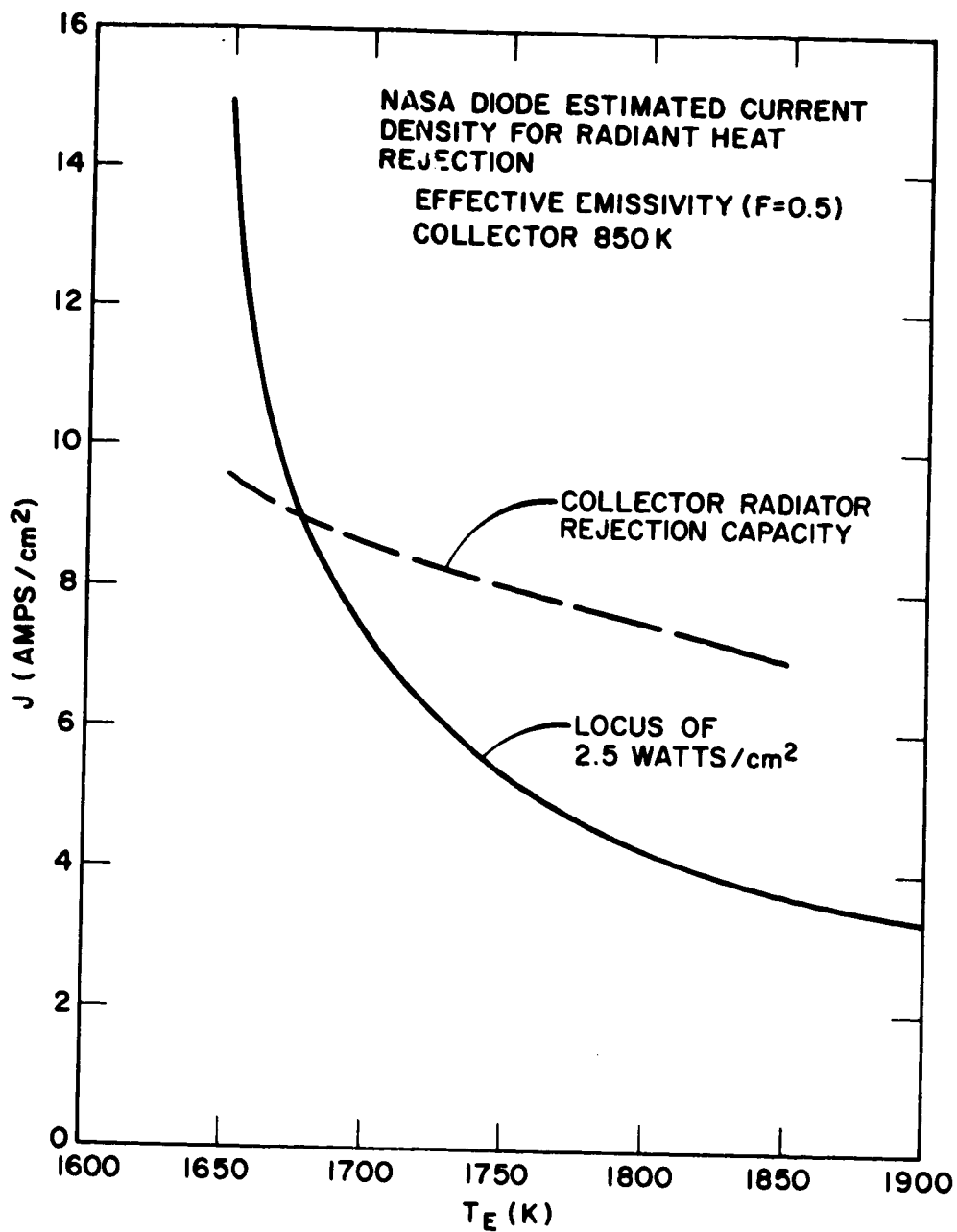
Figure 12. Calculated Converter Performance with Collector Radiator

