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INVESTIGATION OF HIGH POWER
GASEOUS ELECTRONICS

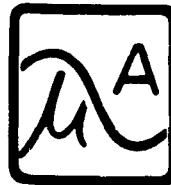
First Quarterly Progress Report

Contract No. DA-36-039-AMC-00097(E)

U.S. Army Signal Corps
Engineering Laboratories

Fort Monmouth, New Jersey

MICROWAVE
ASSOCIATES,
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INVESTIGATION OF HIGH POWER GASEOUS ELECTRONICS
FIRST QUARTERLY PROGRESS REPORT
November 15, 1962 to February 15, 1963

U. S. Army Signal Corps Engineering Laboratories
Fort Monmouth, New Jersey
Contract No. DA-36-039-AMC-00097(E)

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ABSTRACT

Cleanup and thermal recovery of inert gases at the interface between a high power microwave gas discharge and a quartz surface have been investigated. Comparable cleanup and recovery characteristics were observed for argon and krypton gases. Both the total number of atoms sorbed while the discharge was on and thermally desorbed when the discharge was terminated were proportional to the square root of time. Analysis of the data indicates that cleanup and recovery are controlled by activated diffusion processes.

INTRODUCTION

The purpose of this program is to theoretically and experimentally investigate the nature of high power pulsed microwave plasmas in an effort to better understand and improve microwave gas switching techniques. The principle task to which we are devoting our efforts is a research program directed towards understanding the nature of gas cleanup.

Siegler and Dieke¹ in an early paper on cleanup in a microwave discharge, found that cleanup was independent of frequency and inversely proportional to fill pressure in the millitorr range. Complete recovery of the cleaned up gas was obtained by heating the discharge vial with a flame. Pressure was monitored with a modified Pirani gauge and a uranium getter was used to purge gas impurities. Downton² used the technique of adding radio active krypton to inert gas fills. Cleanup was found to continue for thousands of hours at a constant rate for initial gas fills of 10 to 20 Torr. Radiation measurements along with localized thermal desorption of the trapped gas indicated that the trapped gas density was greatest in the surface area adjacent to the area of maximum discharge intensity.

Considerable effort has been devoted to the study of gas cleanup in ionization gauges in the 10^{-8} to 10^{-3} Torr pressure range. Reviews of this work performed up to 1959 are given by Alpert³ and Carter⁴. Cleanup of gases in an ionization gauge is

generally thought to be due to positive ions striking and sticking to the negatively charged glass walls. Cleanup decreases exponentially with time to what most investigators consider to be an apparent saturation level which is equal to less than an equivalent atomic layer of trapped gas. Baker¹⁸ describes a "secondary" type of cleanup in this "saturation" region in which a small amount of gas becomes permanently trapped in the glass walls.

Cleanup rates decrease with increasing temperature while thermal recovery rates increase with increasing temperature. Various investigators have observed the thermal desorption phenomena at the interior glass surface of ionization gauges with many conflicting results. Varnerin and Carmichael⁵ observed that the recovery rate of helium depended directly both upon the quantity of gas pumped and upon a reciprocal power function of time. Blodgett and Vanderslice⁶ observed the release of trapped gas to be proportional to the square root of time provided that equilibrium had been reached during cleanup. Robinson and Berz⁷ noticed an almost exponential recovery of trapped gas but the behavior with temperature was anomalous.

Two different explanations of the recovery process have been proposed. Carter et al^{8,9,10} assert that gas ions penetrate only a short distance into the solid and subsequently return to the gas phase via a single activated desorption step. In this model it is considered that many activation energies for the desorption step are present.

The alternative approach by Carmichael and Trendelenburg¹¹, Baker and Giorgi¹², and Blodgett and Vanderslice⁶ suggests that gas ions are impelled to some depth below the surface where they are neutralized and trapped. Upon reaching equilibrium with the solid lattice the trapped gas atoms then proceed to migrate back to the surface via an activated diffusion process. On reaching the surface these atoms evolve and constitute recovery.

The present work is concerned chiefly with the cleanup and recovery of inert gases at the interface between a high power microwave gas discharge and a quartz surface. In an earlier report Maddix and Ward¹³ showed that argon cleanup rate decreased exponentially with time to a constant long term cleanup rate. The initial cleanup rate exhibited an anomalous temperature dependence although the long term rates were approximately independent of temperature over a -100°C to $+600^{\circ}\text{C}$ range. The bombarding ion flux from the plasma was about 10^{22} ions/cm² sec which is several orders of magnitude greater than the ion flux at the walls of an ionization gauge. During the recovery period the spontaneous thermal re-emission of trapped gas increased with increasing temperature.

In this report additional measurements of argon cleanup and recovery are presented. The work was extended to also include krypton data. Tests were performed which give an explanation for the anomalous initial cleanup temperature dependence. Analysis of the data indicates that cleanup and recovery are controlled by activated diffusion processes.

Experimental

A microwave gas discharge was established at a frequency of 9500 Mc in nickel plated 0.400 x 0.900 inch rectangular waveguide. The discharge was contained in a 5 mm outside diameter by 1 mm wall thickness cylindrical quartz vial mounted as shown in Fig. 1. Because of the self shielding nature of a high power microwave discharge, the principle discharge activity is confined to the part of the vial surface directly facing the incident power direction. A metal iris was also used to further constrain the discharge along the broad dimensions of the waveguide. In this manner a discharge of constant brightness is obtained. The discharge area was taken to be 0.3 cm^2 .

The microwave waveguide and vacuum system is shown in Fig. 2. Power from the transmitter passes through the ferrite circulator to the waveguide arm containing the quartz vial where less than 1% of the incident power is absorbed in the discharge. The main power is reflected back through the circulator and on to load A to be dissipated. A waveguide short is placed at a quarter wavelength behind the vial to lower the discharge breakdown power by placing an electric field maximum at the quartz vial.

In the course of the experiments to be described the incident power was held constant at an average value of 500 watts. The power was modulated at a 0.25 duty cycle and a 1.2 microsecond pulse width. Under these conditions 9 watts of rf power is absorbed per cm^2 of discharge area.

A calibrated thermistor connected to a bridge circuit was used

to monitor pressure. During a test run the vial was isolated from the main vacuum system by means of valve V, in Fig. 2. Hold off pressures of the order of 1×10^{-6} Torr were obtained prior to gas filling. Because test runs were made at different ambient temperatures, initial gas density rather than pressure was set at a constant value of 3.5×10^{16} molecules/cm³. This corresponds to a pressure of 1.0 Torr at standard temperature.

Ambient temperature was controlled by the small waveguide oven shown in Fig. 2. Vial temperature was monitored by means of a thermocouple embedded in the waveguide mount as shown in Fig. 1. Thermal transpiration effects due to the temperature difference between the gas in the vial and that near the thermistor were corrected by means of an experimentally determined temperature-pressure relationship.

In order to obtain reproducible results careful preparation of the vials is necessary. It was found that a raw quartz vial had to be outgassed for sixteen hours at 900°C. Significantly shorter times or lower temperatures would result in reduced cleanup rates or even in pressure increases when the discharge was on. Under these conditions ion induced emission of residual gases is greater than cleanup of the gas under study. Between subsequent runs an outgassing schedule of several hours at 900°C would completely remove the effects of gas trapped during previous runs.

Results

Cleanup and Recovery of Argon at 600°C

In a previous report^{1,2} data was presented which showed argon

cleanup rates to be approximately independent of ambient temperature over a -100°C to $+600^{\circ}\text{C}$ range for discharge times greater than about twenty minutes. During the first twenty minutes that the discharge was on, however, cleanup rates varied with temperature in an erratic manner. In the recovery period the rate of desorption of ionically pumped argon was found to increase consistently with increasing ambient temperature.

