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HIGH TEMPERATURE SOLAR THERMIONIC GENERATORS

SECOND QUARTERLY TECHNICAL REPORT

15 NOVEMBER 1963

**AIR FORCE AERO PROPULSION LABORATORY
RESEARCH AND TECHNOLOGY DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE**

**PROJECT No. 8173
TASK No. 817305-24**

(Prepared under Contract AF 33(657)-11169 by
The Solar Energy Systems Group, New Product
Research Department, Cleveland, Ohio)

HIGH TEMPERATURE SOLAR THERMIONIC GENERATORS

QUARTERLY TECHNICAL PROGRESS REPORT
1 August 1963 - 31 October 1963

PREPARED FOR
Air Force Aero Propulsion Laboratory
Research and Technology Division
Air Force Systems Command
United States Air Force
Wright-Patterson Air Force Base, Ohio

Project No. 8173
Task No. 817305-24

November 15, 1963

Prepared under Contract No. AF 33(657)-11169
by the Solar Energy Systems Group
New Product Research Dept.
Electromechanical Division
Thompson Ramo Wooldridge Inc.
Cleveland, Ohio

FOREWARD

This report is the second Quarterly Technical Report prepared by Thompson Ramo Wooldridge Inc., on Air Force Contract AF 33(657)-11169 under Task Number 817305-24 of Project Number 8173.

The work is being administered under the direction of the Flight Vehicle Power Branch, AF Aero Propulsion Laboratory, Research and Technology Division. Mr. A. E. Wallis, (APIP-2/22208) is the project engineer for the Aero Propulsion Laboratory.

The report covers the work performed from 1 August 1963 through 31 October 1963 at the New Product Research department of the Electromechanical Division of TRW, Cleveland, Ohio, and at Thermo Electron Engineering Corporation, Waltham, Massachusetts, a major subcontractor to TRW.

The work covered by this report was accomplished under Air Force Contract AF 33(657)-11169, but this report is being published and distributed prior to Air Force review. The publication of this report, therefore, does not constitute approval by the Air Force of the findings or conclusions contained herein. It is published for the exchange and stimulations of ideas.

This report is unclassified.

ABSTRACT

Efforts during this quarter included the fabrication of four Series 300 thermionic converters and the initiation of sustained performance evaluations of three of the four. One of the converters (#302) is being operated continuously while the other two (#303 and #305) are being cycled to simulate the 55 minute ON, 35 minute OFF orbital cycle operation. Design emitter temperature is 2000°K and nominal output power to the load at 0.7 volts is 21 watts (7 watts/cm²).

To date, (through October 31, 1963) a total of 545 hours of continuous operation has been recorded for converter #302 with no decrease in performance. Converter #303 withstood a total of 430 cycles when an apparent internal emitter-to-collector short occurred. A failure analysis is currently being performed on this converter. Converter #305 has accumulated a total of 540 cycles. Performance data taken during cycle 509 showed a 17.5% decrease in power output. During the last 31 cycles the performance has held essentially constant at the reduced power output. Test of this converter is continuing.

In addition to the above described fabrication and test effort, a Demonstrator Model Test Stand and Auxiliary Support Vacuum System was fabricated and tested. This equipment was used during the acceptance test of converter #304 and met or exceeded all performance specifications. (See Section 4.0)

These test stands along with converter #304 are now scheduled for delivery to the AF Aero Propulsion Laboratory in early December 1963.

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1.0 INTRODUCTION

This is the second quarterly technical report on Contract AF 33(657)-11169 covering the period from August 1, 1963 to October 31, 1963. The major effort during this quarter was directed toward the fabrication of four Series 300 converters and the initiation of sustained performance evaluations of three of the four converters in the TRW Vac-Ion Thermionic Test Stand. These converters are identical in design and construction to the prototype converter #301, test results for which were reported in the first quarterly report. Section 3.0 of this report presents the results obtained to date on the continuous life test of converter #302 and on the cyclic tests of converters #303 and #305.

In addition to the converter fabrication and test effort described herein, a Demonstrator Model Test Stand utilizing a Vac-Ion pump was designed, fabricated and tested during this quarter. This test stand along with converter #304 and a supporting vacuum system was completed for delivery to the Aero Propulsion Laboratory's Research and Technology Division. This versatile test equipment will permit Air Force evaluations of a wide variety of thermionic converters and generators. Section 4.0 of this report describes these test stands. Section 5.0 lists the work planned for the next quarter.

