Princeton University

DO NOT MICROFILM
COVER

Department of
Mechanical and
Aerospace Engineering

DISTRIBUTION OF THIS DOCUMENT IS LIMITED

MASTER

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

DOE/ET/15352--14

DISCLAIMER

DE83 01C040

DOE/ET/15352-14

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

THEORIES ON PLASMA ARC-DROP IN THERMIONIC ENERGY CONVERTERS

Final Report

on

Thermionics Energy Conversion Research Analysis

S. H. LAM

Department of Mechanical and Aerospace Engineering
Princeton University
Princeton, N. J. 08544

March 1983

Prepared for

THE U. S. DEPARTMENT OF ENERGY
AGREEMENT NO. DE-AC02-76-ET15352

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product or process disclosed or represents that its use would not infringe privately own rights.

ABSTRACT

A summary of the theoretical developments of the problem of plasma arc-drop in thermionic energy converters carried out during 1976-1982 at Princeton University is presented. It reviews the basic formulation of the isothermal model which delineates the physical origin of the arc-drop, its order of magnitude and the possibilities of arc-drop reduction under one-dimensional, steady-state, ignited mode operation, and also the generalization of the isothermal model to the non-isothermal model. The possibility of a heat-to-laser energy recombination laser using a thermionic diode operating in the unsteady mode is discussed. An analysis of the low current regime with attentions focussed on the effects of ion reflections and trapped-ions effects in the emitter sheath is presented.

Introduction

The research program at Princeton aims at the theoretical understanding of the plasma arc-drop observed in thermionic energy converters.

A conventional thermionic converter consists of a flat emitter at temperature T_E (1300°k - 1800°k), separated from a flat emitter at temperature T_C (700°k - 1000°k) by a narrow gap d (.25 mm - .5 mm) which is filled by a cesium vapor in communication with a cesium reservoir at temperature T_R (550°k - 650°k). The current voltage characteristics (C-V) of this device is quite conventional: its current J saturates at some value determined by the Richardson value of the emitter (1-50 Amps/cm²), and falls off sharply at output voltage V in the range 0.2eV - 0.6eV, yielding a so-called Barrier Index of about 2 eV. Theoretically, the Barrier Index is the sum of the collector work function ϕ_C and the plasma arc-drop V_{AD} . Since most ϕ_C operates at about 1.5 eV, the observed V_{AD} is therefore about 0.5 eV, or about $3 kT_E$. All of the above descriptions refer to the so-called ignited-mode operation of the thermionic converter.

The general shape of the C-V and the order of magnitude of V_{AD} can be deduced theoretically without difficulty. The challenge of this research is to understand the detailed mechanisms responsible for the arc-drop, and to investigate and explore possible means of controlling its magnitude. From the practical point of view, a significant reduction of the arc-drop can yield rich dividends in terms of improved efficiency for this simple heat-to-electricity energy conversion device.

A list of reports issued under the DOE contract is given in Appendix A.

II. The Basic Mechanisms

At the emitter temperature T_E , the degree of thermal ionization of the cesium vapor is negligible. The cesium vapor thermionic converter thus must operate in the so-called ignited-mode in which the plasma electron temperature T_e is substantially higher than T_E (2600°k - 2800°k), so that a substantial plasma density n_e (10^3 - 10^5 /cc) exists in the gap.

The ignited-mode operation relies primarily on the large mass ratio of the cesium ion to the electrons. Under conventional operating conditions, the representative mean-free-path of the ions is about 1/20th of d . A continuum diffusive model thus applies. Since electrons are much more mobile in diffusing to the walls, and thus tends to leave the bulk of the plasma slightly ion rich, thin electron retaining electrostatic sheaths exist at the edges of the plasma. At the collector side, a monotonic sheath structure is usually expected. At the emitter side, the electrostatic potential distribution normally exhibits a peak. Electrons emitted from the emitter must have sufficient energy to climb over this peak. These electrons must then traverse the gap, sustaining an ohmic voltage drop and getting heated up in the process. The net ionization rate in the gas phase in the steady state is balanced by the net loss rate of ions lost to the walls by diffusion. Because of sluggishness of the diffusion of the massive ions, the converter will "ignite" when the gap d is sufficiently large and when the electron temperature is sufficiently high, producing a dense plasma which serves as the conducting path for the converter current.