The same general behavior has been obtained in the present reporting interval from additional experiments performed with argon and krypton gases. The data is presented as plots of the number of atoms sorbed or desorbed as a function of the square root of time because of an apparent linear relationship between these two variables.

An explanation for the erratic temperature dependence of initial argon cleanup rates can be obtained from an examination of the data presented in Fig. 3. Four separate 600°C argon cleanup runs are shown. The data for Run #1 was taken from a previous report¹³. The data for the other runs was obtained from a different quartz vial with a geometry comparable to that used in Run #1.

Processing before each run consisted of outgassing at 900°C with a small vial size oven. This step was followed by a return to room temperature to connect the waveguide to the quartz vial. A larger oven was placed over the waveguide assembly and the ambient temperature was raised to 600°C . In the cases of Runs #1 and #20, the waveguide oven was held overnight for sixteen hours at 600°C ; whereas,

in the cases of Runs #17A and 19 the waveguide oven was at temperature for only a half-hour before starting the test. In all cases a residual hold off pressure of about 1×10^{-6} Torr at 600°C was obtained prior to gas filling.

All runs in Fig. 3 show an approximate constant rate of change between the number of atoms sorbed and the square root of time for time square root values greater than 5. For values less than 5 an abrupt increase in the number of atoms sorbed is observed in Runs #1 and 20 but not in Runs #17A and 19.

These two types of behavior are believed to be the results of differences in surface cleanliness. When the vial is lowered to room temperature after the 900°C outgassing, residual impurity gases in the vacuum system are physically adsorbed on the ultra clean surface created at 900°C . Time intervals of the order of sixteen hours are evidently needed to completely remove these physically adsorbed impurity gases for the particular temperatures and background pressures under consideration.

In view of the above results, it is not surprising that inconsistent initial cleanup rates were obtained at lower temperatures because of varying amounts of impurity gases physically adsorbed on the quartz surface. The concentrations of these impurities would be a function of time, temperature, and composition of the residual gases in the system. The constant cleanup rates observed at later times indicate that the surface impurities do not appreciably affect the long term measurements. The constant long term cleanup rates also

imply that the 900°C processing completely outgassed the quartz bulk.

Future tests will be run with improved hold off pressures to determine what degree of ultra high vacuum is necessary to obtain reproducible initial gas cleanup rates.

It can be seen that the data points in Fig. 3 do not fall exactly on straight lines. The points tend to deviate from straight lines in a random manner. This is believed to be partly the result of drift in the thermistor control circuit and partly the result of temperature variations between the inside of the quartz vial and the point in the waveguide mount where the thermocouple is located. It is difficult to control these variations at the high rf power levels used in the tests.

Fig. 4 shows the corresponding 600°C argon recovery data obtained when the 600°C cleanup runs of Fig. 3 were terminated by shutting off the microwave gas discharge. Although there is a certain amount of scatter, it is seen that the average values of the number of atoms desorbed fall on a straight line when plotted against the square root of time.

A long term 600°C argon cleanup test is shown in Fig. 5. The number of argon atoms desorbed is proportional to the square root of time for periods as long as (260)⁸ seconds or eighteen hours. On the basis of hard sphere packing, the 8.0×10^{16} atoms per cm² sorbed during this time interval is equivalent to a minimum of 57 atomic layers of argon.

Cleanup of Krypton at Various Temperatures

Krypton cleanup data at various temperatures is given in Fig. 6. Again it is seen that cleanup is directly proportional to the square root of time. The krypton cleanup data in Fig. 6 shows two striking similarities to the 600°C argon cleanup data in Fig. 3. First, the average long term cleanup slope of the four argon curves is 5.5×10^{14} atoms/cm² sec^{1/2} while the slopes of the 700°C and 300°C krypton runs are 7.1×10^{14} and 5.1×10^{14} atoms/cm² sec^{1/2} respectively. Second, the transition between the rapid initial cleanup rate and slower long term cleanup rate occurs when approximately 2.6×10^{16} atoms/cm² have been sorbed for the two clean surface 600°C argon runs and also for the 700°C krypton run. These two similarities indicate that argon and krypton have comparable cleanup characteristics. The lack of a rapid initial cleanup for the 200 and 300°C krypton cleanup runs in Fig. 6 is attributed to the presence of surface impurity gases as described earlier.

A probable explanation for the relatively constant long term krypton cleanup rate over the 200 - 700°C ambient temperature given in Fig. 6 compared to the temperature sensitive recovery rates is as follows. During the recovery period the rf power is off and the vial surface temperature is the same as the ambient temperature. However, when the rf power is on, the arc loss value of 9 watts/cm² dissipated at the vial surface raises the surface temperature to some unknown value. Evidently this high value of dissipated power raises the quartz surface to a temperature which is relatively independent

of the ambient temperature. Thus cleanup rate is independent of ambient temperature.

In view of these considerations, the minimum difference between the ambient temperature on the outside surface of the vial and the inside surface temperature should occur at the highest ambient temperatures. Accordingly the best comparison of cleanup and recovery rates can be made at 600° with the available data. In the case of the four 600°C argon runs of Figs. 3 and 4 the average cleanup rate is 5.5×10^{14} atoms/cm² sec^{1/2} compared to an average recovery rate of 2.7×10^{14} atoms/cm² sec^{1/2} for the corresponding recovery runs. If it is assumed that the same mechanism governs both cleanup and recovery rate, then the 2 to 1 ratio of cleanup rate to recovery rate implies that the inside vial surface temperature is considerably higher than 600°C.

Recovery of Krypton at Various Temperatures

Krypton recovery rate was observed to increase with increasing temperatures. This behavior was similar to that reported earlier for argon recovery¹³. A rapid initial recovery rate was followed by a slower long term recovery rate. Straight lines were obtained when the number of atoms recovered was plotted as a function of the square root of time. An Arrhenius plot of the square of the long term krypton recovery rate versus reciprocal temperature is given in Fig. 7. The reason for using the square of the recovery rate will be discussed later.

As was the case for long term krypton and argon cleanup, the

magnitude of the krypton recovery rate is also comparable to the magnitude of the argon recovery rate. Long term krypton recovery rates of 4.8×10^{14} and 2.4×10^{14} atoms/cm² sec^{1/2} at 700°C and 460°C respectively compare with an average long term argon value of 2.7×10^{14} atoms/cm² sec^{1/2}.

An Arrhenius plot of the initial krypton and argon recovery rate versus reciprocal temperature is given in Fig. 8. The data was extrapolated to $t = 0$ and is presented in terms of the number of atoms desorbed per second versus reciprocal temperature. It is seen that both the krypton and argon data points fall on a common straight line.

DISCUSSION

The foregoing results for both cleanup and recovery can be explained on the basis of diffusion theory. The situation we seek to describe is illustrated in Figs. 9A and 9B. At $x = 0$ we have a boundary between the quartz wall and the plasma sheath. In an earlier report¹³ it was shown that an ion flux of about 7×10^{20} particles/cm² sec and a minimum energy of 350 electron volts is incident on the quartz wall at $x = 0$. During the long term cleanup period about only 1 out of 10^7 of these particles is trapped.

The work of Nielson¹⁴ suggests that the depths of penetration at these energy levels can only be a few angstroms. This depth is considerably less than that required to contain all of the trapped gas atoms if a hard sphere packing model is assumed. Accordingly, a thin layer of depth x_D is assumed in which the structure has been altered by radiation damage by the ion flux out of the plasma. The depth of penetration of the most energetic ions is represented by x_D . At depths greater than x_D the quartz bulk is undamaged by ion bombardment.

