Mr Miller

THERMO ELECTRON

CORPORATION

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ADVANCED THERMIONIC TECHNOLOGY

FY1975 MASTER

PROGRESS REPORT NUMBER 4
for
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Prepared by

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NATIONAL THERMIONICS PROGRAM REVIEW

Thermo Electron was host to the National Thermionic Program Review held on October 3 and 4 in Waltham, Massachusetts. Representatives of the USAEC, NASA Headquarters, Thermo Electron, Rasor Associates, NASA Lewis, Jet Propulsion Laboratory, General Electric, Los Alamos Scientific Laboratory, Naval Research Laboratory, Arizona State University, State University of New York and Princeton University participated in the conference. Although the focus of the meeting was programatic, experimental data and system design studies were presented and discussed. It was a consensus of the participants that the conference was valuable in adding perspective to their individual efforts.

TASK IA & B. ANALYSIS OF LOW WORK FUNCTION SURFACES

Activation Chamber

A series of (Ba, Sr, Ca) O activation experiments have been conducted using Vidicon cathode assemblies. These structures, which are compatible with the photoemission flange geometry, provide convenient sample preparation and mounting prior to opening the vacuum system to atmosphere.

Thermionic and photoemission measurements were made on BaO, (Ba, Sr, Ca) O and BaO-Cs-Ag samples. Cesium was deposited in the vacuum chamber from a cesium channel. For the latter experiment, Ag was vapor deposited onto the $BaCO_3$ precursor in another vacuum chamber, prior to activation. The results of these measurements are summarized in Figure 1, along with retarding potential data reported by Nottingham* for (Ba, Sr, Ca) O. Although the temperature dependence of the Thermo Electron data is similar to Nottingham's, the work function values (assuming A = 120) are substantially lower. Thus far, the (Ba, Sr, Ca) O low work function electrodes appear to be chemically stable in a cesium atmosphere.

Surface Characterization Chamber

The BaO-Ag-Cs sample, described in the previous section, was subjected to Auger analysis. The surface

*W. Nottingham in Handbuch der Physik, Vol. 21, Ed. S. Flügge (Springer-Verlag, Berlin, 1956) p. 133.