The above description is distinctly different from the operation of an Ideal Vacuum thermionic converter. In the Ideal case, the gap is assumed to be much smaller than the expected Debye length ($\sim 10^{-3}$ mm), thus space change effects can be assumed negligible. Since no collision occurs, all emitted electrons with sufficient energy will reach the collector. None will scatter back to the emitter by collisions, and no directed energy will be randomized. This idealized model yields a saturation current identical to the emitter Richardson value, and has zero plasma arc-drop.

III. The Simple Isothermal Model

In reference (1), a simple mathematical model was presented which served as the spring board for all later developments. Its main ideas are summarized below.

The electron continuity equation is written as follows:

$$J = J_E - J_{BS} = J_C \quad (3.1)$$

where J_E , J_{BS} , J_C are the electron current density emitted over the "peak", the back scattered electron current density from the plasma to the emitter over the peak, and the current density at the collector, respectively. If one now assumes that both electron retaining sheaths are relatively high so that the Boltzmann electron distribution can be used, we have

$$J_C = \left(\frac{a_e n_p}{4} \right)_1 e^{-\chi_c/\tau} \quad (3.2)a$$

$$J_{BS} = \left(\frac{a_e n_p}{4} \right)_0 e^{-\chi_E/\tau} \quad (3.2)b$$

where χ_C and χ_E are sheath heights non-dimensionalized by kT_E (See Fig. 1), τ is T_e/T_E , a_e is thermal velocity of electrons at T_e , n_p is plasma density, and subscripts 1 and 0 indicate conditions at the collector and emitter edges of the plasma.

We next assume the plasma electron temperature distribution is isothermal: $\tau = \text{constant}$. With this approximation, the electron momentum equation (with inertia term neglected) is

$$j = - \frac{\pi}{4} \frac{\lambda_e}{d} \frac{1}{\sqrt{\tau} \hat{N}_E} \left[\tau \frac{dn_p}{d\xi} + n_p \frac{d\chi}{d\xi} \right] \quad (3.3)$$

where

$$j = \frac{J}{J_E} ,$$

$$\hat{n}_E = \frac{2J_E}{a_E} ,$$

$$\xi = \frac{x}{d} ,$$

λ_e is the electron momentum mean-free-path and $\chi(\xi)$ is the non-dimensional (by kT_E) potential distribution in the plasma. Integrating across the gap, the plasma potential drop $\Delta\chi_p = \chi_1 - \chi_0$ is found as follows:

$$\Delta\chi_p = \tau \ln \frac{n_{p1}}{n_{p0}} + j R \quad (3.4)$$

where R is called the normalized plasma resistance defined by

$$R \equiv \frac{4}{\pi} \frac{d}{\lambda_e} \sqrt{\tau} \int_{0^+}^{1^-} \frac{\hat{n}_E}{n(\xi)} d\xi \quad (3.5)$$

Consideration of global electron energy conservation under the isothermal approximation yields

$$\tau = 1 - \frac{1}{2} j V_d \quad (3.6)$$

where V_d is defined in Fig. 1 and is related to V_{AD} by

$$V_{AD} = kT_E \left(\ln \frac{J_E}{J_R} - V_d \right) \quad (3.7)$$

where J_R is the Richardson current of the emitter. Combining Equations (3.2), (3.4) and (3.6), we obtain

$$V_d = \frac{\ln\left(\frac{1-j}{j}\right) - j R}{1 + \frac{1}{2} \ln\left(\frac{1-j}{j}\right)} = V_d(j, R) \quad (3.8)$$

A plot of $V_d(j,R)$ is shown in Fig. 2. The corresponding vacuum ideal C-V is also shown.

This simple model relies on three main assumptions: firstly, the qualitative assumption about the existence of a potential peak in the emitter sheath, secondly, the use of the Boltzmann approximation in arriving at Eqs. (3.2), and finally, the isothermal assumption. It is important to note that the ionization (or recombination) mechanisms, the quantitative aspects of the sheath structures, the distribution and boundary conditions of the plasma density are not explicitly involved. All of these complications are collected into the single parameter R which depends on $n_p(\xi)$. Thus within this model, if one wishes to control the plasma arc-drop, one must strive to control the magnitude of R .