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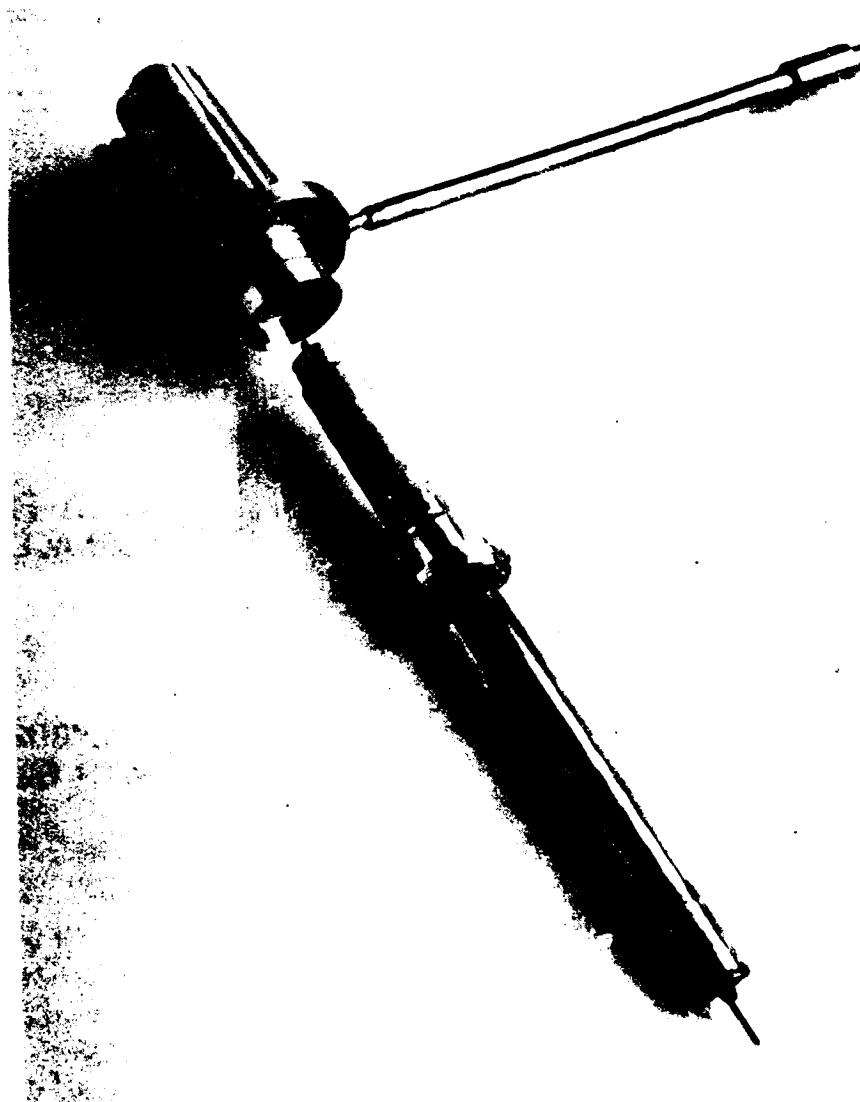
Figure 13. Photograph of Emitter and Collector Subassemblies
Prior to Assembly
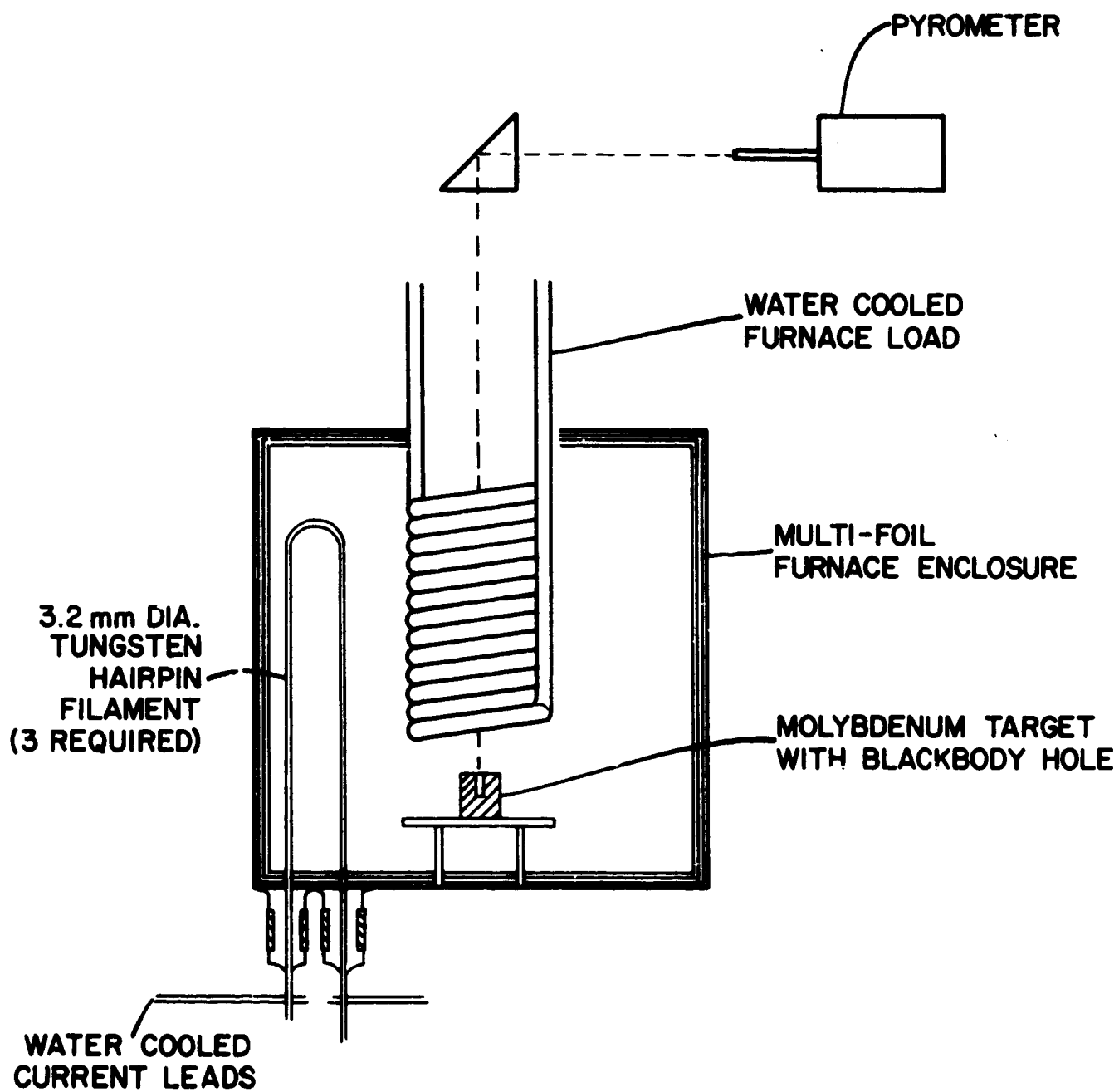