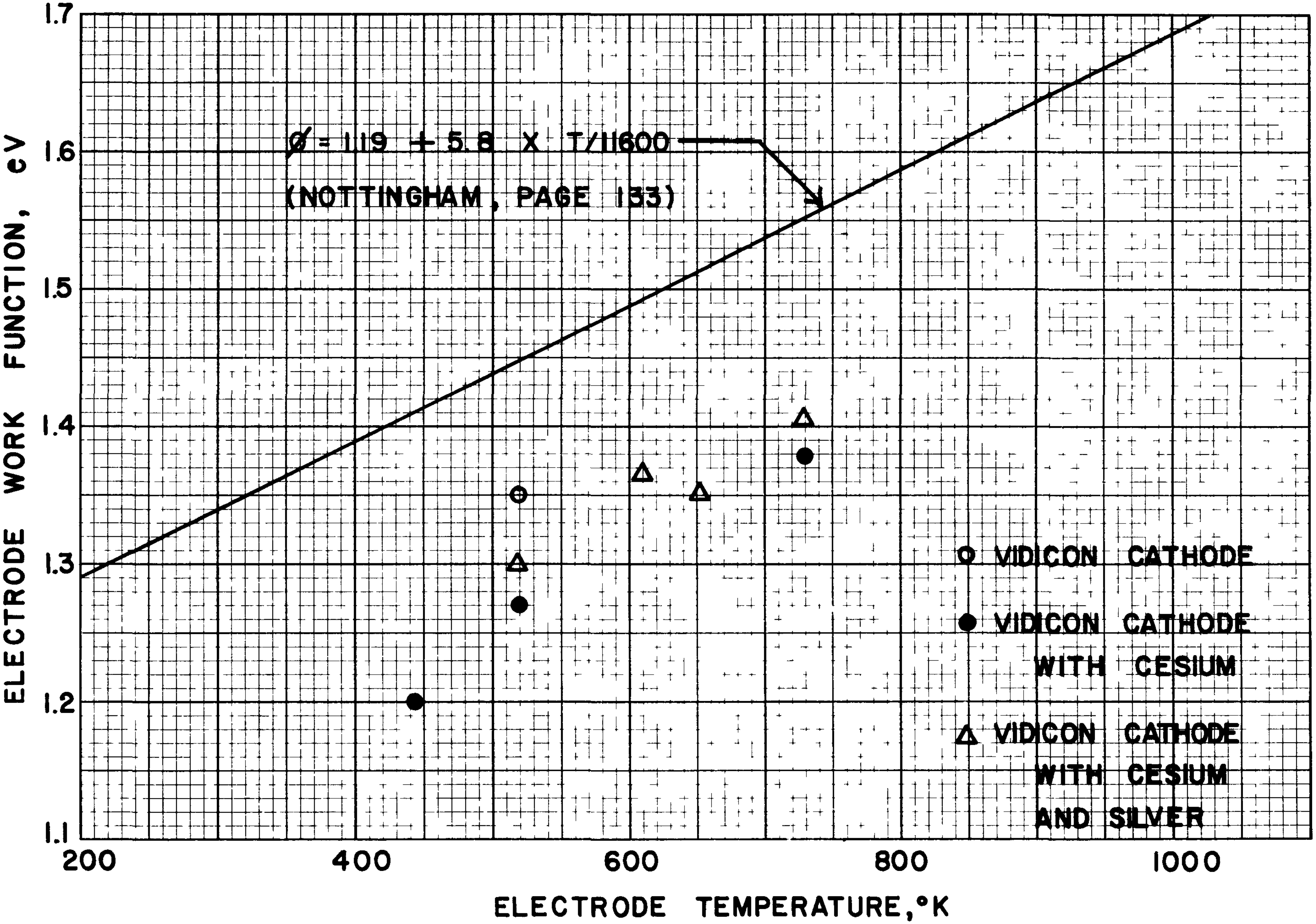

Figure 1. Comparison of Vidicon Cathodes - (Ba, Sr, Ca) O - with Zero, Cesium & Silver-Cesium Coverage

layer (1000 Å) was sputtered in steps, in between which Auger spectra were taken. As shown by the typical Auger spectrum in Figure 2, no silver could be detected in this layer. These measurements indicate that the silver evaporated rather than diffused into the oxide layer.

Multistation Chamber

The fabrication of the multistation chamber shown in Figure 3 has been completed. This apparatus has individual stations with removable experimental components which are separated from each other by compartment baffles. This arrangement permits the operations of cleaning, oxidation, cesiation, inspection and measurement to be performed in isolated stations. The surface to be investigated is mounted on the end of a temperature controlled tube which can be "shifted" from station-to-station by means of a gimbal-bellows-indexing assembly. Vacuum levels down to 10^{-10} torr have been obtainable.

The Ag-O-Cs surface was chosen for initial studies since it has a low work function and has been well characterized as a photoemissive material. Work function measurements as a function of electrode temperature are given in Figure 4. The Thermo Electron data (solid line) are compared to those of Weber*. All data correspond to an "A" of 120. A pronounced temperature dependency is evident. The favorable comparison of the Thermo Electron data with those of Weber is evidence that the Multistation Chamber is functioning satisfactorily.