It is important to recognize that $V_d(j,R)$ is not a C-V characteristic of a thermionic converter, (even for the hypothetical case when R is a constant). In Fig. 2, lines of constant τ are also plotted using Eq. (3.6). If τ is below the value required for ignition, then the theory does not apply, since there would be insufficient plasma density to justify the quasi-neutral (small Debye length) plasma assumption. The ignition temperature, τ^* , is of course determined by considerations of ionization kinetics, the gap d , and boundary conditions. If we use $\tau^* = 1.5$ (a reasonable number for the ignition temperature), we can read from Fig. 2 the values for V_d (for $R = 0, 2.5$ and 5.0), yielding estimates of V_{AD} of about 3 to 4 kT_E . These values are consistent with the observed values of the Barrier Index. Once the converter is ignited, points on the physical C-V curve is mapped into Fig. 1 by its corresponding local values of R and j (or τ). The precise relationship between the physical C-V curve and Fig. 2 obviously depends on all the other complicating factors.

Since R is a positive-definite quantity, Fig. 2 shows the upper bound of the "practical ideal" thermionic converter operating in the ignited mode when $R = 0$. The degradation of performance measured against the Ideal vacuum curve can be traced directly to the existence of scattering which randomizes the emitted electron stream. This scattering loss is unavoidable as long as the converter operates in the continuum regime. Note that the scattering loss remains even if the electron momentum mean-free-path is assumed infinite (mathematically).

IV. The Detailed Isothermal Model

To complete the mathematical formulation, one must include the effects of ionization kinetics on the plasma distribution in the gap. Toward this end, one requires the governing diffusion equation for $n_p(\xi)$ and its boundary conditions at the sheath-plasma interfaces. The complete physical C-V can then be constructed by combining the two computations.

This task was carried out by Yen, as part of his M.S.E. thesis, in Reference 2. No great surprises were encountered, and reasonable physical C-V characteristics were constructed numerically using realistic physical parameters.

Of specific interest is the analysis of the structures of the sheaths. The collector sheath, being monotonic, causes no difficulties and the Boltzmann approximation was used. The non-monotonic emitter sheath, however, requires detailed investigation. A "mono-energetic" model is used here.

The back-scattered plasma electrons is described by the Boltzmann approximation in the emitter sheath. Consistent with this approximation which implies that the sheath is high, the positive ions falling into the sheath and the emitted electrons crossing over the peak are assumed to be mono-energetic. In addition, all ions entering the sheath from the plasma side are assumed to reach the emitter wall and are absorbed. No trapped ions are allowed in the "potential well" formed by the potential peak. Since Debye length is expected to be small in comparison to the relevant mean-free-paths, the sheath is assumed collisionless. More will be said on these points later.

The outputs of the sheath analysis are boundary conditions for $n_p(\xi)$ at the emitter and collector sheath edges. They are of the form

$$n_{p_0} = \frac{\lambda_i}{d} K_0(j, \tau) \left(\frac{dn_p}{d\xi} \right)_0 \quad (4.1)a$$

$$n_{p_1} = - \frac{\lambda_i}{d} K_1(j, \tau) \left(\frac{dn_p}{d\xi} \right)_1 \quad (4.1)b$$

where $K_0(j, \tau)$ and $K_1(j, \tau)$ are functions provided by the sheath analysis. They have been non-dimensionalized so that they are nominally of order unity. Since λ_i/d , the ion Knudson number, is small at the sheath edges as can be seen from Eq. (4.1). From Eq. (3.5), it is seen that these low $n_p(\xi)$ region contribute most to the magnitude of R . It is also clear that R will depend logarithmically on λ_i/d -- a weak dependence.

The electron energy equation is bypassed in this model via the isothermal assumption. Thus only global electron energy conservation (Eq. 3.6) is respected. However, even though we shall see later that the electron temperature in a non-isothermal model does not have large variations, the exponential electron temperature dependence of ionization rates renders the isothermal assumption unrealistic. The bulk of Yen's work thus addresses the task of a detailed computation of the electron temperature distribution and the appropriate modification of the whole theoretical model. Aside from the fact that a more realistic (shifted toward the emitter) plasma density distribution was obtained, no surprises were observed. The electron temperature distribution obtained were relatively flat, with local sharp "hooks" near the sheath edges. In fact, the computations were performed with electron conductivity values about 5 times larger than the correct values in order to stabilize the numerical results near the hooks. These hooks were further studied as will be discussed in the next section.