Because of the high ion flux, the surface layer becomes saturated with neutralized argon atoms of uniform concentration in a matter of several seconds. For practical purposes this density distribution is represented as occurring at $t = 0$ as shown in Fig. 9B. Experimentally the saturation condition is achieved when the cleanup rate changes from the initial fast rate to the slower long term rate. This transition occurs when 2.6×10^{16} atoms/cm² sec have been sorbed as seen

for the case of the two 600°C argon runs of Fig. 3 and the 700°C krypton run of Fig. 6. This value represents 18.5 atomic layers of argon on the basis of hard sphere packing.

The low sticking coefficient of 10^{-7} indicates that the vast majority of the incident ions are probably reflected back to the plasma as neutral atoms. However, a net cleanup is observed, and it is felt that the trapped ions diffuse out of the radiation damaged surface layer into the undamaged quartz bulk.

If a single diffusion coefficient (D) is assumed, then the form of Fick's law which describes the process in one dimension is

$$\Gamma = -D \frac{\partial n}{\partial x} \quad (1)$$

where Γ = net ion flux trapped at the surface

n = number of trapped atoms/cm³

It is considered that the value of Γ is determined solely by conditions inside the surface and not by conditions at $t < 0$ in the neutral gas and plasma phase. This means that the ion flux from the plasma does not change as the pressure decreases due to cleanup. This assumption of a time independent incident ion flux is justified by discharge arc loss measurements which show, for a fixed incident power, that ion density is very nearly independent of gas pressure.

At some later time, $t = t$, gas atoms will have diffused into the quartz bulk yielding a density profile as shown in Fig. 9B. The average

depth of penetration will, of course, vary with time as determined by Equation (1).

The solution of Equation (1) as given by Jost¹⁵ for the conditions we have just described is

$$n(x,t) = n_o \left[1 - \operatorname{erf} \left(\frac{x}{2\sqrt{Dt}} \right) \right] \quad (2)$$

where erf stands for the error function. The concentration gradient can be found by differentiating Equation (2) yielding

$$\frac{\partial n}{\partial x} = -\frac{n_o}{\sqrt{\pi Dt}} e^{-\frac{x^2}{4Dt}} \quad (3)$$

At the wall surface we have

$$\left. \frac{\partial n}{\partial x} \right|_{x=0} = -\frac{n_o}{\sqrt{\pi Dt}} \quad (4)$$

Thus, the net ion flux into the wall becomes

$$r|_{x=0} = -D \left. \frac{\partial n}{\partial x} \right|_{x=0} = n_o \sqrt{\frac{D}{\pi t}} \quad (5)$$

To find the total number of atoms (N) sorbed per unit area in a time t, we merely integrate Equation (5) to obtain

$$N = 2 n_o \sqrt{\frac{Dt}{\pi}} \quad (6)$$

Thus for a constant diffusion coefficient, the total number of atoms cleaned up should vary directly with the square root of time. Support for this cleanup theory is given by the linear relationship between the number of atoms sorbed and the square root of time in the curves of Figs. 3, 4, and 6. This theory predicts no limitation to the time during which cleanup occurs. Cleanup should continue indefinitely as long as a constant incident ion flux is maintained at the inner quartz surface. The rate of cleanup is determined by the diffusion coefficient and cleanup could conceivably continue to the point where the gas diffuses through the total wall thickness of the container to the outer surface and out into the surrounding atmosphere.

A similar model can be set up for the recovery process. In this case the $x = 0$ plane will be at some point inside the quartz bulk as shown in Fig. 10. The number of atoms desorbed will be directly proportional to the square root of time as long as the concentration of trapped atoms is uniform at $x = 0$. When this condition no longer holds as at $t = t$, the square root relationship will not be valid. This theory predicts that part of the trapped gas will diffuse deeper into the quartz and not be recovered. Experimentally a linear

relationship between the number of atoms desorbed and the square root of time has been observed for desorption times of several hours as shown in Fig. 4. To date the experiments have not been sensitive enough to determine if a small portion of the trapped atoms continue to diffuse deeper into the quartz where they become permanently trapped during the recovery process.

An activated diffusion process will vary with temperature in the following manner

$$D = D_0 e^{-\frac{Q}{RT}} \quad (7)$$

where Q = energy of activation for diffusion

R = universal gas constant

As discussed earlier, the quartz wall temperature is not equal to the ambient temperature during the cleanup period. Accordingly temperature variations can be studied only during the recovery period.

The constant long term slope of the plots of the number of atoms desorbed as a function of the square root of time can be obtained from Equation (6). Hence, we have

$$\frac{\Delta N}{\Delta t^{1/2}} = 2 n_0 \left(\frac{D}{\pi} \right)^{1/2} \quad (8)$$

Combining (7) and (8) gives

$$\left(\frac{\Delta N}{\Delta t^{1/2}}\right)^2 = \frac{4n_0^2}{\pi} D = \frac{4n_0^2}{\pi} D_0 e^{-\frac{Q}{RT}} \quad (9)$$

and

$$\ln \left(\frac{\Delta N}{\Delta t^{1/2}}\right)^2 = \ln \frac{4n_0^2 D_0}{\pi} - \frac{Q}{RT} \quad (10)$$

A plot of $\left(\frac{\Delta N}{\Delta t^{1/2}}\right)^2$ versus $\frac{1}{T}$ should give a straight line with a slope of $\frac{Q}{R}$. The straight line drawn through the krypton data in Fig. 7 represents an energy of activation of 40,000 calories/mole. This is the value of the diffusion coefficient of argon in quartz determined by Norton¹⁶ and T'sai and Hogness¹⁷ from permeation studies. The diffusion coefficient of krypton in quartz should be close to this value in as much as the cleanup and recovery rates of krypton and argon have been observed to be nearly equal.

The initial recovery rate was observed to be faster than the long term recovery rate. This implies that the energy of activation for diffusion in the radiation damaged surface layer is less than in the quartz bulk. The energy of activation for diffusion out of the surface layer can be determined by considering the rate equation

$$\frac{dN}{dt} = -\frac{N}{\tau} \quad (11)$$

where N = number of atoms per cm^2 of surface area

τ = characteristic pumping time

A diffusion or desorptive process requires that an atom surmount a potential energy barrier in changing position. If the barrier is of height Q_s , the atom will have sufficient energy to pass over the barrier only a fraction ($e^{-Q/RT}$) of the time. If ν is the vibrational frequency of the trapped atom, the probability (p) per unit time that the atom will get over the barrier is

$$p \sim \nu e^{-\frac{Q}{RT}} = \frac{1}{\tau} e^{-\frac{Q}{RT}} \quad (12)$$

where T = temperature

Q_s = energy of activation

R = gas constant

τ = sticking time or the time that a trapped atom remains at the surface

The sticking time is given by

$$\tau = \tau_0 e^{\frac{Q}{RT}} \quad (13)$$

Now, the solution to (11) is

$$N = N_0 e^{-\frac{t}{\tau}} \quad (14)$$

where N_0 = the number of atoms per cm^2 of surface area at $t = 0$.
Combining (11), (13) and (14) gives

$$\frac{dN}{dt} = - \frac{N_0}{\tau_0} e^{-\frac{Q}{RT}} e^{-\frac{t}{\tau}} \quad (15)$$

At $t = 0$ we have

$$\ln \left. \frac{dN}{dt} \right|_{t=0} = \ln \left(\frac{N_0}{\tau_0} \right) - \frac{Q}{RT} \quad (16)$$

Fig. 8 shows a plot of (16). From the slope of the curve we get an energy of activation (Q_s) = 5000 cal/mole. This value compares with a value of 3000 cal/mole found by Blodgett and Vanderslice⁶ for the initial recovery of argon from FN glass.