*S. Weber in Doctoral Thesis, Erlanger Institute of Technology, 1964

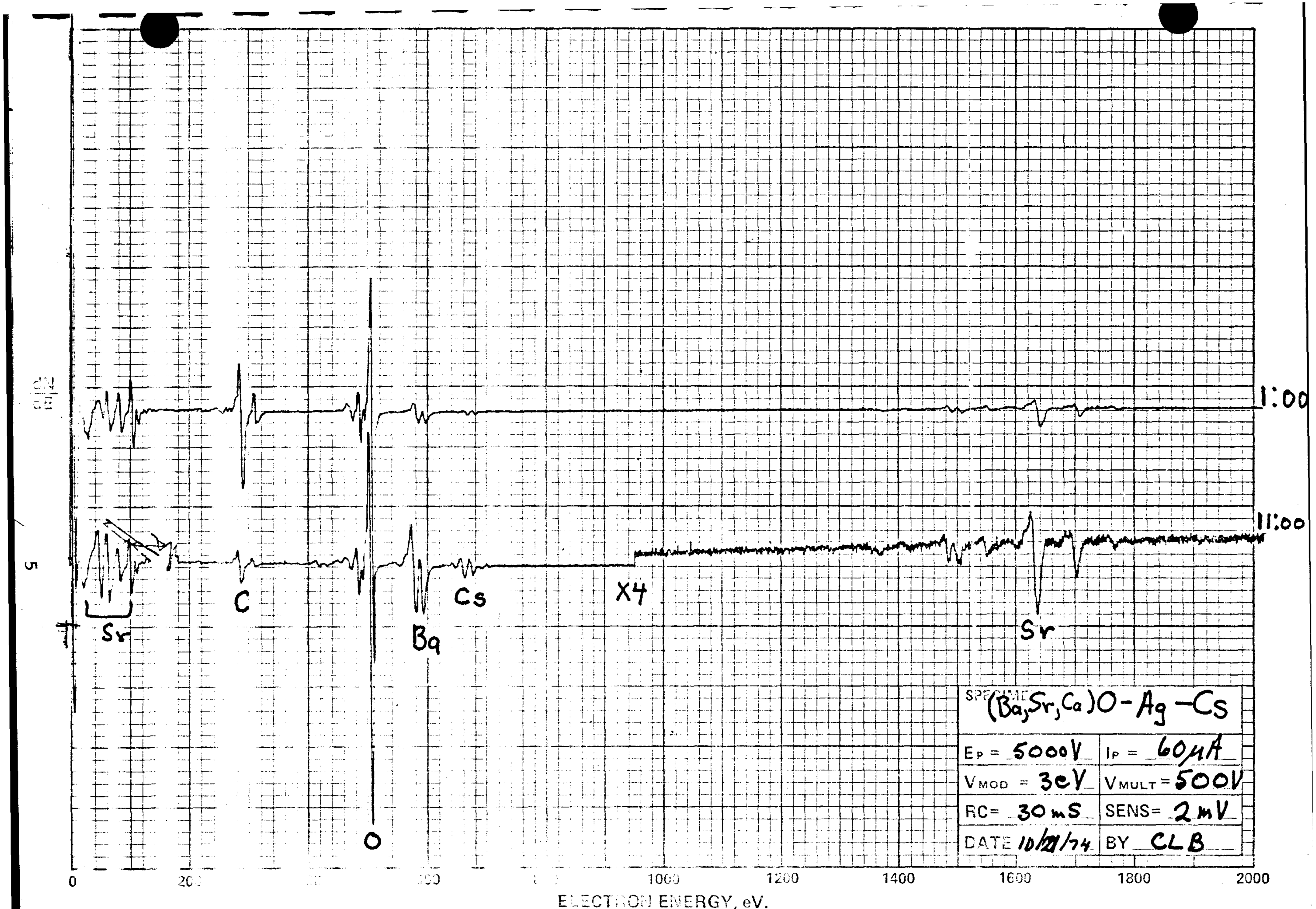

Figure 2. Auger Spectra of (Ba, Sr, Ca) O-Ag-Cs Cathode

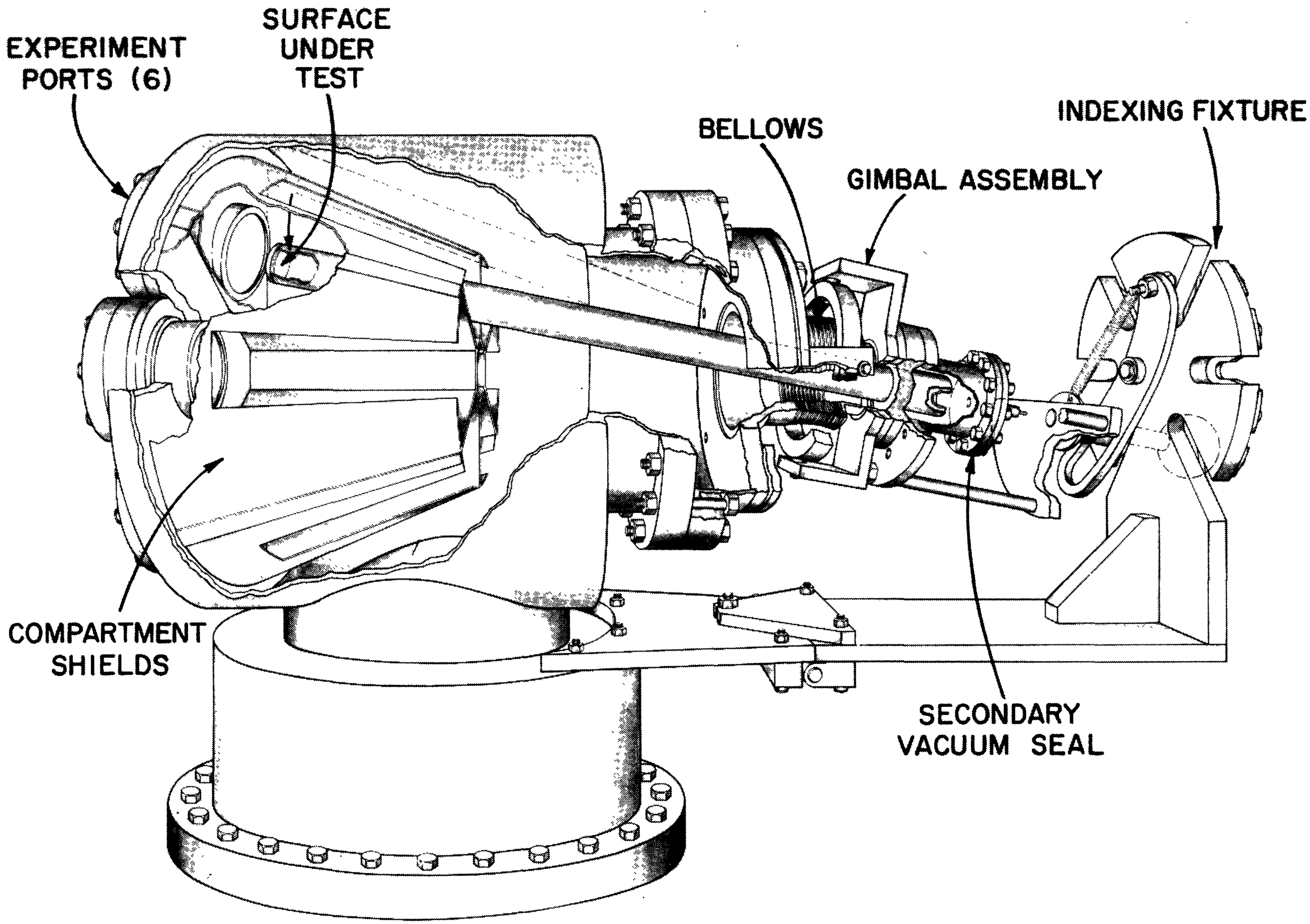

Figure 3. Multistation Chamber

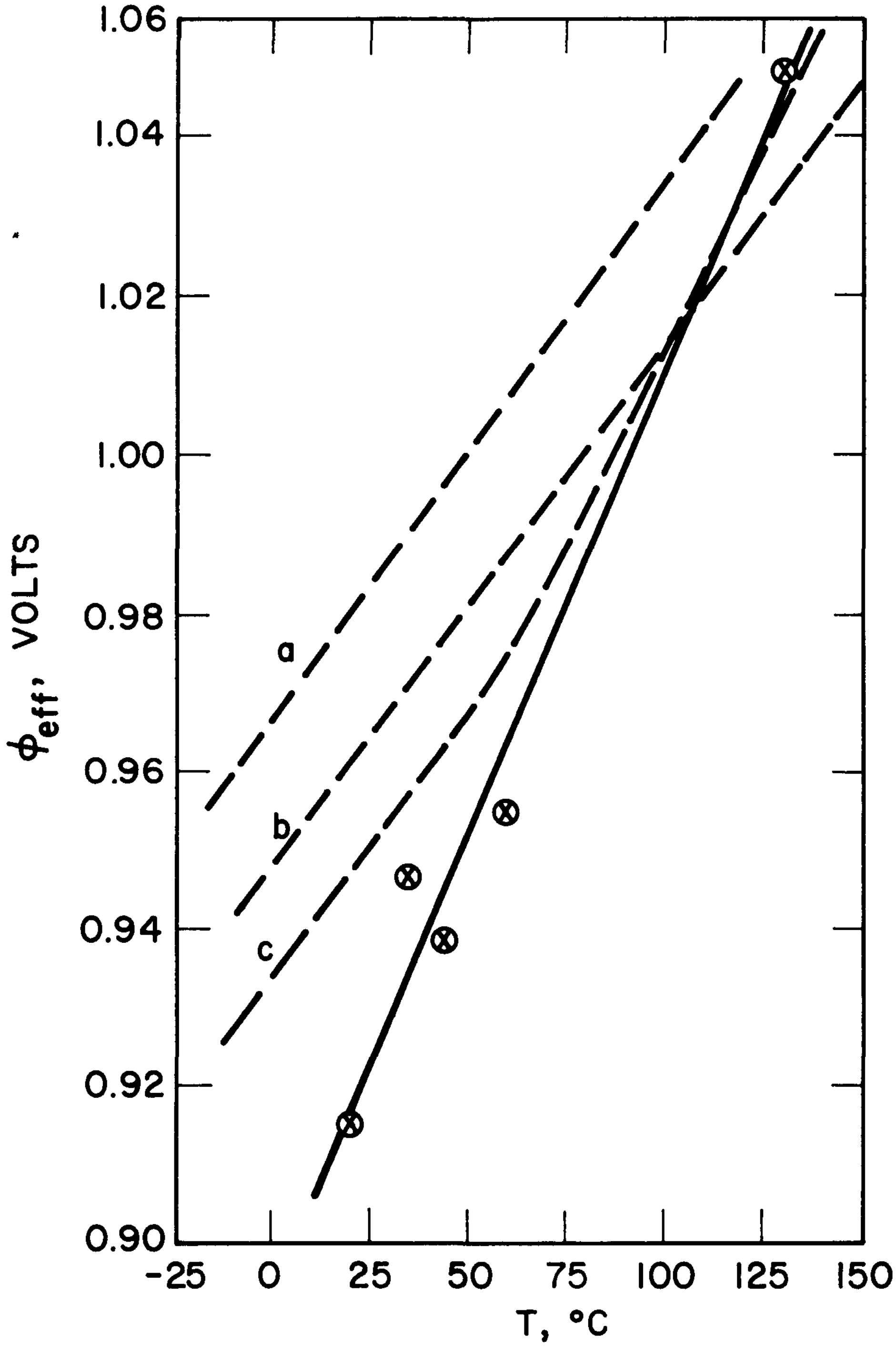

Figure 4. Ag-O-Cs Work Function versus Electrode Temperature. Thermo Electron Data (Solid Line) is compared to those of Weber (Dashed Lines). All Data Correspond to "A" of 120.

TASK II. SYSTEM STUDIES

Stone and Webster have continued to evaluate the effects of parameter perturbations on a steam system with thermionic topping of the water walls, superheater and reheater. The conventional boiler must be modified to higher gas temperatures by inter-component firing. Typical mean gas temperatures in conventional boilers are around 2800F. Analysis indicates that significant improvements in thermionic topped systems can be achieved by increasing the mean gas temperature to 3400F. Such a temperature should still permit nitrogen oxide formation to be limited to acceptable levels.

For a throttle pressure of 1800 psig, reheater and superheater temperatures of 1000F, emitter temperatures of 2330F (corresponding to collector temperatures on the boiler, superheater and reheater of 760, 970 and 1010F; respectively), the station efficiency (including stack, generator, power conditioning and distribution efficiencies) was 46 percent - compared the steam station efficiency without topping of 36.8 percent. These results are consistent with a previous, but less detailed, study carried out in conjunction with Combustion Engineering.

The thermionic data utilized in these analyses correspond roughly to "second generation" performance. "Third generation" thermionic data will be considered in the analysis in the near future.