2.0 SUMMARY

The fabrication of four thermionic converters (Nos. 302, 303 304 and 305) was successfully completed. After an acceptance test of each of the four, converter #302 was placed on continuous test, operating at the design emitter temperature of 2000°K. To date this converter has accumulated 545 hours of test time with no apparent reduction in performance. Converter Nos. 303 and 305 were placed on cyclic operation to simulate the 55 minute ON, 35 minute OFF orbital cycle operation. Converter #303 withstood a total of 430 cycles (645 total test hours) when an apparent short between emitter and collector occurred. A detailed failure analysis of this converter is currently being performed. Converter #305 to date has withstood 540 cycles (810 total test hours). Performance data taken during cycle 509 shows a 17.5% decrease in power output when compared to initial performance data. The performance during the last 31 cycles (540-509) has held essentially constant. Evaluation of this converter is continuing.

Converter #304 was performance tested in the Demonstrator Model Test Stand and has been packaged for delivery to RTD.

The Demonstrator Model Test Stand was tested for compliance with the established performance specifications such as ultimate vacuum system pressure with a converter operating at 2000°K and has met or exceeded all specifications. Section 4.0 presents more information on this test stand and its supporting vacuum system.

3.0 LIFE AND CYCLE TEST RESULTS OF SERIES 300 ADVANCED THERMIONIC CONVERTERS.

All of the Series 300 converters scheduled for continued life and cycle tests were completed and acceptance tested at Thermo Electron Engineering Corporation early in this quarter. Figure 1 is a view of converter #303 before outgassing and cesium charging. Each of the converters except #304 was subjected to preliminary performance tests at Thermo Electron to establish approximately the characteristics of each. Typical performance data are summarized in Figures 2 and 3 for converter #303. Figure 2 shows three I-V plots for temperatures of 1800, 1900, and 2000°K for the converter optimized at 0.7 volts. The optimized I-V characteristic for converter #303 is also shown in this Figure to illustrate the effect of steady-state data taking techniques as opposed to the point-by-point method with the converter optimized at a particular load voltage. Figure 3 relates the optimum cesium temperature to output current for each selected voltage with a 2000°K emitter. The values given for optimum cesium temperatures shown in this Figure are not believed to be true optimum temperatures for all the converters of this series. These initial temperature measurements appear to be unusually low. Data recorded for other converters of the series are higher, i.e., temperatures as high as 420°C were reported by Thermo Electron in these preliminary tests for converter #302. Data for converter #302 is shown in Figure 4.

The converters when installed at TRW were found to operate more nearly alike and at optimum cesium temperatures similar to those noted previously for the Series 2B converters. The Series 300 converter power outputs obtained at TRW are in some instances slightly lower than would be indicated by the data obtained by Thermo Electron but this is largely due to the manner in which the data is taken. This point is illustrated by a comparison of Figure 26 and 28 presented in the first quarterly report for the prototype converter #301. It is seen that the highest output is achieved for steady-state point optimization in which cesium temperature is optimized for a fixed voltage and a controlled emitter temperature. The point-by-point measurement technique which uses a cesium temperature optimized at a given voltage suffers because of non-optimum conditions at any other load setting. Further, the emitter temperature does change somewhat no matter how quickly the operator adjusts the load bank. Depending upon whether the load is increased and then decreased or first decreased and then increased, and on how rapidly data is taken, an entirely different set of curves may be obtained.

The effect of load application is shown in Figure 5 for converter #304. Both these curves were generated under the same conditions of optimum cesium temperature, emitter temperature and constant power input. This data was taken by noting meter readings, but identical plots have been obtained using the XY recorder. It is important to note that these I-V characteristics represent the converter performance where T_E is not held constant but power input to the emitter is constant. The major contributors to the changed shapes of the two curves shown are the varying electron cooling loss and the varying cesium coverage on the emitter as a function of emitter temperature. Figure 6 shows the corresponding load-power vs. voltage curves for converter #304.