The results of the present work suggest a tie in with the ionization gauge cleanup. In fact the present work could provide a means for gaining fresh insight in interpreting the vast amount of data accumulated in the ionization gauge work. The microwave discharge data obviously supports a diffusion controlled explanation

of cleanup and recovery in contrast to the single activated jump to the gas phase type of recovery.

The same range of ion energies are involved in the two types of experiments; but, significantly, the ion flux to the walls is several orders of magnitude greater in a microwave discharge.

It is felt that the exponential decay in cleanup rate in the ionization gauge can be compared with the rapid initial cleanup in the microwave discharge case. Likewise the saturation region of the ionization gauge cleanup corresponds to the long term cleanup of the microwave discharge. Possibly cleanup is occurring in the "saturation" range of an ionization gauge but at a rate which is too small to be readily detected. Such a slow cleanup is compatible with the "secondary" ionization gauge cleanup observed by Baker¹⁸

The high ion flux out of a microwave discharge simplifies the cleanup analysis by presenting a condition where it is reasonable to assume that the bombarding ions saturate the solid in a short time. Re-emission of the trapped gas is a significantly smaller fraction of the incident flux and diffusion into the undamaged bulk is more apparent. In the ionization gauge it is likely that the available trapping sites in the radiation damaged surface are never completely filled up; hence the dependence of "saturation" cleanup levels on ion energy and previous cleanup history. In an ionization gauge the saturation cleanup level is inversely proportional to ambient temperature because re-emission rates become comparable to cleanup rates at high temperatures.

CONCLUSIONS

The linear dependence of the number of inert gas atoms sorbed and desorbed on the square root of time during cleanup and recovery respectively supports the theory of a diffusion controlled process. The existence of rapid initial cleanup and recovery rates followed by slower long term cleanup and recovery rates justifies the existence of a radiation damaged surface layer with low energies of activation for diffusion and an undamaged bulk region with a higher energy of activation for diffusion. The microwave discharge cleanup and recovery data gives added support to the theory of diffusion controlled recovery of ionically pumped gas in ionization gauges.

PROGRAM FOR NEXT QUARTER

1. Continue cleanup and recovery measurements with other inert gases.
2. Investigate the effects of ultra high vacuum on initial cleanup rates.
3. Compare in greater detail the relationship between microwave gas discharge cleanup and recovery with ionization gauge cleanup and recovery.
4. Continue the analysis of plasma sheath theory to better define the characteristics of the incident ion flux.

IDENTIFICATION OF PERSONNEL

This section contains a list of key technical personnel assigned to the contract and taking part in the work covered by this report. The approximate man hours of work performed on the contract by each of the people listed are given. Also included is a brief description of the background of each person.

M. A. Allen - Head of the plasma group. His background is in high power microwave tubes and plasma physics gained in over six years at Stanford University Microwave Laboratory from where he received his Ph.D. in Physics in 1959 - 50 hours.

H. S. Maddix - The Project Engineer, supervises the experimental and theoretical work on the program. His experience since graduating in 1951 from Rensselaer Polytechnic Institute has been in the fields of gaseous electronics and gas discharge research studies. He holds an M.S. in Physics from Northeastern University. - 235 hours.

C. S. Ward - Project Leader in the plasma physics group is engaged in a study of condition existing at the plasma sheath and has contributed to the interpretation of the experimental cleanup data. Mr. Ward received his Masters' degrees in plasma physics from the University of Pennsylvania in 1957 and from M.I.T. in 1959. Since joining Microwave Associates in 1960, he has been engaged in high power duplexer research studies. - 70 hours.

J. Gregory - An engineer in the plasma physics group is engaged in the experimental studies of gas cleanup. His experience since graduating

in 1960 from the University of Massachusetts includes two years at Sanders Associates where he was involved with problems of high voltage breakdown and also with the evaluation of radar systems modules. He has been engaged in high power waveguide breakdown and cleanup studies since joining Microwave Associates in January 1962. - 450 hours.

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Figure 9A	Plasma-Quartz Wall Cross Section
Figure 9B	Depth Distribution of Trapped Gas During Cleanup
Figure 9C	Depth Distribution of Trapped Gas During Recovery