Figure 14. Experiment for Furnace Loss Measurements
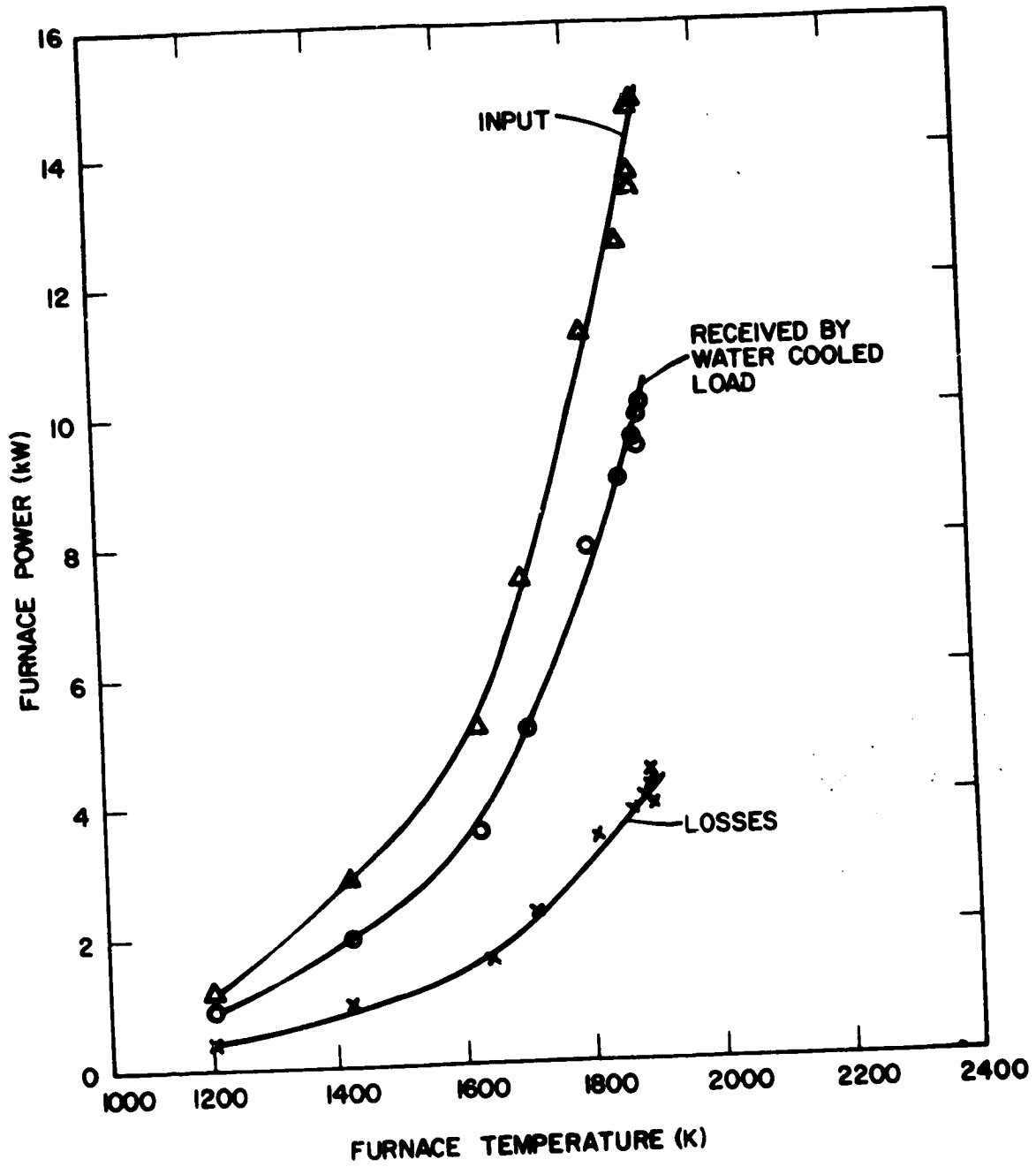
Figure 15. Furnace Loss Measurements
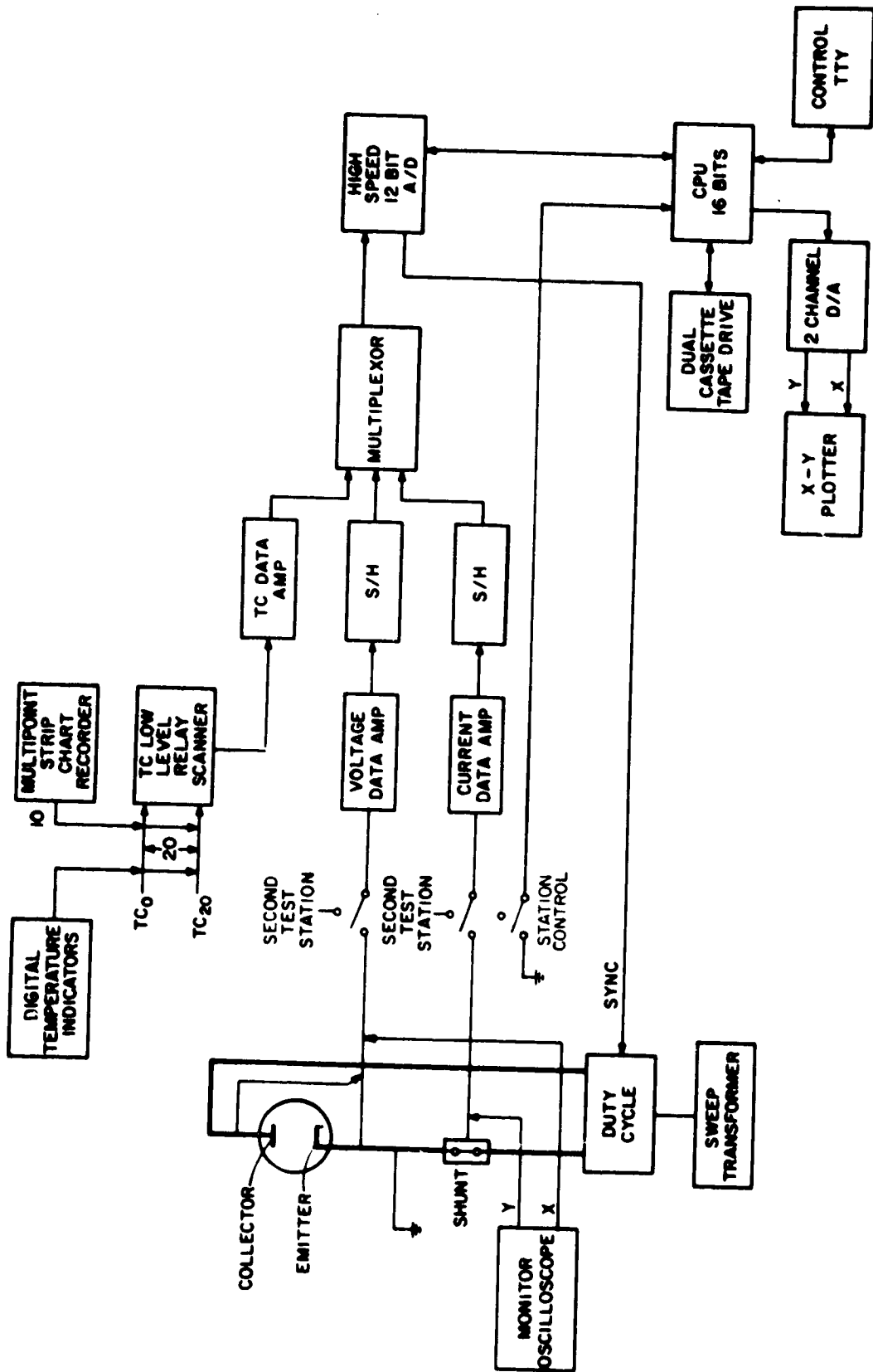
Figure 16.   Data Acquisition System

