NASA CR 171990

THE IDENTIFICATION OF EXCITED SPECIES IN ARC JET FLOW

August 15, 1987

(NASA-CR-171990) THE IDENTIFICATION OF EXCITED SPECIES IN ARC JET FLOW Summer Faculty Fellowship, 1984 (Northeastern Univ.) 87 p Avail: NTIS HC A05/MF A01 CSCL 20H G3/72

N87-30156

Unclas
0098644

NASA

National Aeronautics and Space Administration

Lyndon B. Johnson Space Center
Houston, Texas

THE IDENTIFICATION OF EXCITED SPECIES IN ARC JET FLOW

Ronald J. Willey
Department of Chemical Engineering
Northeastern University
360 Huntington Ave.
Boston, Massachusetts 02115

August 15, 1987

Prepared for
LYNDON B. JOHNSON SPACE CENTER
Houston, Texas 77058

NASA CR 171990

1. Report No. NASA CR 171990	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle The Identification of Excited Species in Arc Jet Flow		5. Report Date 15 Aug. 1987
		6. Performing Organization Code
7. Author(s) Ronald J. Willey		8. Performing Organization Report No.
		10. Work Unit No.
9. Performing Organization Name and Address Department of Chemical Engineering, Northeastern University, Boston, MA		11. Contract or Grant No. NGP-44-005-803 1984 Summer Faculty Fellowship
		13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address		14. Sponsoring Agency Code

15. Supplementary Notes

This Report represents the full results of spectroscopic work done in an arc jet, including spectral photographs of the arc during a NASA Summer Faculty Fellowship completed in the summer of 1984.

16. Abstract

Spectrographic work done at the Atmospheric Reentry Material and Structures Facility (Arc Jet) located at the Johnson Space Center has led to the identification of several excited molecular and atomic states. The excited molecular states identified are: first positive nitrogen system $(B^3\Pi \rightleftharpoons A^3\Sigma)$, second positive nitrogen system $(C^3\Pi \rightleftharpoons B^3\Pi)$, first negative nitrogen system $(B^3\Sigma_u^+ \rightleftharpoons X^2\Sigma_g^+)$, the γ system for nitric oxide $(A^2\Sigma^+ \rightleftharpoons X^2\Pi)$ and the 306.4 nm system of OH $(A^3\Sigma^+ \rightleftharpoons X^2\Pi)$. Excited atoms identified were nitrogen, oxygen, hydrogen, silicon, copper, sodium, barium, potassium, and calcium. The latter five are considered contaminants. Excited molecular states of oxygen were not seen, suggesting full dissociation of oxygen molecules to oxygen atoms within the arc column and nozzle. Further, evidence exists that O^- may be present since a background continuum is seen, and because of the existence of positive species (first negative system of N_2^+). Interpretation of spectrographic plates was enhanced by the use of a Perkin Elmer PDS Microdensitometer, and by the application of a second order least squares routine which determined wavelength as a function of plate location. Results of this work will ultimately improve models used in the calculation of heat transfer rates to the Space Shuttle and the aerobraking orbital transfer vehicles.

17. Key Words (Suggested by Author(s))		18. Distribution Statement
Molecular Spectra	Air	
Arc Jet	Argon	
Atomic Spectra	Nitrogen	
Species Identification		
Shock Layer		
Oxygen		

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
	Unclassified		

*For sale by the National Technical Information Service, Springfield, Virginia 22161

Table of Contents

List of Tables

List of Figures

Appendices

Appendices (Continued)

Appendices (Continued)

THE IDENTIFICATION OF EXCITED SPECIES IN ARC JET FLOW

Ronald J. Willey
Assistant Professor
Department of Chemical Engineering
Northeastern University
Boston, Massachusetts