V. The Electron Energy Equation

In the non-isothermal theory, the electron energy equation governing $\tau(\xi)$ must be solved simultaneously with the plasma density equation coupled with the sheath equations. In Yen's work⁽²⁾, the whole solution process was numerical, and involved tedious trial-and-error iterative computations. As mentioned previously, sharp hooks were obtained for $\tau(\xi)$ near the plasma sheath interfaces. It was not clear whether these hooks were results of numerical instabilities or were the correct results of the model under investigation.

In reference 3, Lam found a mathematical transformation for the electron energy equation and reduced it to the classical WKBJ turning-point problem. When the properly non-dimensionalized electron conductivity parameter is infinite, the model yields the isothermal solution $\tau = \text{constant}$ as expected. However, when the electron conductivity parameter is finite, a WKBJ turning-point occurs in the electron energy equation, resulting in relatively sharp hooks for $\tau(\xi)$ near the plasma-sheath interfaces. Analytical expressions for these hooks as well as approximate $\tau(\xi)$ were obtained by the use of standard WKBJ techniques, in reasonable agreement with the computed results. These analytical developments were invaluable in subsequent developments of the theory.

Reference 3 is included as Appendix B of this report.

VI. The Unsteady Analysis and the Recombination Laser

The theoretical developments so far have produced results which are in general agreement with observed data, both qualitatively and quantitatively. It has been shown that the arc-drop is theoretically a resilient quantity, remaining approximately 3 to 4 kT_E under a wide range of conditions. Furthermore, it contains a non-reducible contribution from scattering losses of about 1 kT_E under conventional conditions.

The idea of using the thermionic diode in the ignited mode, not primarily as an energy converter, but as a direct conversion device from heat to laser energy, is explored. The basic idea is as follows. When a thermionic diode in ignited mode is operating near saturation current, the plasma density and the plasma electron temperature are both high. If the output voltage is suddenly raised to drive down the current, a transient will occur in which the state of the plasma slowly adjusts itself to the new steady state at a substantially lower plasma density and temperature. Since diffusion loss of electrons to the walls is hampered by ambi-polar diffusions which is a slow process, the plasma electrons will recombine and populate the high energy levels first, and collisionally cascade down to the lower energy levels. If the state-to-state collisional transition rates of cesium has a bottleneck somewhere, a population inversion will occur and a recombination laser can be constructed.

Lawless⁴ studied this problem as his Ph.D. Thesis in great details. First of all, the unsteady equations for $n_p(\xi)$ and $\tau(\xi)$ were derived and programmed on a digital computer. Coupled with these equations are kinetic equations of the

population of each energy level of the cesium atom, involving all the state-to-state collisional and radiative transition rates. Because the time-scales for the kinetic equations is small, an elegant quasi-steady solution was obtained which were used in the global calculations. Because of computational costs, a relatively coarse mesh is used, and the analytical results describing the temperature hooks were used to great advantage near the sheath edges.

Using the best available estimates of the state-to-state transition rates, Lawless⁴ found that there is indeed a bottleneck, and sample runs of a sudden drop in J indeed shows population inversions. This recombination laser idea is being followed up by Dr. Lawless at Carnegie Mellon University under an NSF Grant, and Rasor Associates has expressed an interest in doing some exploratory experiments. A direct heat-to-laser energy converter with the simplicity of a thermionic diode has certain unique advantages, but so far only its scientific feasibility has been established by the work of Lawless⁴.

The unsteady theoretical developments yield two other dividends. The steady state solutions are much easier to compute using the unsteady formulation than the conventional shooting technique. More importantly, by including the possibility of radiation escape in the ionization kinetics, the ignition temperature is found to be slightly higher as a consequence, yielding a steeper-than-Boltzmann rise in the knee region of the physical C-V characteristics.

VII. The Low Current Regime

The theoretical developments so far are qualitatively and quantitatively in agreement with most experimental observations. In general, the assumptions used are consistent with the physical model under study. There is but one exception: the low current regime.