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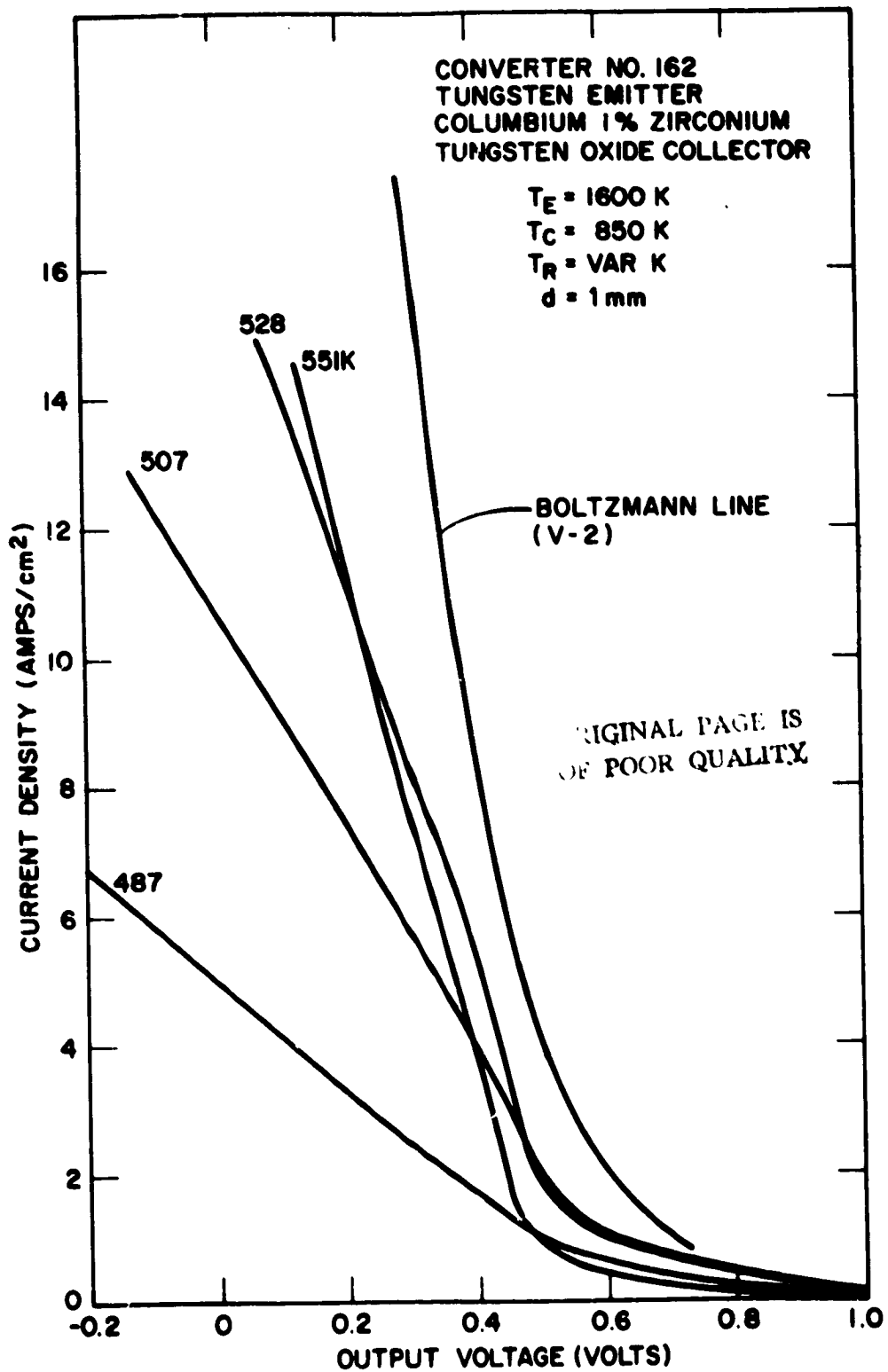
Figure 17.   Cesium Family for Converter No. 162 Showing
"Oxygenated Performance" at a 1-mm Spacing