ABSTRACT

Spectrographic work done at the Atmospheric Reentry Material and Structures Facility (Arc Jet) located at the Johnson Space Center has led to the identification of several excited molecular and atomic states. The excited molecular states identified are: first positive nitrogen system ($B^3\Pi \rightleftharpoons A^3\Sigma$), second positive nitrogen system ($C^3\Pi \rightleftharpoons B^3\Pi$), first negative nitrogen system ($B^3\Sigma_u^+ \rightleftharpoons X^2\Sigma g$), the system for nitric oxide ($A^2\Sigma^+ \rightleftharpoons X^2\Pi$) and the 306.4 nm system of OH ($A^3\Sigma^+ \rightleftharpoons X^2\Pi$). Excited atoms identified were nitrogen, oxygen, hydrogen, silicon, copper, sodium, barium, potassium, and calcium. The latter five are considered contaminants. Excited molecular states of oxygen were not seen, suggesting full dissociation of oxygen molecules to oxygen atoms within the arc column and nozzle. Further, evidence exists that O^- may be present since a background continuum is seen, and because of the existence of positive species (first negative system of N_2^+). Interpretation of spectrographic plates was enhanced by the use of a Perkin Elmer PDS Microdensitometer, and by the application of a second order least squares routine which determined wavelength as a function of plate location. Results of this work will ultimately improve models used in the calculation of heat transfer rates to the Space Shuttle and the aerobraking orbital transfer vehicles.

Center Research Advisor: Dr. Carl Scott

INTRODUCTION

It has been recognized that catalytic recombination of atoms on spacecraft surfaces affects the heat flux during atmospheric reentry (Scott, 1982, and Breen et al., 1973). Current heat flux predictions account for chemical heat flux by recombination coefficients for ground state atoms to ground state molecules (Scott, 1981 a & b) and have greatly improved previous predictions. Although measured heat transfer rates on the forward fuselage agree with calculations, rearward vehicle heat transfer rates under predict observed temperatures by as much as 160 K°. To account for low rearward predictions, it has been hypothesized that energy is carried from the forward section of the vehicle by excited molecules and atoms. The excited species then shed their excitation energy at rearward portions of the vehicle as they relax.

It is the purpose of this work to determine what excited species exist in a flow environment similar to spacecraft reentry.

EXPERIMENTAL

Experiments were conducted at the NASA Lyndon B. Johnson Space Center (JSC) 10-MW arc tunnel facility. More specifically, experiments were conducted in Test Position No. 2 which consists of a 5-MW arc heater, and a 2.44 m diameter chamber. Typical chamber pressures are 60 to 100 Pa. A 3.175 cm diameter throat was used with one of two exit nozzles of 19.05 cm and 63.50 cm diameters respectively.

Spectra were measured in the shock layer of three test articles, an RCC (reinforced carbon-carbon) puck, an HRSI (high temperature reusable surface insulation) wedge, and an RCC wedge, in one of four gas mixtures. The four gas mixtures were: O_2 in N_2 (air) with a mole ratio of O_2 to N_2 equivalent to that of air; N_2 only; O_2 in argon with a mole ratio of O_2 to argon equivalent to that of O_2 to N_2 in air; and argon only. Test article and gas mixture combinations are given in Table 1. Spectra were also taken of free stream conditions, conditions in which no test article was present.

A typical run condition for the 19 cm exit nozzle consists of arc power at 1.41 MW with inlet gas flow rates at 0.0105 kg/sec for O_2 and 0.0355 kg/sec for N_2. Under these conditions, the exit gas from the nozzle has an enthalpy of 13.3 MJ/kg and a pitot pressure of 2.54 kPa. The range of enthalpy was 11.5 to 16.1 MJ/kg for air and N_2 conditions. Further details of run conditions may be obtained from the JSC arc tunnel facility.

Spectra were measured with a McPherson Model 216.5 0.5 m combination scanning monochromatic spectrograph and polychromator. The majority of the species identification was done by evaluation of spectra recorded on spectrographic plates. Spectra were taken at five centering wavelengths of 260, 380, 500, 620, and 740 nm on Kodak Type 103-0 (260 and 380 nm wavelengths), Type 103-F (500 and 620 nm wavelengths), and Type 1-N (740 nm wavelength) spectrographic plates. Each plate spanned approximately 140 nm of wavelengths, thus there was some overlap at each setting. The spectrograph's entrance and exit slits openings were set at 10 microns. Slit height was set at 4 mm for both slits. Exposure times varied with conditions studied, however, typical times with a test article in place were 2 and 25 seconds for all center wavelengths except 740 nm, in which 10 and 100 seconds were used. A 440 nm long wavelength band pass cut-off filter was used for wavelengths above 440 nm to prevent the low wavelength second order lines from appearing on the plates.

Wavelength calibration of the plates was done by taking spectra of spectral calibration lamps. Lamps used were mercury for 260, 380, and 500 nm centerline wavelengths, neon for 620 and 740 nm, and argon for 740 nm. A xenon lamp was overlaid the mercury 500 nm calibration to provide some additional lines in this wavelength range.