VIEW OF CONVERTER #303 BEFORE OUTGASSING
AND CESIUM CHARGING

FIGURE 2 PSUEDO-STATIC I-V CHARACTERISTICS FOR CONVERTER #303
@ $T_E = 2000^\circ\text{K}$, $T_E = 1900^\circ\text{K}$, AND $T_E = 1800^\circ\text{K}$

FIGURE 3 CESIUM RESERVOIR TEMPERATURE VERSUS
OUTPUT CURRENT FOR VARIOUS LOAD
VOLTAGES - CONVERTER #303 @ $T_E = 2000^\circ\text{K}$

FIGURE 4 CESIUM RESERVOIR TEMPERATURE VS OUTPUT CURRENT FOR VARIOUS LOAD VOLTAGES - CONVERTER #302 @ $T_E = 2000^\circ K$

FIGURE 5 PSUEDO-STATIC I-V CHARACTERISTIC FOR CONVERTER #304 - OPTIMIZED AT 0.7 VOLTS

$T_E = 1665^\circ\text{C}$ @ OPTIMIZED LOAD SET POINT (OBSV)

$T_{cs} = 375^\circ\text{C}$

CONSTANT POWER INPUT

FIGURE 6 POWER OUTPUT VS LOAD VOLTAGE FOR CONVERTER #304 - OPTIMIZED @ 0.7 VOLTS

The marked variations initially observed by Thermo Electron in optimum cesium reservoir temperature may be due to several things. It is possible the converter spacing was initially somewhat closer due to inaccuracies in assembly fixturing or residual stresses in converter members. A high cesium temperature and substantially higher performance as was indicated by some of the preliminary data is definitely consistent with very close spacing. It follows that a small number of operational cycles would relieve such stresses and restore the proper interelectrode spacing. This restoration of the design spacing would also result in a return of the optimum cesium temperature to the range previously noted in the Series 2B converters.

The other possibility is that some error or circuit difficulty in the temperature measurement instrumentation at Thermo Electron caused faulty readings. The measurements at TRW were made using direct reading pyrometers and were supported by a L and N potentiometer using a thermoelectric reference junction.

3.1 Test Stand and Support Equipment

A Vac-Ion test system employing a 400 liter/sec pump with a 6 port manifold was designed and fabricated by TRW during a previous program. This test stand shown in Figure 7 was prepared to accept the first of three Series 300 converters for a combination cycle and continuous life test. The test stand is equipped with stainless steel, water-cooled chambers. These chambers were fitted with additional side view ports with quartz windows and magnetically operated evaporation shields to facilitate viewing and emitter temperature measurements.

The vacuum test stand is supported by a control console containing 4 cesium heater supplies, 2 filament supplies and a load bank monitoring panel. Two high voltage DC power supplies flank this grouping to provide the bombardment power for the cyclic and continuous operation of the converters. Each converter has its own adjustable water-cooled load bank equipped with ammeter shunts and voltage terminals.

The load voltage and load current for each converter are monitored by a commutator switch arrangement and are displayed on both panel meters and a continuous strip chart recorder. Plug-jacks also make the output voltage and current simultaneously available to an X-Y plotter.

Cesium reservoir temperatures, collector temperatures, radiator temperatures and seal temperatures are monitored selectively on three direct reading pyrometers which range from 0° to 1100° C. Any thermocouple output may also be continuously recorded if required. The pyrometer readings are also supported by potentiometer readings using a thermoelectric reference junction to insure high accuracy for all cesium temperature measurements.

The measurement of emitter temperature is accomplished using a Pyro-Micro optical pyrometer. The pyrometer is arranged to sight into a small hole drilled in the emitter end piece to reduce the influence of reflections within the test chamber and approach black body conditions. A careful evaluation of this sighting arrangement has been carried out at Thermo Electron

VAC-ION LIFE TEST STAND

FIGURE 8 OBSERVED VS. TRUE TEMPERATURE FOR 0.030" DIA. X 0.120" DEEP HOLE IN TANTALUM

and an emissivity correction and a transmission correction curve was generated to insure a high degree of accuracy in the measurement made. The correction curves are shown in Figure 8 for the test converters using a pyrex enclosure. A careful check of the transmission losses associated with the quartz windows used in the TRW test chambers showed a maximum error of 8°C between this curve and the true calibration curve for quartz at approximately 2000°K . Since this represents an error of not more than 0.5%, the curves generated by Thermo Electron have been used unaltered for the measurements made during life and cycle tests at TRW.