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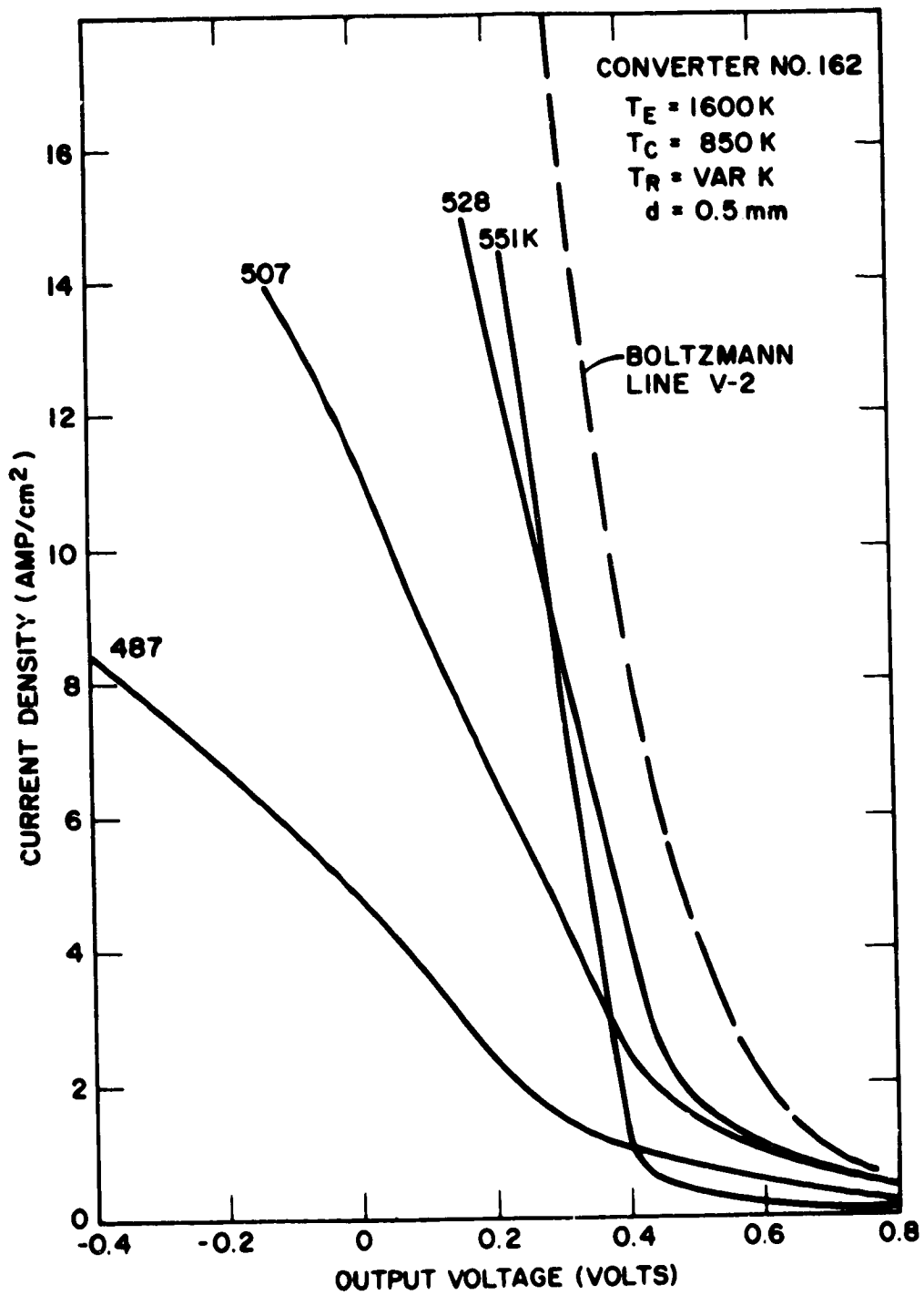
Figure 18. Cesium Family for Converter No. 162 Showing
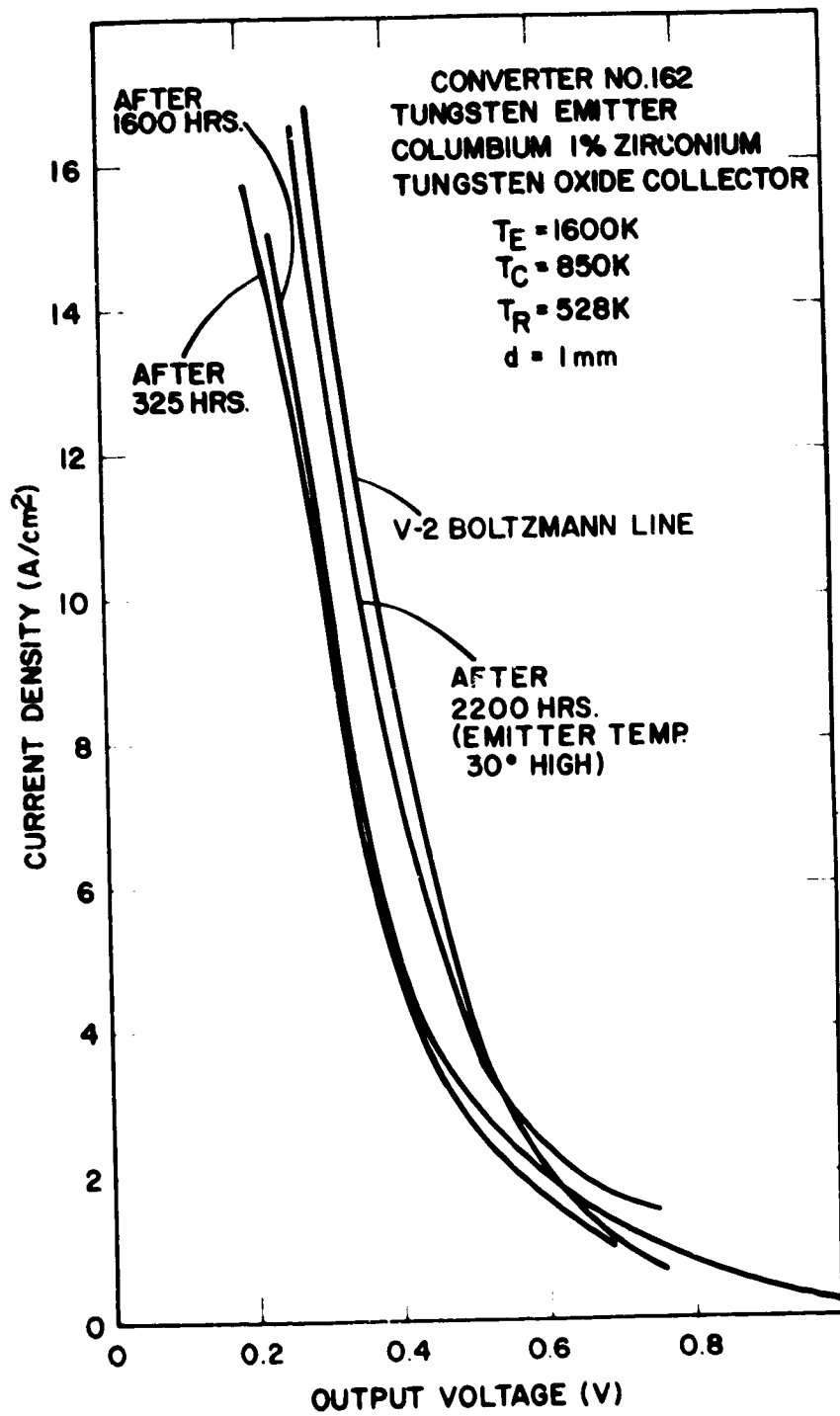"Oxygenated Performance" at a 0.5-mm Spacing