The spectrograph was also set up as a scanning monochromator and used with limited success. Using the spectrograph successfully in this mode, may save time in species determination since plate development time will be eliminated. Figure 1 is the current equipment arrangement for the scanning monochromator mode.

Species Identification Procedure

Species identification was accomplished by three approaches: comparison of plates, wavelength determination by a hand operated micrometer, and wavelength determination by a microdensitometer. The first approach, comparison of plates, worked very well.

By taking spectra at conditions of air, pure nitrogen, pure argon and oxygen/argon feed mixtures, molecular bands could be separated and identified. An example would be the comparison of spectra for the three conditions of pure nitrogen, oxygen/argon, and air. Inspection of these three together would show molecular bands due to nitrogen only, molecular bands due to oxygen only (none were detected in this work), and finally molecular bands due to nitrogen and oxygen together (most notably NO bands). Atomic lines due to oxygen or nitrogen atoms could also be separated by the same procedure. Once a particular molecular band or atomic line had been identified, overlaying the plate with the known band or line over a plate with an unknown band or line, allowed a comparison and verification of an excited species presence or absence. Alignment of overlaid plates is checked by aligning the calibration lamp spectra on each plate.

Wavelength determination by a hand operated micrometer was done by finding X-location in inches of various atomic lines on a plate. The procedure required knowledge of at least one known line in a spectrum and a plate "equation" of the form.

$$Y = b_0 + b_1 x + b_2 x^2 \tag{1}$$

where Y = wavelength in nm

x = micrometer reading in inches

b_0, b_1, b_2 = constants

The constants, b_0, b_1, and b_2, were determined by using the calibration lamp spectrum with known atomic lines and plate locations. Further details of the procedure are presented below under the description of the microdensitometer. With a spectrum positioned properly (the known line located such that its micrometer location gave the correct wavelength in Equation (1)), other unknown atomic lines and band head locations could be measured and assigned a wavelength by Equation (1).

Wavelengths could then be compared to known wavelengths for elemental atomic lines or molecular bands given in the MIT Wavelength Table or Pearse

(Pearse, 1965). Based on a suitable match, and some insight, an assignment of an excited species to that particular wavelength was made.

Wavelength determination by microdensitometer scans were similar to that used for the hand operated micrometer. In this approach, the microdensitometer 5is scanned across a spectrum, recording image density on a nine-track tape. The process, all automated by a Digital PDP 11/05 microcomputer, required input of the desired pixel size (in microns), the step size, the number of pixels in one scan, and scan mode. Data are then recorded sequentially on a nine-track tape by scan (each scan represented a record of data). Each block of data are preceded by a header which identifies the plate scanned and which half. Scanning of plates was done with a 10 x 400 micron pixel at a 10 micron step in the X-direction for 5000 pixels and a 6000 micron (6 mm) step in the Y-direction for the number of spectrum on a plate. In this mode, half of a plate could be scanned at a time. A move command allowed relocation of the microdensitometer table to the second half of the plate. Further details of the microdensitometer operation are presented in Appendix A.

Raw data for the nine-track tape were read into mass storage of Univac 1182-E computer located at JSC by using FORTRAN (ASCII) subroutines of NTRAN$ and BITS. NTRAN$ provided the input/output operations from the foreign tape to the Univac mass storage. BITS converted the 32 bit word format of the Digital PDP microprocessor to the Sperry Rand 36 bit word format (stored in mass storage). Once sequential density readings were stored in mass storage, further processing consisted of locating maximum density versus location (atomic line location) and preparing plots of density versus wavelength. Since locations were in microns, the plate calibration equation used was:

$$Y = b_0 + b_1 x + b_2 x^2 \quad (2)$$

where Y = wavelength in nm/100

$$x = \frac{\text{micron location - 50000}}{5000}$$

= centimeter location from the center of the plate

The choice of centering the x-location was to minimize errors at the edges of a plate. The constants, b_0, b_1, b_2, were determined by a least squares fit of the calibration lamp known wavelengths versus locations. An example of a fit is shown in Appendix B for Hg and the 260 nm centerline. Actual versus predicted wavelength differed by a maximum of only 0.015 nm. Plate constants determined by this approach are shown in Table 2.