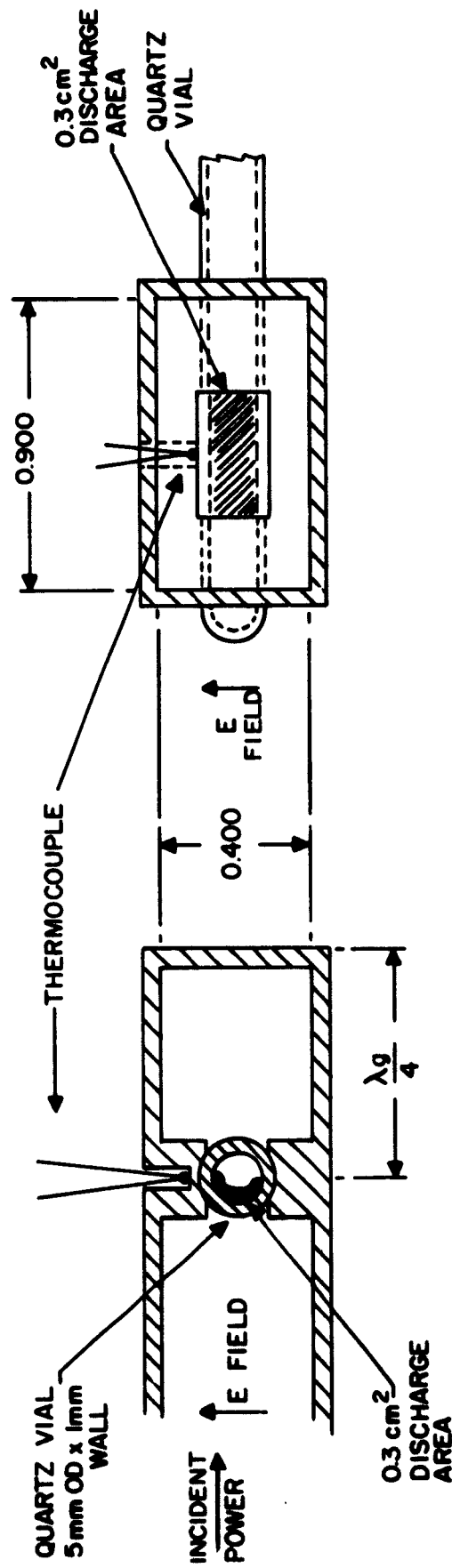


FIGURE 1A
WAVEGUIDE MOUNT
CROSS SECTION

FIGURE 1B
WAVEGUIDE MOUNT
END VIEW

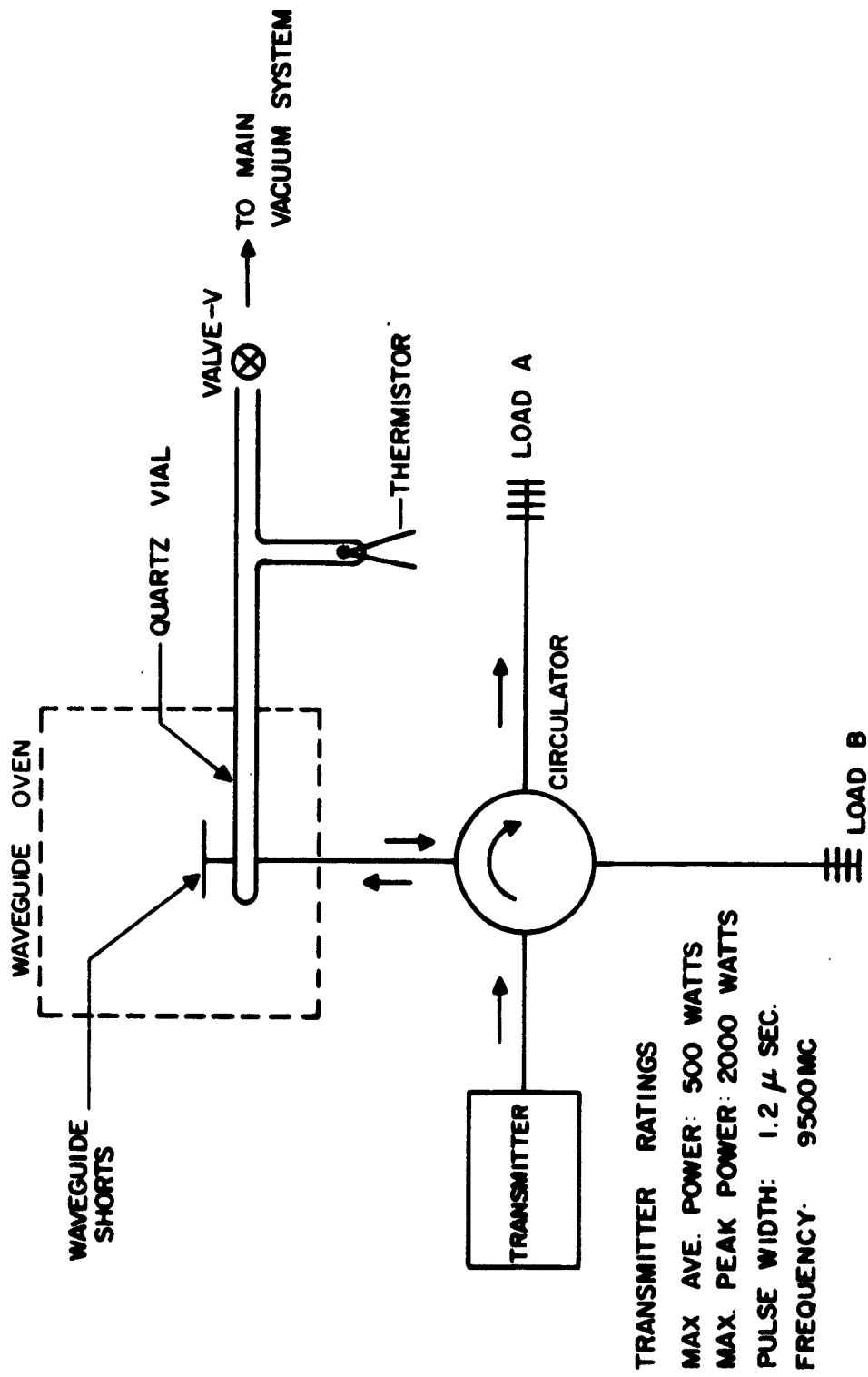


FIGURE 2
WAVEGUIDE AND VACUUM SYSTEM

FIGURE 3
ARGON CLEAN UP AT 600° C