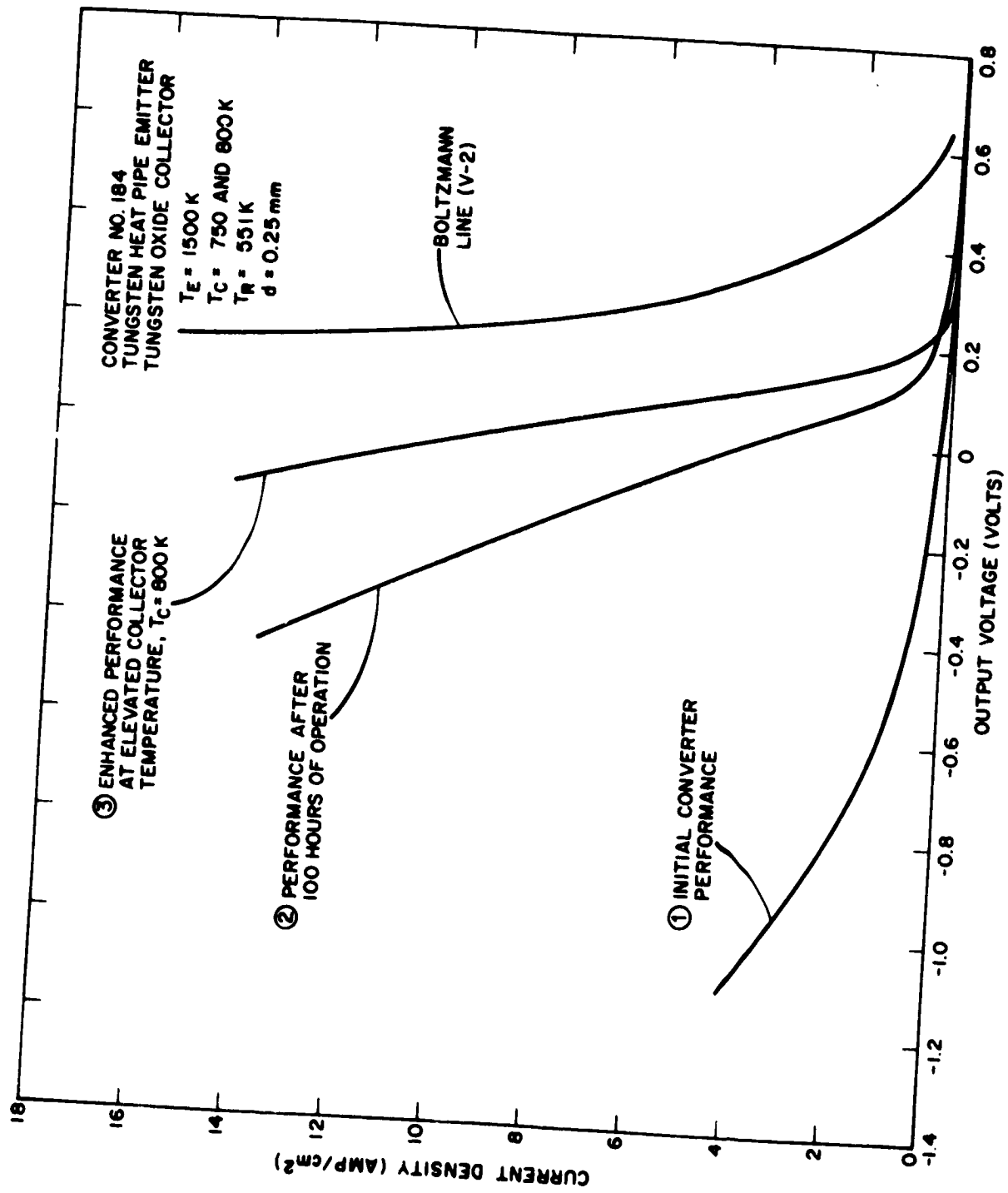Figure 19. Converter No. 162 Performance During Life Test