An interesting aspect of the system studies is that the heat transfer calculations suggest that the emitter heat pipe incorporated in the conceptual design of the thermionic diode may not be essential.

TASK III. RESEARCH CONVERTER EXPERIMENTS

Gold Converter (Converter No. 96)

Gold in combination with cesium can be expected to produce a moderately low work function collector surface. Sommer* has demonstrated that the stoichiometric compound CsAu is a semiconductor. Work functions of about 1.45 eV were measured in the simulated converter. A variable spacing converter with a gold collector and a tungsten emitter was constructed to study the collection performance of gold in the converter environment.

The collector was prepared by evaporating a thin film of gold on the molybdenum substrate. During outgassing, the emitter temperature was raised to 1700°K and the collector temperature was raised to 825°K (since gold has a low vapor pressure at this temperature).

Performance data obtained over the emitter temperature range of 1200 to 1700°K and interelectrode spacings from 5 to 20 mils showed barrier indices near 2 eV with current densities between 2 and 10 $amps/cm^2$. The optimum collector temperature for T_E = 1400 to 1700°K was 850°K, and the T_C/T_R values for the minimum barrier indices ranged between 1.5 and 1.6. Lower mode data were obtained in order to measure the collector work function. Collector work functions of 1.40 to 1.45 eV were observed over a T_C/T_R value range of 1.4 to 1.6. These values are significantly better than those previously obtained with highly oriented non-oxygenated emitters and collectors.

*A. H. Sommer, Nature 152, 215 (1943)

After the high temperature data was obtained, the performance was somewhat reduced and the barrier index increased to around 2.1 eV. Further improvements in performance may be expected in an oxygenated converter.

Plasmatron (Converter No. 97)

As a result of a comprehensive review of enhanced mode thermionic converters, a "Plasmatron" configuration has been designed. This review included enhanced mode converters fabricated and tested by Thermo Electron (e.g., crossed ExM devices, cavity diode, arc triode, proposed dual mode converter, electronegative additive diodes and rare gas additive diodes) as well as pre-1965 devices (such as unignited triode, Plasmatron tube, and auxillary discharge converters of Gabor, Bloss, Knechtli, etc.). Converters utilizing nuclear generated ions were not evaluated extensively because of their fundamental limitations. Particular attention was given to the hybrid mode converter* achieved inadvertently by Rasor Associates. Such a device appears to have much in common with the Plasmatron, a controllable gas discharge tube developed by Johnson and Webster. If the results reported by Rasor Associates can be reproduced, the hybrid converter will represent a major advancement in thermionic conversion technology.

*Rasor Associates, Status & Highlights Summary, August 1973

Because of its potential significance, an effort is being made to duplicate the hybrid converter results at Thermo Electron by modifying the standard variable spaced diode used for collector evaluation. This modification, termed the "Plasmatron", is subject to the constraints of: (1) utilizing the same bellows and ceramic seal as the variable spaced diode and (2) minimum perturbation to the test station. The configuration used by Rasor Associates can be approximated in the variable spaced diode by machining a cavity in the collector to mate with an extension on the emitter. The Plasmatron thermionic converter layout is shown in Figure 5.

In an attempt to provide a test vehicle that may provide additional insight into the physical processes of the hybrid converter, the Plasmatron converter incorporates several design changes: (1) variable cavity gap spacing, (2) split collector, (3) electroplated platinum emitter, (4) three temperature sensors and (5) two electron bombardment filaments. The detailed design of the Plasmatron has been completed and the converter is being fabricated. This device should be evaluated during the next reporting period.