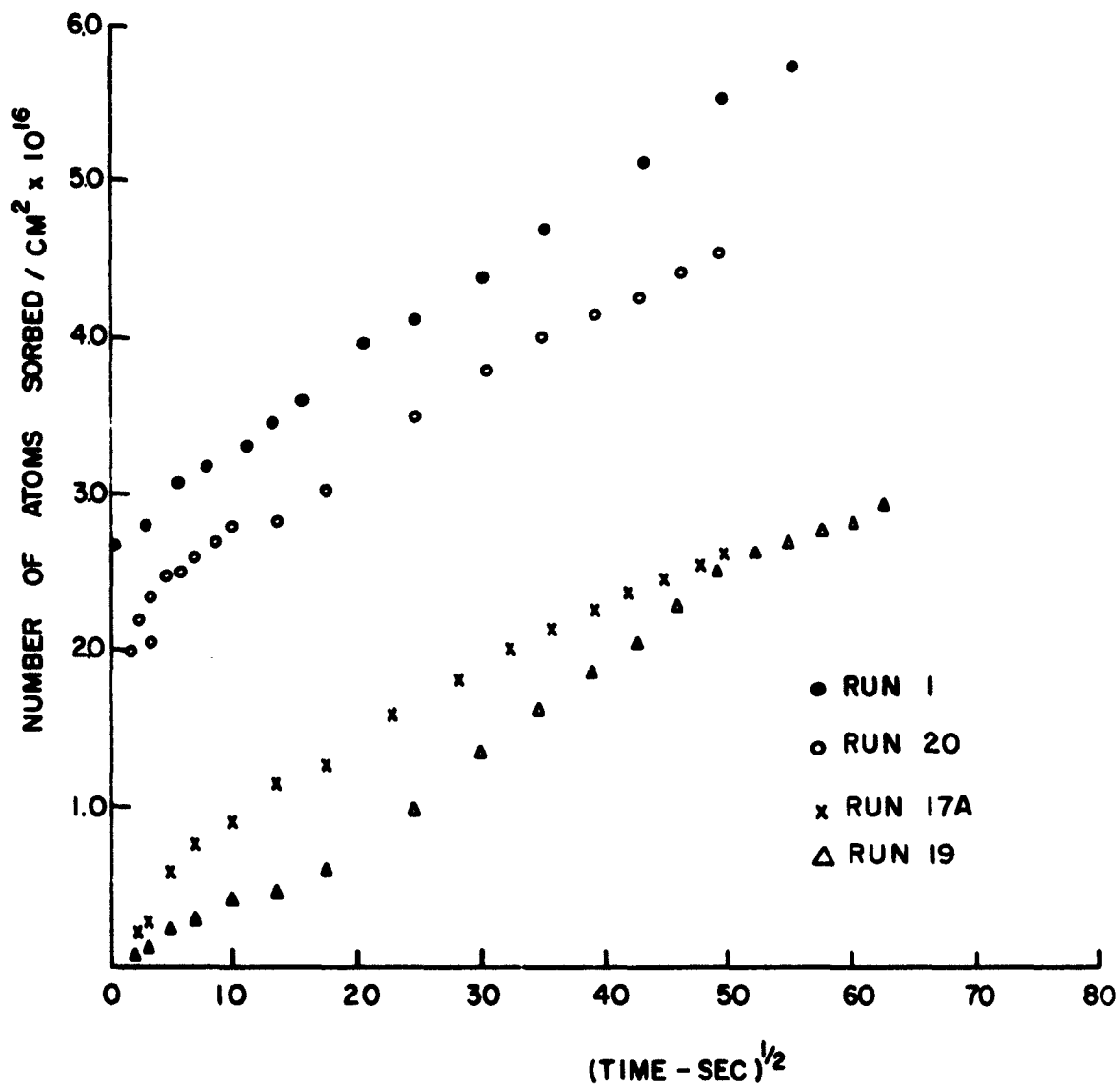


FIGURE 4
ARGON RECOVERY AT 600° C

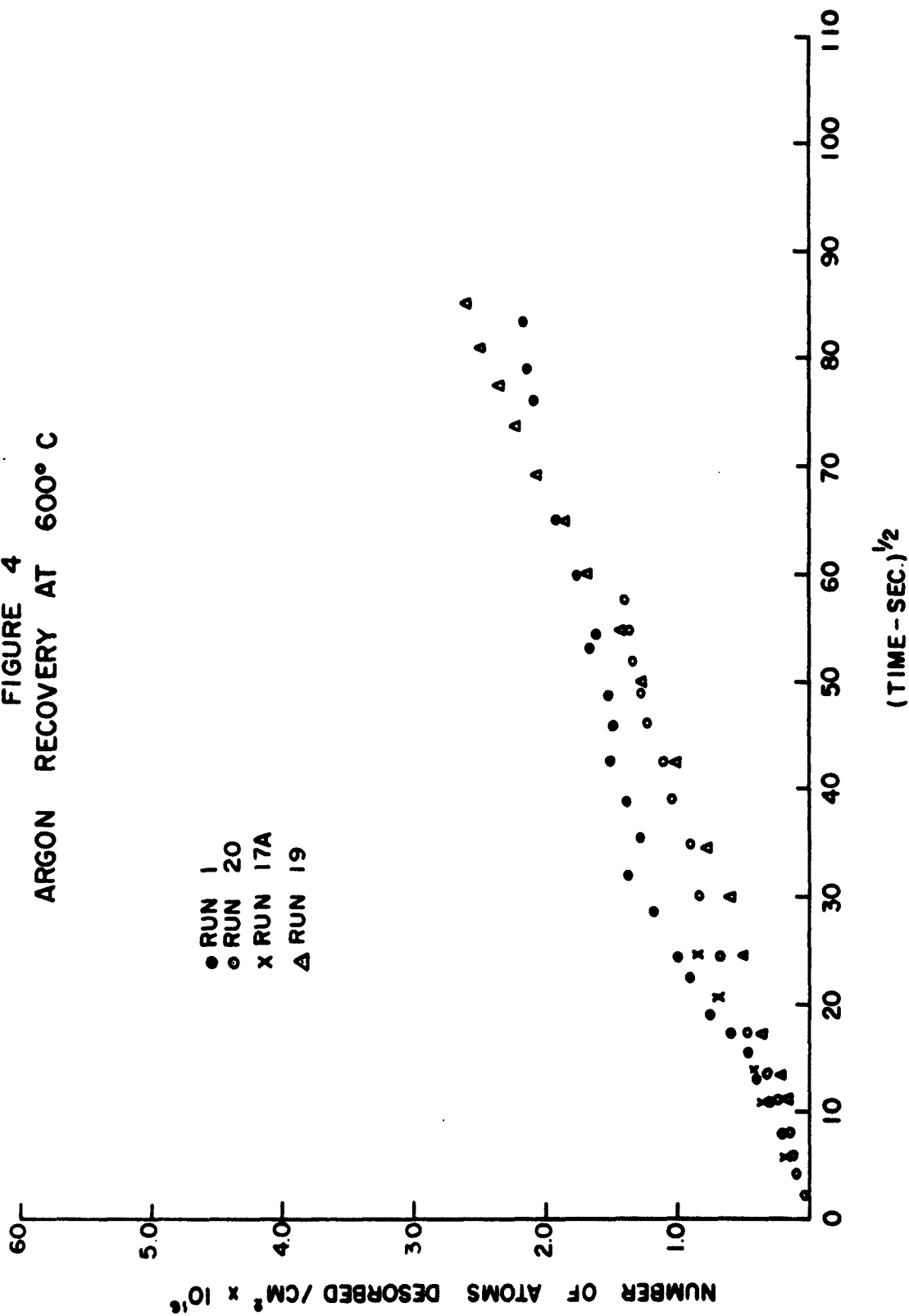


FIGURE 5
ARGON CLEAN UP
AT 600°C

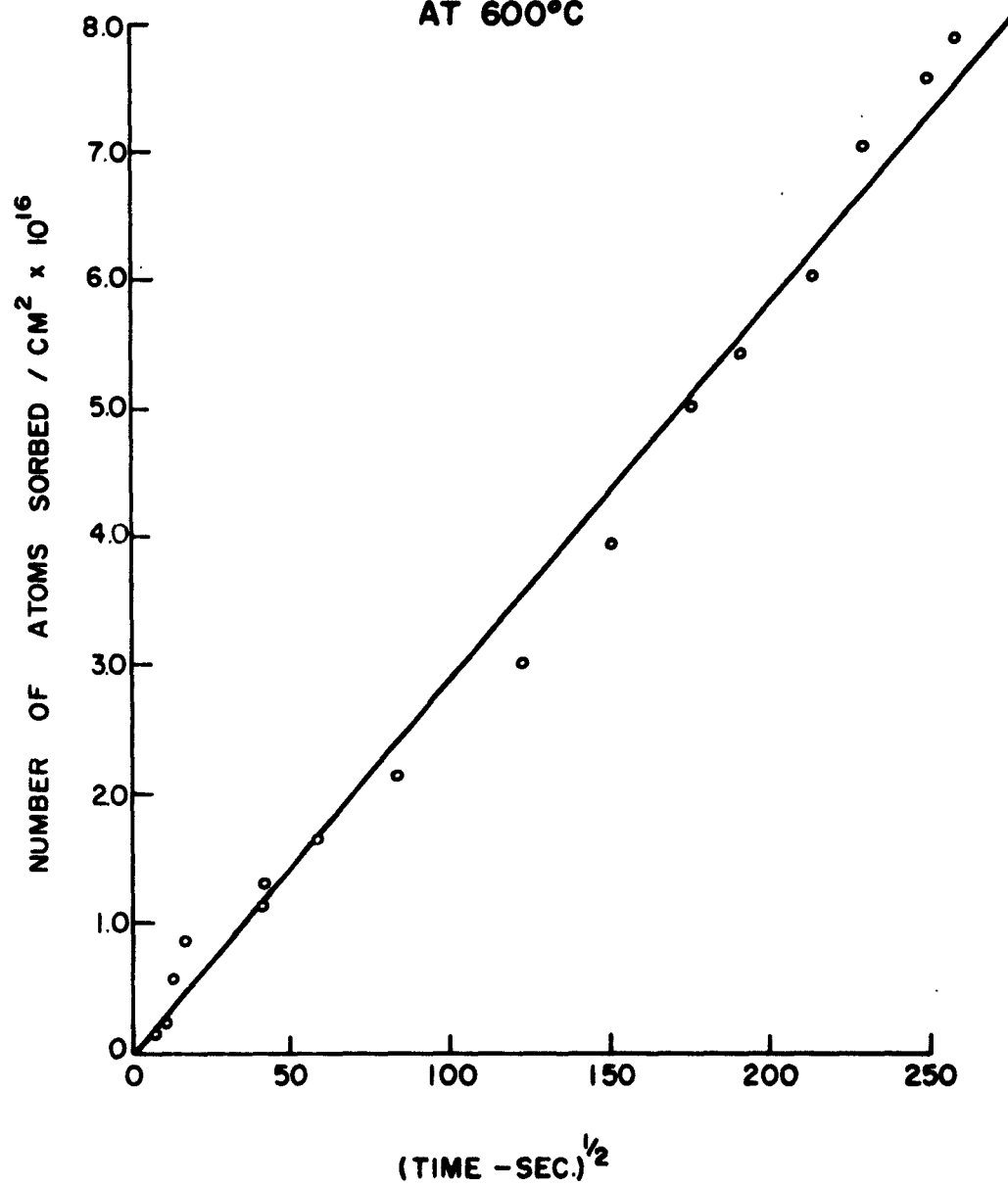
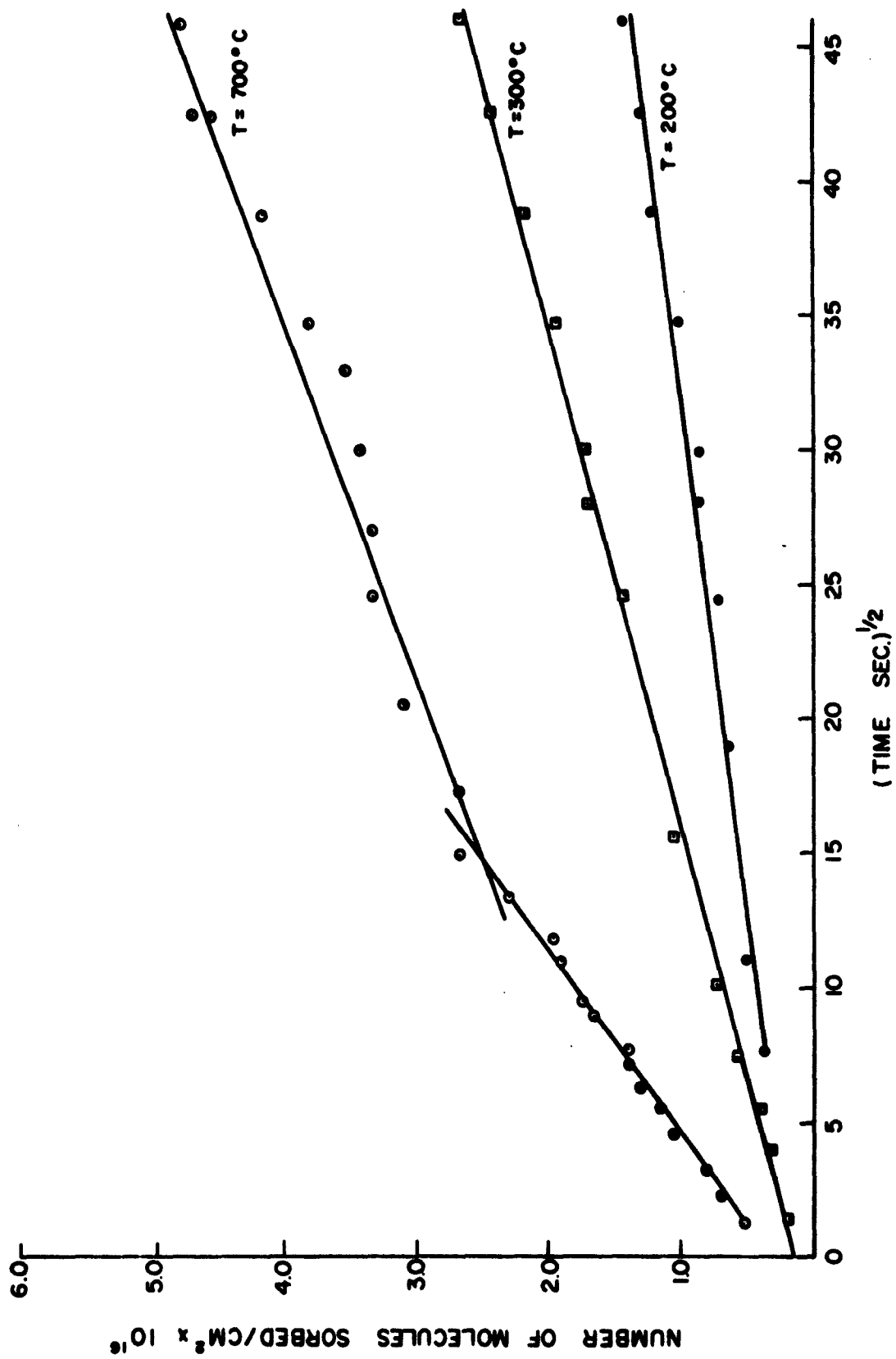