According to our physical model, all positive ions entering the sheath, particularly the emitter sheath, are assumed to be able to reach the walls. This assumption is clearly correct when the "back sheath" height (on the emitter side) is shorter than the "front sheath" height. As the converter current is lowered to some finite fraction of the emitter Richardson current, this theory predicts that the back sheath height will become taller than that in the front. Thus the ions entering the emitter sheath at low current levels should be reflected by the sheath, in direct contradiction to the original assumption. Furthermore, the assumption of zero trapped ions in the emitter sheath "potential well" seemed reasonable when the back sheath height is short, but when the back and front sheaths are both tall, the no-trapped-ion assumption becomes questionable.

The investigations of ion reflections and trapped ions effects are being carried out by Mr. G. Main as his Ph.D. thesis. A number of refinements of the sheath analysis became necessary. First of all, the mono-energetic assumption for the ion distribution function entering the sheath must be removed. We find that the original mono-energetic model solution was indeed a singular case: the collisionless sheath analysis does not mathematically permit the specification of an entering ion distribution function which contains non-zero

population for zero velocity ions. Physically this implies that at the sheath edge, space-charge effects and collisional effects interact in some way to remove these zero velocity populations. Instead of analyzing the details of this interaction, computations were carried out by simply using a "cut-off" velocity for the entering ion distribution. The computed sheath solutions' dependence on this cut-off velocity is found to be weak. For example, the "Bohm" velocity of the ions is found to depend logarithmically on the cut-off velocity used. As a consequence, a fixed small cut-off velocity is used for all sheath solutions.

Using the new sheath solutions, which has the capability of handling reflection of ions, the isothermal theory is reformulated. Since we are now only interested in the low current regime, recombination is expected to be unimportant and is therefore neglected, allowing the plasma density equation to be solved analytically. This new isothermal theory continues to assume that no trapped ions are present. The computed results shows that the effects of reflection of ions is to decrease the ignition temperature τ slightly, coupled with a significant decrease in the predicted plasma density. As a consequence, the net effect is to slightly increase the predicted arc-drop at sufficiently low current levels.

While we have mentioned several times that theoretical C-V characteristics are in general qualitative and quantitative agreements with experiments, this is not so in the low current region. Frequently, but not always, the low current region exhibits a low current plateau, showing substantially

smaller arc-drop in this region than the Boltzmann-like region of the C-V curve. Positive ion reflection by the emitter sheath has been explored and found it unable to explain this low current plateau (using the cut-off artifice). What, then, are the other possible causes for this frequently observed plateau?

We next explore the consequence of trapped ions and the consequence of including some finite positive ion-emission from the emitter surface. Computations for these developments are currently under way and will be continued under AFOSR sponsorship. A paper by Main and Lam entitled "Effects of Reflections and Trapped Ions on the Thermionic Emitter Sheath" has been submitted and accepted by the 1983 18th AI.Ch.E. IECEC August meeting in Orlando, Florida. It is included here as Appendix C.

VIII. Conclusions

The thermionic energy converter is an ingenious device. Operating in the ignited mode, it is a simple, reliable, high power density energy converter. At the present measured arc-drop values, its efficiency is marginally competitive with other advanced energy conversion devices. Its competitive position would be significantly improved if the arc-drop could be decreased by 1 - 2 kT_E 's.

Research carried out under the DOE Contract has provided improved understanding of the origin of the arc-drop, and demonstrated theoretically the resiliency of its value under a variety of operating conditions. As is legendary in the thermionic community, there are many "small" features of the observed experimental data which has no theoretical explanation. The low current plateau is one of these unexplained observations. If one wishes to exploit the simplicity, reliability and high power density of this device and wishes to improve its efficiency performance, one must continue to attempt to improve our theoretical modelling so that all significant experimental observations are fully understood. If one can explain the low current plateau theoretically, which has a low observed arc-drop, then perhaps one can control this plateau and make its output power density respectable.