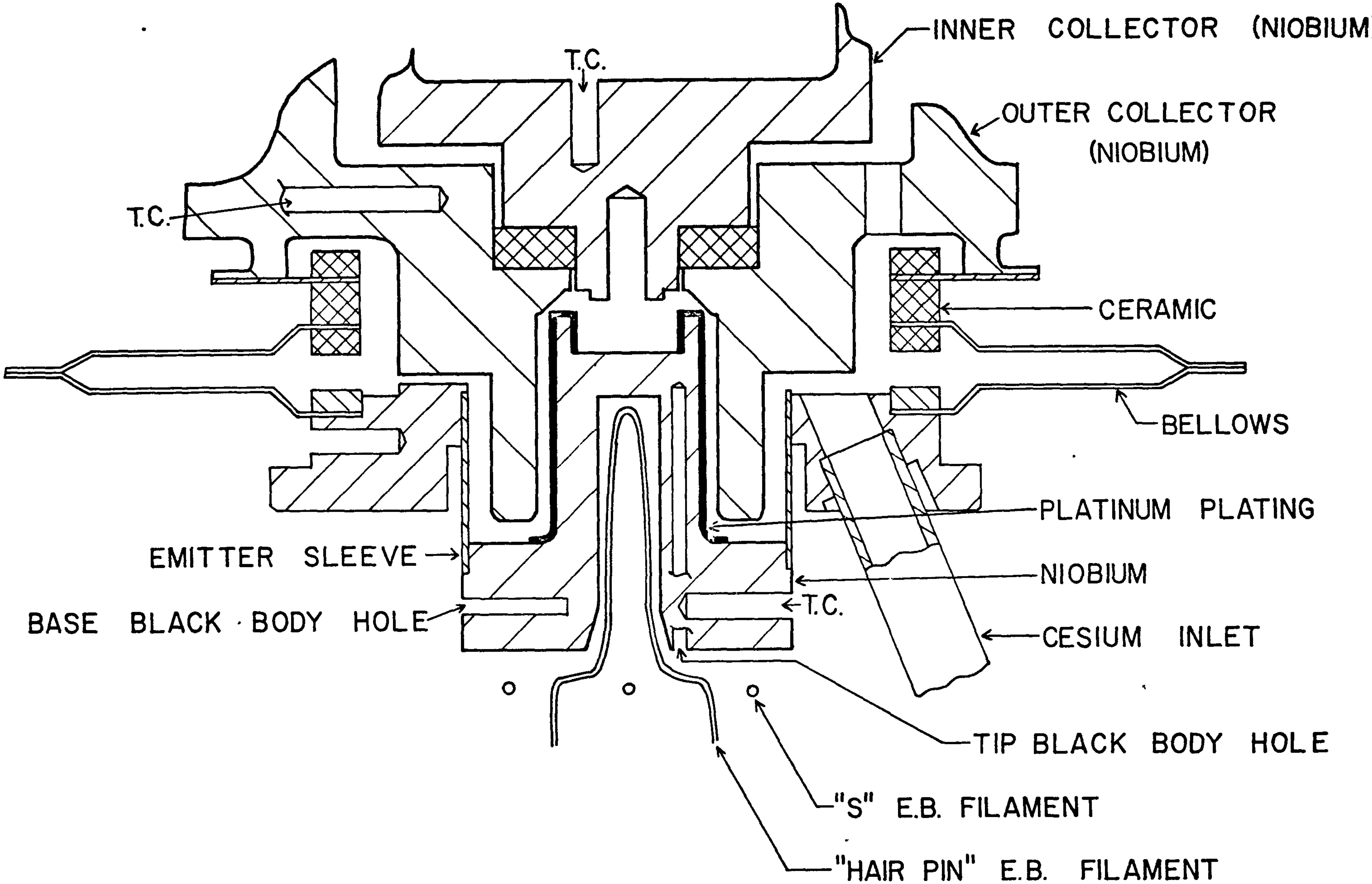

Figure 5. Plasmatron Thermionic Converter

TASK IV. HOT SHELL EVALUATION

An effort has been initiated to evaluate TRW's Hafnalloy and other alloy systems as hot shells for thermionic converters in contact with reactive combustion products. The program is divided into three tasks. The first task is the selection, preparation and characterization of candidate materials. The next task is the environment testing of the candidate materials. The last task is the preparation of sheet for determination of physical and mechanical properties.