FIGURE 6
KRYPTON SORPTION



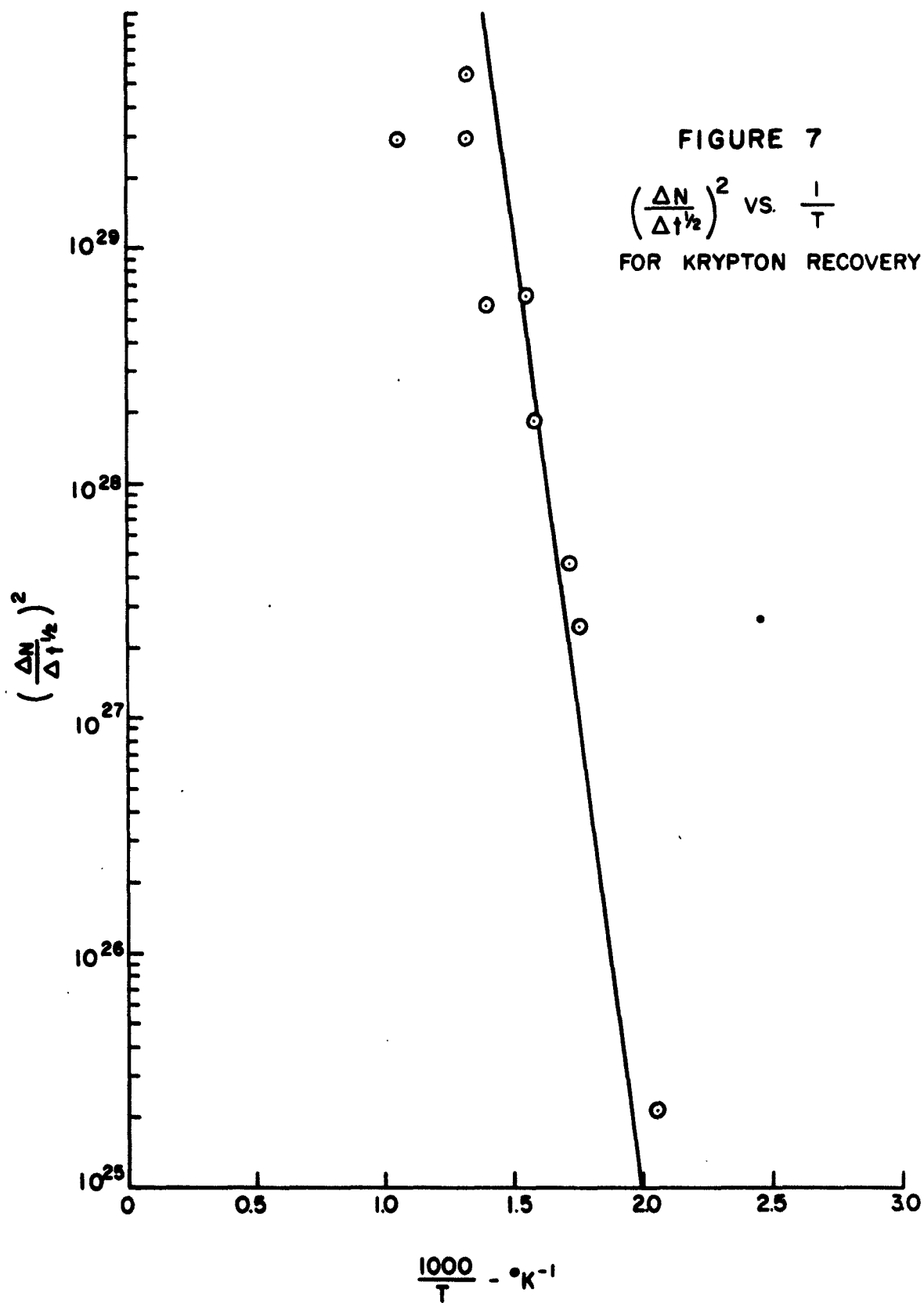
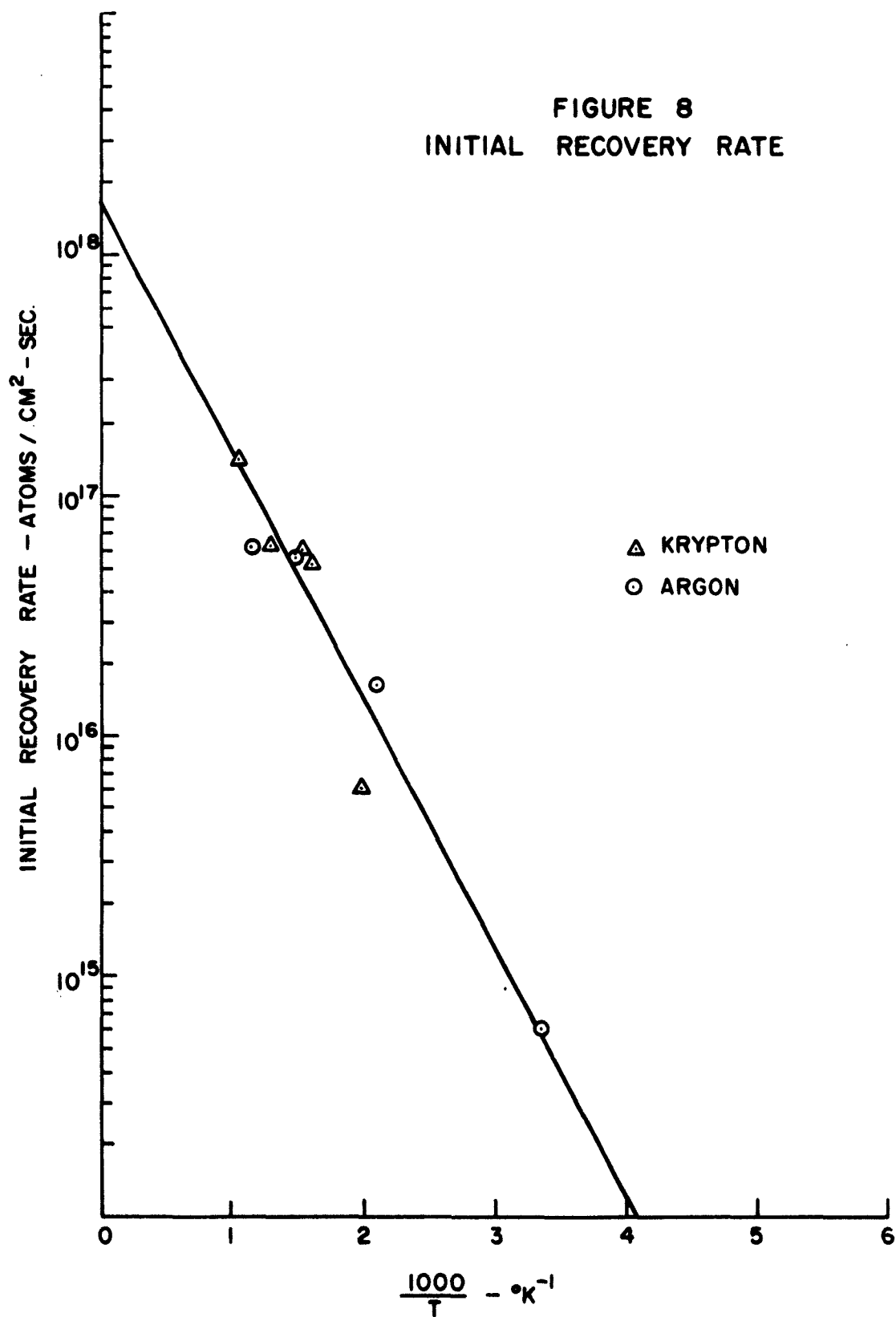