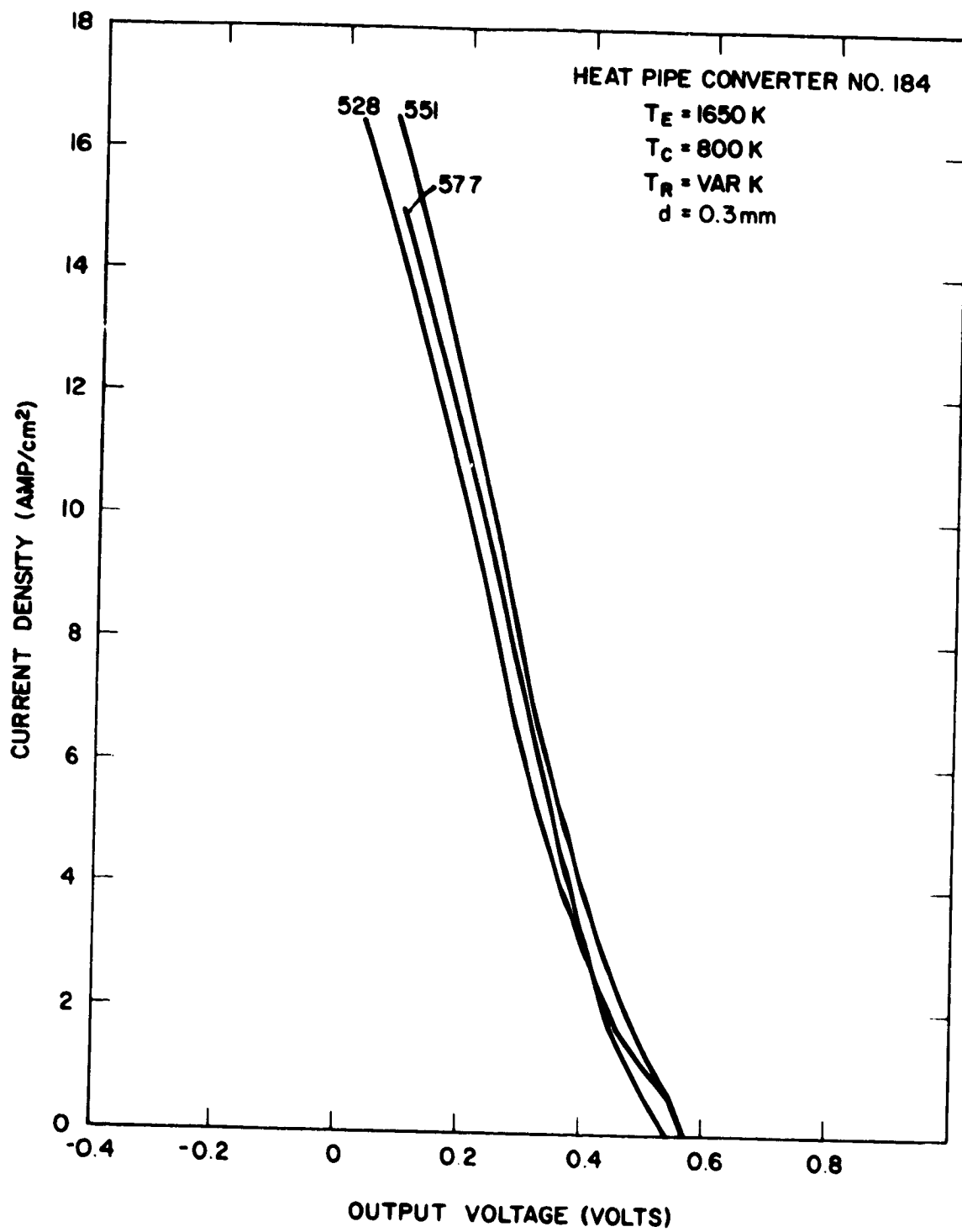Figure 20. Initial, Activated, and Enhanced Performance of Converter No. 184