3.2 Continuous Life Test - Converter #302

The continuous life test of converter #302 was started at 3:00 p.m. on October 9, 1963. This was the last of the four converters delivered to TRW by Thermo Electron. The converter performance was cesium temperature optimized at a load voltage of 0.7 volts with the input power adjusted to obtain an observed emitter temperature of 1660°C (2000°K). Figure 9 shows the pseudo-static I-V characteristics for this converter after 113, 295, and 545 hours of continuous operation. It is of importance to note that the performance appears to be improving with time in the 0.4 to 0.8 voltage range. This apparent performance improvement may be due to the possible development of a reduction in emitter-to-collector spacing with operating time. The continuous test evaluation of this converter is continuing into the next quarter of the program.

3.3 Cycle Life Tests - Converter Nos. 303 and 305

The cycle life tests of converter nos. 303 and 305 were started on September 26, 1963. Each converter was cesium temperature optimized at a load voltage of 0.7 with the input power adjusted to obtain an observed emitter temperature of 1660°C (2000°K). Figure 10 shows the pseudo-static I-V characteristics for converter #303 obtained during cycle nos. 30, 66, 116 and 197. This data was taken using the X-Y recorder. It should be noted that curve #3 (cycle 197) was taken at an observed $T_E = 1690^{\circ}\text{C}$ and at a non-optimum cesium temperature for a 0.7 volt load setting which accounts for a slightly higher characteristic curve.

On Monday, October 28, the week-end record showed the output power from converter #303 was lost during cycle 430. Examination of the converter showed that one of the four equally spaced, external emitter leads had again shorted to the collector body. This same lead had shorted during cycles 380 and 424 with a resultant loss in power to the external load. This short was caused by the distortion of one of the copper lead-wires which pass through a clearance in the converter mounting plate which is electrically connected to the collector via the collector-to-radiator transition piece. (See Figure 1 of this report and Figure 22 of the First Quarterly Technical Report - TRW ER-5464). The lead wire bowed under the thermal cycling developed stresses and contacted the collector. A design modification is therefore indicated for the next set of converters to be fabricated during the third quarter.

Since this short was external, a straightening of the lead-wire allowed the test to be continued after cycles 380 and 424; however after the short was

FIGURE 9 PSUEDO-STATIC I-V CHARACTERISTICS FOR CONVERTER #302 @ INDICATED TIMES

FIGURE 10 PSUEDO-STATIC I-V CHARACTERISTICS FOR
 CONVERTER #303 @ INDICATED TIMES

relieved following cycle 430, the converter did not produce any output upon restart. Further analysis and non-destructive type tests indicated the possibility of an internal emitter-to-collector short. The converter has been removed from the Life Test Stand and a more detailed failure analysis will be made during the next quarter to determine whether or not a successful repair can be made.

It is of interest to note that the I-V characteristic taken during cycle 389 and reproduced in Figure 11 shows a substantial improvement over the performance characteristics taken earlier (Figure 10) for converter #303. The lower optimum cesium temperature for a load voltage of 0.86 volts along with the increased I-V characteristic is representative of converter operation with a reduced emitter-to-collector spacing. It is possible that cyclic thermal stressing of converter members have progressed in such a way to reduce the interelectrode spacing to the point of a permanent short. Further investigations and analysis are needed to establish the actual failure mode however.

Figure 12 shows the pseudo-static I-V characteristics for converter #305 obtained during cycles 66, 116, and 509. This data was taken using the X-Y recorder. When the load current at 0.6 volts of curve #3 is compared with the corresponding curve #1 value of load current, a 17.5% reduction in output power can be noted. The cause for this recorded reduction in output power of converter #305 has not been determined. The cyclic test of this converter is continuing and to date, 540 cycles (810 total test hours) have been accumulated. The performance during the last 31 cycles has not changed significantly.

3.4 Specific Comments and Observations Relating to the Series 300 Converter Design and Test Program

Cesium Tubulation Tests

During this quarter Thermo Electron has completed the thermal cycle tests of the nickel and tantalum tube-to-molybdenum block brazes. One 1/8 inch diameter x 0.010 inch wall nickel tube and the two 3/16 inch diameter x 0.010 inch wall tantalum tubes have successfully completed 1368 thermal cycles without failure. One 1/8 inch diameter x 0.10 inch wall nickel tube failed at the molybdenum block braze and was pinched off after 1064 cycles. Since the Series 300 converter utilized the 3/16 inch diameter x 0.010 inch wall tantalum tubes, it is not expected that a tubulation failure of the type experienced in the Series 2B converters will occur during cycle tests of converter nos. 303 and 305. Figure 13 shows the cesium tubulation test setup at Thermo Electron.