References

1. S. H. Lam, "Preliminary Report on Plasma Arc-Drop in Thermionic Converters", DOE Report #C00-2533-3, Department of Mechanical and Aerospace Engineering, Princeton University, March, 1976.
2. A. T. Yen and S. H. Lam, "A Theory of Thermionic Energy Converter with Variable Plasma Electron Temperature", DOE Report #C00-2533-10, Department Mechanical and Aerospace Engineering, Princeton University, September, 1978.
3. S. H. Lam, "The Effects of Electron Thermal Conductivity on Thermionic Energy Converters", 14th IECEC, Boston, Massachusetts, 1979. See Appendix B of this report.
4. J. L. Lawless and S. H. Lam, "The Plasmadynamics and Ionization Kinetics of Thermionic Energy Conversion", DOE #C00-2533-13, Department of Mechanical and Aerospace Engineering, Princeton University, February, 1982.
5. G. Main and S. H. Lam, "Effects of Reflections and Trapped Ions on the Thermionic Emitter Sheath", 18th IECEC, Orlando, Florida, 1983. See Appendix C of this report.

FIG. 1 QUALITATIVE SKETCH OF MOTIVE DISTRIBUTION. WORK FUNCTIONS AND MOTIVES ARE IN UNITS OF kT_e/e .

FIG. 2 NORMALIZED C-V CHARACTERISTIC, SELF-IGNITED CASE

APPENDIX A

List of DOE Reports

1976 - 1983

THERMIONIC ENERGY CONVERSION RESEARCH ANALYSIS

Report #	Title of Report	Date Prepared
C00-2533-1	Thermionic Energy Conversion Research Analysis Annual Progress Report (10-1-74 to 9-31-75) Under Contract AT(11-1)-2533	10/75
C00-2533-3	Preliminary Report On Plasma Arc-Drop in Thermionic Energy Converters, Under Contract AT(11-1)-2533	3/76
C00-2533-4	Thermionic Energy Conversion Research Analysis Annual Progress Report (10-1-75 to 9-30-76) Under Contract AT(11-1)-2533	1976
C00-2533-5	Thermionic Energy Conversion Research Analysis 1976-77 Annual Progress Report (10-1-76 to 9-31-77) Under Contract E(11-1)-2533	1977
C00-2533-6	Quarterly Progress Report on Thermionic Energy Conversion Research Analysis (10-1-77 to 12-31-77) Under Contract EY-76-S-02-2533.A002	10/77
C00-2533-7	Quarterly Progress Report on Thermionic Energy Conversion Research Analysis (1-1-78 to 3-31-78) Under Contract EY-76-S-02-2533.A002	4/78
C00-2533-8	Thermionic Energy Conversion Research Analysis 1977-78 Annual Progress Report (10-1-77 to 9-31-78) Under Contract E(11-1)-2533	1978
C00-2533-9	Quarterly Progress Report on Thermionic Energy Conversion Research Analysis (4-1-78 to 6-30-78) Under Contract EY-76-S-02-2533	7/78
C00-2533-10	A Theory of Thermionic Energy Converter with Variable Plasma Electron Temperature Under Contract AT(11-1)-2533	9/78
C00-2533-11	Quarterly Progress Report on Thermionic Energy Conversion Research Analysis (6-1-78 to 9-30-78) Under Contract AT(11-1)-2533	10/78

THERMIONIC ENERGY CONVERSION RESEARCH ANALYSIS

Report #	Title of Report	Date Prepared
COO-2533-12	Thermionic Energy Conversion Research Analysis Quarterly Progress Report (10/1/78 to 12/31/78) Under DOE Contract AT(11-1)-2533)	1/79
COO-2533-13	The Plasmadynamics and Ionization Kinetics of Thermionic Energy Conversion	2/82
DOE/ET/15352-14	Theories on Plasma Arc-Drop in Thermionic Energy Converters	3/83

APPENDIX B

THE EFFECTS OF ELECTRON THERMAL
CONDUCTIVITY ON THERMIONIC ENERGY CONVERTERS

Presented at the 14th A.I.Ch.E Intersociety
Energy Conversion Engineering Conference
Boston, Mass. 1979

*Remove -
cycles separately*

APPENDIX C

EFFECTS OF REFLECTIONS AND TRAPPED IONS
ON THE THERMIONIC EMITTER SHEATH

To be presented at the 18th A.I.Ch.E.
Intersociety Energy Conversion Engineering Conference
Orlando, Florida, August, 1983

*Cycled
Apparatus*