The candidate materials have been identified and the test samples are being prepared. These are:

1) Hafnalloy (Hf-2.5 Sn) uncoated.
2) Hafnalloy (Hf-2.5 Sn) coated with TRW L20 aluminide.
3) Hafnalloy (Hf-2.5 Sn) coated with TRW silicide slurry.
4) TRW patented columbium alloys (patents 3,753,699 and 3,753,701).
5) Wah Chang's WC 3015
6) TD-NiCr or TD-NiCrAlY.
7) TRW modified Fe-Cr-Al-Y alloy.
8) TRW computer innovated alloy A.
9) TRW computer innovated alloy B.
10) TRW computer innovated alloy C.

Of course, new alloys may be added or modified as testing progresses.

The compositions of the major equilibrium species for the two test cases (air-rich mixture and stoichiometric mixture) and the corresponding simulation premixed gases to be used in the laboratory evaluations are given in Table I. Case 1 represents the combustion of C_6H_6 with 3 percent excess air, C_4HS_4 (thiophene) at 0.51 lb/10^6 BTU, and NO at 0.31 lb/10^6 BTU. Case 2 represents the combustion of C_6H_6 with a stoichiometric quantity of air with the same thiophene and NO conditions as Case 1.

TABLE I.

IDEAL EQUILIBRIUM COMBUSTION PRODUCTS AND SIMULATION GAS COMPOSITIONS

Species	Case 1 *	Simulation Gas Mixture No. 1	Case 2 *	Simulation Gas Mixture No. 2
CO	0.06	—	0.18	—
CO_2	15.56	16.90	15.88	17.27
H_2O	7.77	**	7.98	**
N_2	76.09	82.45	76.02	82.61
NO	0.14	—	0.05	—
O_2	0.56	0.61	0.07	0.08
SO_2	0.04	0.04	0.04	0.04

* Case 1: Chemical species from complete combustion of C_6H_6 with 3% excess air, C_4HS_4 (thiophene) at 0.5 lb/10^6 BTU, and NO at 0.3 lb/10^6 BTU.

Case 2: Chemical species from complete combustion of C_6H_6 with stoichiometric amount of air, C_4HS_4 (thiophene) at 0.5 lb/10^6 BTU, and NO at 0.3 lb/10^6 BTU.

** Water is added to the flowing gas mixture by means of a bubbler.

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SUBMITTED PROGRAM MILESTONES FY75

		Target Date	Actual Date
1.	Submit technical program plan for approval	July 20, 1974	July 18, 1974
2.	Activate GaP in semiconductor activation chamber	September 1974	
3.	Examine Ag-O-Cs surface in multistation apparatus	October 1974	October 4, 1974
4.	Complete test station for hot shell evaluation	December 1974	
5.	Preliminary study of BaO/SrO surface completed	January 1974	
6.	Submit topping cycle report	April 1975	
7.	Low temperature parametric data mapped	May 1975	
8.	Summary report on low work function collectors	June 1975	

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TASK BREAKDOWN

PERIOD ENDED 10/27/74

Task No.	Title	Total This Month	Total to Date	Contract Cost	Cost Remaining
I. A.	Surface Theory	$ 2,495	$ 10,096	$ 46,730	$ 36,634
II. B.	Experimental Surface Physics	26,389	100,980	280,377	179,397
I. C.	Plasma Theory	3,336	7,725	46,738	39,013
II.	System Studies	1,389	3,760	70,091	66,331
III. A.	Collector Evaluation	20,699	101,711	186,901	85,190
III. B.	Emitter Evaluation	6,962	14,818	93,453	78,635
III. C.	Parametric Data	7,319	18,998	93,520	74,522
IV.	Hot Shell Evaluation	2,347	3,593	140,134	136,541
	Sub Total	70,936	261,681	957,944	696,263
	Fixed Fee (6.897%)	4,893	18,048	66,070	48,022
	Total	75,829	279,729	1,024,014	744,285
	Open Commitments	---	139,668	---	(-139,668)
	Total Including Commitments	75,829	419,397	$ 1,024,014	604,617

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TASK BREAKDOWN

PERIOD ENDED 10/27/74

Title	Total This Month	Total to Date	Contract Cost	Cost Remaining
Capital Equipment	$ 2,035	$ 4,425	$ 69,859	$ 65,434
Open Commitments	---	17,062	---	(-17,062)
Total Including Commitments	$ 2,035	$ 21,487	$ 69,859	$ 48,372