Electron Bombardment Shields and Filaments

The test data obtained on the prototype converter #301, as well as the acceptance test data on converter nos. 303 and 305, show that the seal temperatures were exceedingly high (920°C). These high seal temperatures were due to electron bombardment of the seal structure in that the seal was not shielded

FIGURE 11 PSUEDO-STATIC I-V CHARACTERISTIC FOR
 CONVERTER #303 DURING CYCLE 389

FIGURE 12 PSUEDO-STATIC I-V CHARACTERISTICS FOR CONVERTER #305 @ INDICATED TIMES

CESIUM TUBULATION TEST SET-UP FOR
THERMAL CYCLIC EVALUATIONS

from the EB filament view and is at the emitter EB potential of 800 volts. Before installing converters nos. 302, 303, and 305 in the TRW Vac-Ion Test Stand, a molybdenum shield was incorporated which removed the upper seal flange from the EB heater view. The seal temperatures dropped by 200°C and operated typically at 700-720°C. A substantial reduction in EB current to achieve the observed 1660°C emitter temperature was also noted. It is currently planned that an improved shield structure be incorporated into the next set of converters to be fabricated in the third quarter of the program.

Experience with the tantalum filaments utilized in the EB assembly of the Series 300 converters has not been entirely satisfactory. Although less filament power is required to obtain the electron emission from the tantalum filament as compared to tungsten filaments, the Ta filaments tend to sag and short to the emitter structure. Further, a Ta filament used on converter #302 burned out with a resultant interruption of the test. A W filament was substituted but required 21 amperes at 7.0 volts as compared to 14.0 amperes at 6.2 volts for the tantalum filament to achieve adequate electron emission. The selection of a slightly reduced wire size for the W filament is indicated in future EB assemblies.

Color Gradients and Apparent Cracks in Emitter Structures

A total of 122 hours of operation and 28 thermal cycles were accumulated on the prototype converter #301 during the early laboratory performance evaluations. Examination of converter #301 subsequent to these tests revealed a definite color gradient in the emitter spacer-emitter disc region. This color gradient was not previously observed in the Series 2B converters. This same type of emitter structure color gradient did appear however during the acceptance testing of converter nos. 303 and 305. At the time it was speculated that evaporated and outgassed materials were being gettered by the emitter structures. The prime source of evaporated material could have been the copper braze materials in the seal structures which were operating as high as 920°C before the incorporation of the seal structure shield as discussed above. It is of interest to note that the color gradients disappeared from the emitter structures of converter nos. 303 and 305 during cycle testing at TRW.

Apparently the micro layers of materials that caused the color gradients evaporated or outgassed during repeated thermal cycling under the influence of an extremely clean and ultra high vacuum system environment.

Another point of interest relates to the location of an apparent emitter structure crack which appeared on converter nos. 301, 303 and 305 with varying degrees of severity. Figure 14 shows a close-up view of the emitter of converter #301 after initial performance tests. Note that the location of the crack is in the thin walled sleeve section of the emitter structure as compared to the apparent cracks which developed during the Series 2B cyclic tests in the emitter disc-to-emitter sleeve region (See Figure 15).

When the chamber housing of converter #303 was removed to repair an EB filament sag during cycle 302, the emitter sleeve was examined. It was observed

CLOSE-UP VIEW OF PROTOTYPE CONVERTER #301 EMITTER STRUCTURE

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CLOSE-UP VIEW OF CONVERTER 2B2 EMITTER STRUCTURE

that the apparent crack which was in the thin walled sleeve section as shown in Figure 14 had healed but the previously observed crack of the Series 2B converters was developing. Previous metallographic analysis of the Series 2B emitter structure showed that after 2000 hours of thermal cycling the emitter structure became nearly monocrystalline despite the outward appearance of the emitter.