Better accuracy was achieved with the microdensitometer than with the hand micrometer and allowed determination of unknown wavelengths to within 0.03 nm. The procedure does require a known line in the spectrum since a small offset occurs plate to plate. Known atomic lines of copper, sodium, or oxygen were present in most cases.

Plots of spectrum data could be accomplished by use of a subroutine library called DISSPLA. Examples of the plots generated are shown in Figures 2-4 and are discussed under results. Appendix C contains a listing of program names used to read and process data from the microdensitometer. Copies of these programs are located in Appendix C.

RESULTS

A series of spectral measurements made of the shock layer and free stream emission are discussed here.

A summary of measured excited atoms and molecules is presented in Table 3. Excited atomic species identified were: oxygen, nitrogen, copper, sodium, hydrogen, calcium, barium, silicon, potassium, and argon. Excited molecular species identified were: 1st positive nitrogen, 2nd positive nitrogen, 1st negative nitrogen (N_2+), nitric oxide γ system, and OH 306.4 nm system.

<u>Discussion</u>

Excited atomic species such as oxygen, nitrogen, potassium, barium, calcium, copper, and silicon were mainly observed in the bright white light of the RCC puck surface. This surface perpendicularly faced the arc column, and thus it is suspected that some of this light may represent reflected light from the arc column itself. A continuum was also seen under these conditions suggesting O^- and possible O_2^- negative ions.

In the shock layer of the RCC puck with air, excited states of N_2 (N_2 1st and 2nd positive and N_2^+ 1st negative) are readily observed as well as the NO system. The mechanism for creation of these excited states of N_2 was probably ground state N_2 molecules raised to higher energy levels as they passed into the high temperature shock layer. Similarly, excited oxygen atoms are observed in the shock layer. The probably source was ground state oxygen atoms from the column excited as they cross into the shock layer. No molecular bands of O_2 were observed. This suggests that all oxygen is dissociated in the arc column. Excited NO molecules also existed in the free stream (at a lower concentration compared to the shock layer) and were probably created in the arc column.

Excited copper atoms, particularly those associated with the 324.7540 and 327.3962 nm wavelength, were prevalent in any condition in which N_2 was present (copper was observed in the free stream, shock layer, and surface), however, no excited copper atoms were observed for conditions in which argon was a carrier. Argon probably erodes the anode slower than nitrogen.

Figure 2 shows a sample spectrum for the shock layer of air before the RCC puck surface. The atomic copper lines are pronounced along with the band structure of the 1st negative system of N_2^+. Less pronounced (to the left of the figure) is the band structure for the 2nd positive system of N_2.

Comparing Figure 3 to Figure 4 shows an interesting phenomenon of argon line broadening when oxygen is present. Note that the argon lines are very broad in Figure 3 (the oxygen condition) while in Figure 4 they are quite narrow (as expected). The reason for this is not clear with a possibility of electron densities being higher when oxygen is present.

Excited atomic hydrogen and OH were observed in only one instance: the shock layer of the RCC puck with pure argon. Existence of H and OH suggests some residual water in the test chamber at the time the spectra were taken. Some residual N_2 was also seen under these conditions. This spectrum centered at 260 and 380 nm gives the best example of the 2nd positive N_2 system (Plate 42 of this work). Plate's photographs, annotated with species identification, are shown in Appendix D.

The best example of NO γ system can be seen in the air free stream spectrum centered at 260 nm (Plate 45). Examples of the 1st negative N_2^+ and 1st positive N_2 systems can be seen in the spectrum of the N_2 shock layer in spectrum centered at 380 nm, 500 nm, 620 nm and 7400 nm (Plates 23, 24, and 25).

Spectrum of the HRSI wedge air shock layer showed two distinct zones between the shock layer and the surface layer. 1st negative N_2^+ and 2nd positive N_2 were seen in the surface layer clearly, but they only faintly appear in the shock layer. The spectrum showed both zones because the spectrograph slit was focused across both layers (Plate 58, which is not shown in Appendix D).

An important question arises, which currently remains unresolved: Is the surface composed of excited N_2 molecules or is the spectrum of reflected light from the arc column? The implication of surface excited N_2 molecules would support surface energy transfer mechanisms by chemical means to excited molecular states.

A summary of excited species observed when the RCC puck was inserted in air is shown in Figure 5.