FIGURE 8
INITIAL RECOVERY RATE



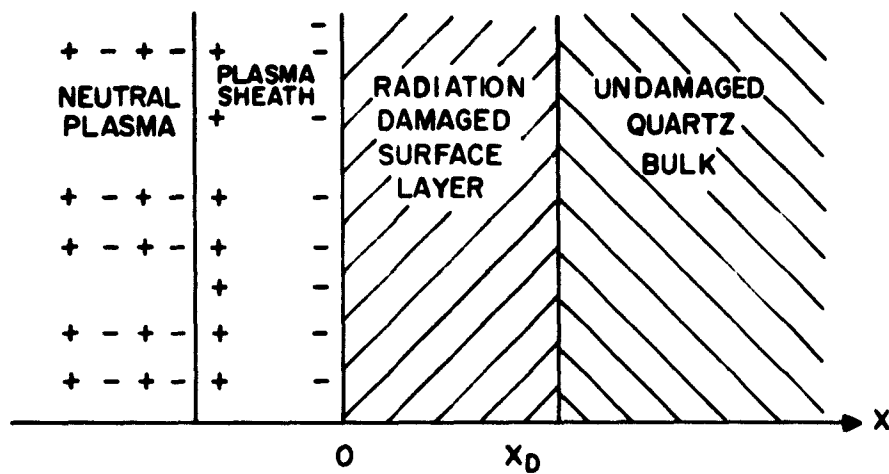


FIGURE 9A PLASMA -QUARTZ WALL CROSS SECTION

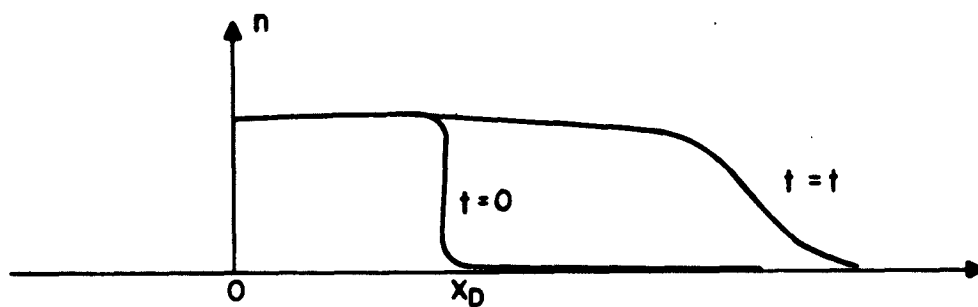


FIGURE 9B DEPTH DISTRIBUTION OF TRAPPED GAS DURING CLEAN UP

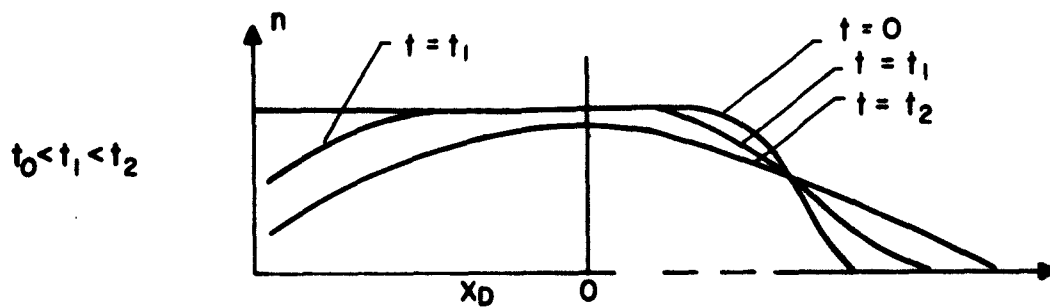


FIGURE 9C DEPTH DISTRIBUTION OF TRAPPED GAS DURING RECOVERY

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This contract is supervised by the Microwave Tubes Branch, Electron Tubes Division, ECD, USAELRDL, Fort Monmouth, New Jersey. For further technical information, contact Mr. John Carter, Project Engineer, Telephone 201-59-61742.