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Figure 21. I-V Curve for Converter No. 184

MODULE 1

CONVERTER LOCATION	CONVERTER NO.	EMITTER HEAT PIPE MATERIAL	NOMINAL SPACING mm
A	184	CVDF	0.3
B	185	AVCE	0.3
C	192	CVDF	0.25

NOTES:

1. AVCE   ARC VACUUM CAST EXTRUDED
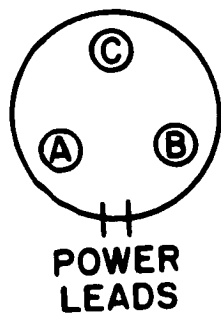2. CVDF   CHEMICAL VAPOR DEPOSITED FROM FLUORIDE

POWER LEADS

Figure 22.   Converter Designation and Location for Module 1
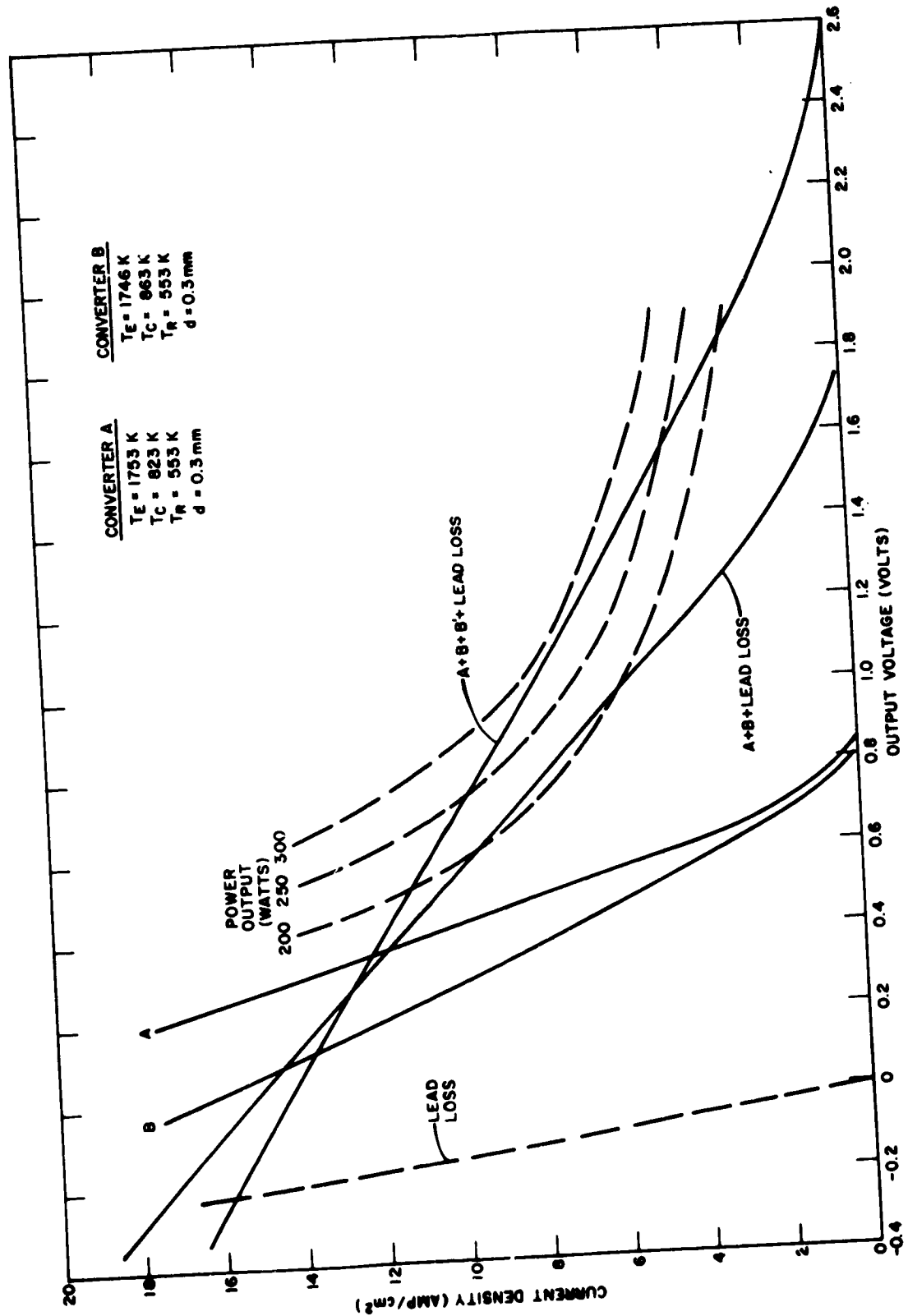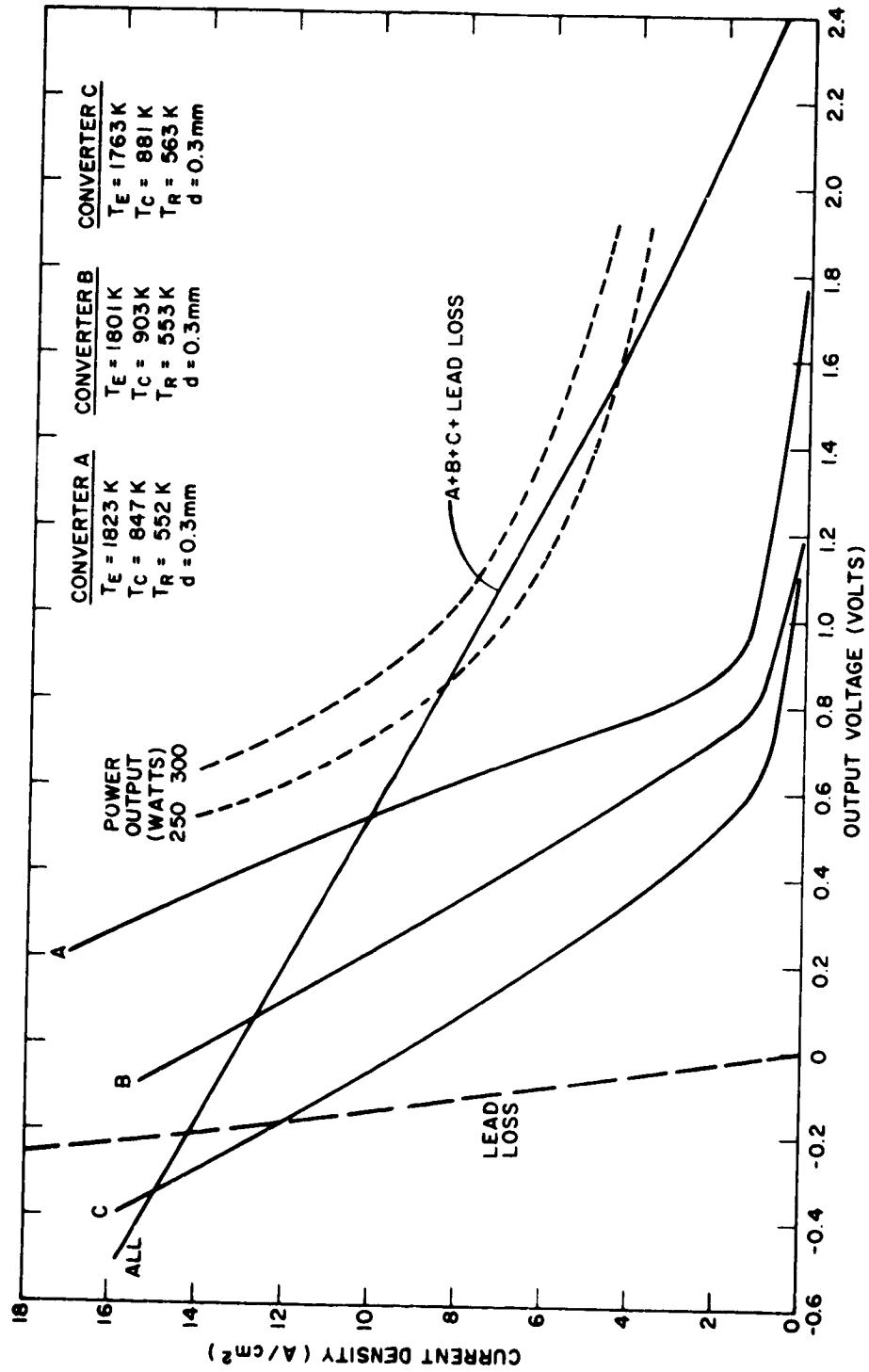
Figure 23. Optimized Module Performance

Figure 24. Performance of a Three Converter Module

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16 Abstract

A thermionic-converter module simulating a configuration for an out-of-core thermionic nuclear reactor has been designed, fabricated, and tested. The module consists of three cylindrical thermionic converters. The tungsten emitter of the converter is heated by a tungsten, lithium heat pipe. The emitter heat pipes are immersed in a furnace, insulated by MULTI-FOIL thermal insulation, and heated by tungsten radiation filaments. The collector consists of tungsten oxide vapor deposited on niobium, 1%-zirconium alloy. The interelectrode spacing is 0.30 mm. The active area of the emitters is 115 cm^2 and the diameter is 19 mm. The collector heat is rejected by radiation from a niobium, 1%-zirconium heat pipe utilizing a potassium working fluid. The performance of each thermionic converter was characterized before assembly into the module. An electrically heated, water-cooled collector heat rejection system replaced the collector heat pipe for these tests. Dynamic voltage, current curves were taken using a 60-Hz sweep and computerized data acquisition over a range of emitter (1300 to 1850 K), collector (700 to 855 K), and cesium-reservoir (around optimum power) temperatures. An output power of 215 W was observed at an emitter temperature of 1750 K and a collector temperature of 855 K, for a two diode module. With a three diode module, an output power of 270 W was observed at an average emitter temperature of 1800 K and a collector temperature of 875 K.

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