4.0' DEMONSTRATOR MODEL TEST STAND

The Demonstrator Model Test Stand and its Auxiliary Support Vacuum System required for delivery under this contract has been completed during this quarter. Both vacuum systems have been checked out and used to conduct preliminary performance tests of converter #304. Converter #304 will be delivered to the Air Force along with the test stands in place of converter #305 which was originally scheduled for delivery. This substitution was necessitated by a slight delay in receipt of converter #304 at TRW for use in the life and cycle test program. To minimize the possible loss in test time, converter #305 was installed in the TRW life test stand in place of #304.

The Demonstrator Model Test Stand is shown in Figure 16 with converter #304 installed in the vacuum chamber. The complete system includes a 125 liter/sec Varian Vac-Ion pump and controller, a versatile internal load bank, a complete instrumentation panel, and a single point cesium heater supply. This unit was designed so as to permit its use in testing all types of converters or multiple converter generators over a wide range of sizes. Current measurements are possible in ranges of 0 to 30, 0 to 100 and 0 to 300 amperes by proper selection of meter shunts and load bank terminals. Increased capability is possible by the substitution of other shunts. Voltages for as many as 6 points may be monitored over ranges of 0 to 1, 0 to 3, 0 to 10 and 0 to 30 volts. Thermocouple temperatures for as many as 18 points are displayed on 3 direct reading pyrometers covering the complete range of temperatures associated with thermionic devices. A Pyro-Micro Optical Pyrometer is also included to facilitate emitter temperature measurements. Also, each metering system is provided with output terminals to permit the use of recorders or other instruments if desired. The connections for all instrumentation and the internal load bank are made at a terminal board recessed in the top of the test stand and at the 4 large copper terminals located at the front edge of the test stand top.

Other accessories such as a magnetically operated chamber shield to prevent darkening of the glass walls by evaporated materials, and external load bank for general purpose and dynamic testing, and miscellaneous bracketry and cooling fans are also included.

The auxiliary support vacuum system containing a 4 inch PMC diffusion pump and a Welch Duo Seal mechanical pump is shown in Figure 17. This system is intended primarily to service and rough down the Vac-Ion system, but it is a fully qualified system suitable by itself for testing thermionic converters. This system is easily capable of attaining pressures of 10^{-6} and below and contains all necessary thermocouple and ion gages, manifold valving, dual fluid cold traps and other accessories. It can, by proper placement, be arranged to make use of all the load banks, instrumentation, and heater supplies available in the Vac-Ion test stand demonstrator to carry out any converter test.

The vacuum system performance specifications which are listed below have all been met or exceeded during the performance testing of converter #304.

DEMONSTRATOR MODEL TEST STAND

AUXILIARY SUPPORT VACUUM SYSTEM

Vac-Ion Test Stand Demonstrator

1. Ultimate pump vacuum (clean) 1×10^{-8} mm hg or less.
2. Ultimate system vacuum (clean, with outgassed converter installed but cold) 1×10^{-7} mm hg or less.
3. Ultimate system vacuum (clean, with outgassed converter operating at design temperature 2000°K) 1×10^{-6} mm hg or less.
4. Normal operating life (continuous at 1×10^{-6} mm hg) 25000 hours.

Diffusion Pump System

1. Ultimate system vacuum with liquid nitrogen trapping 1×10^{-6} mm hg or less.
2. Ultimate system vacuum with water trapping 1×10^{-5} mm hg or less

The results of the performance tests on converter #304 are consistent with data obtained on other converters of this series. This performance data is summarized in Figure 18 for optimized voltages of .6, .7, and .8 volts.

FIGURE 18 PSUEDO-STATIC PERFORMANCE CHARACTERISTICS FOR CONVERTER #304
 AT T_{cs} OPTIMIZED FOR LOAD VOLTAGE OF 0.6, 0.7, AND 0.8 VOLTS

5.0 WORK PLANNED FOR THE NEXT QUARTER

The following items of work are planned for the next quarter:

1. Continue sustained life and cycle testing of converters nos. 302 and 305.
2. Failure analyze converter #303 to determine if a repair is possible and if not, perform a metallographic analysis so that indicated design changes can be incorporated into the next set of converter. (Series 310)
3. Deliver the Demonstrator Model Test Stand, Auxiliary Support Vacuum System and converter #304 to RTD.
4. Modify Series 300 converter design as indicated by evaluations to date and initiate fabrication of Series 310 converters.
5. Initiate a preliminary solar thermionic generator design.

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