CONCLUSIONS

1. Three excited states of N_2 have been identified, first positive, second positive and first negative systems.
2. Excited NO is present as the γ system.
3. Excited oxygen and nitrogen atoms are present.
4. Contaminants observed include copper, sodium, potassium, barium, and calcium.
5. No excited molecular states of O_2 were observed.
6. A second order linear regression equation is sufficient for data analysis.
7. Argon is less severe on anode erosion compared to nitrogen.

RECOMMENDATIONS

1. Continue developing monochromatic mode of scanning.
2. Improve optics so that spectra of point positions can be taken.
3. Take spectra of the afterglow from various test articles.
4. Determine if the "white" surface light seen on test articles is from the surface or a reflection from the arc column.

ACKNOWLEDGMENT

I would like to thank Dr. Carl Scott for his very supportive assistance throughout the course of this project.

I would also like to briefly acknowledge the assistance of Dr. Fred Wierum, Mr. Robert Zuteck and all of the arc jet facility personnel, Mr. Walter Lueke, Mr. Jerry D. Greer, Mr. Glenn Morgan, Mr. Stan Williams, Mr. Doug Flewellan, Ms. Patricia Ford, and Ms. Janice Gray throughout different stages of this project. Thank you for a most excellent, stimulating summer.

Ronald J. Willey

REFERENCES

1. Breen, J., Cibrian, R., Delgass, W. N., Krishnan, N. G., Nordine, P.C., and Rosner, D. E., "Catalysis Study for Space Shuttle Vehicle Thermal Protection System," Yale University, Final Report, Contract No. NAS 9-13058, NASA CR-134124, Oct. 1973.

2. DISSPLA, Integrated Software Systems Corporation, San Diego, CA, 1981.

3. Felder, W., and Young, R. W., "Quenching of $O(^1S)$ by $O(^3P)$," J. Chem. Phys., Vol. 56, pp. 6028-6030, 1972.

4. Griem, H. R., "Plasma Spectroscopy," McGraw Hill, New York, NY, 1964.

5. Herzberg, G., Atomic Spectra and Atomic Structure, Dover, NY, 1944.

6. Herzberg, G., Molecular Spectra and Molecular Structures I. Spectra of Diatomic Molecules, D. Van Nostrand, New York, 1965.

7. Mastrup, F. N., "Development of Spectroscopic and Optical Scattering Diagnostics for Non-Equilibrium Reacting Gas Flows," TRW Systems Group, Technical Report AFFDL-TR-70-17, 1970.

8. McPherson Instrument "Model 216.5 0.5 m Combination Scanning Monochromator Spectrograph and Polychromator Instruction Manual," McPherson Instrument, Acton, MA.

9. M.I.T. Wavelength Tables, the M.I.T. Press, Cambridge, MA, 1963.

10. Oriel Corp. Instrumentation for Spectroscopy and Detection UV-VIS-IR, Stratford, CT, pp. 21-22.

11. Pearse, R. W. B. and Gaydon, A. G., The Identification of Molecular Spectra, Chapman & Hall, London, 1965.

12. Scott, C. D., "Line Broadening of the Triplet Diffuse Series of Helium in an Arc Jet Plasma," Ph.D Dissertation, University of Texas at Austin, 1969.

13. Scott, C. D., "An Experimental and Analytical Study of Slip and Catalytic Boundary Condition Applied to Spheres in Low Reynolds Number Arc Jet Flows," Rarefied Gas Dynamics, edited by M. Becker and M. Fiebig, 1974, pp. D.14-1 - D.14-12.

14. Scott, C. D., "Catalytic Recombination of Nitrogen and Oxygen on High-Temperature Reusable Surface Insulation," in Aerothermodynamics and Planetary Entry, edited by A. L. Crosbie, Vol. 77 of Progress in Astronautics and Aeronautics, 1981, pp. 192-212.

15. Scott, C. D., "Space Shuttle Laminar Heating with Finite Rate Catalytic Recombination," AIAA Paper 81-1144, 1981b.

16. Scott, C. D., "Catalytic Recombination of Nitrogen and Oxygen on Iron-Cobalt-Chromia Spinel," AIAA Paper 83-0585, 1983.

17. Scott, C. D. and Derry, S. M., "Catalytic Recombination and Space Shuttle Heating," AIAA Paper 82-0481, 1982.

18. Scott, C. D., Ried, R. C., Maraia, R. J., Li, C. P., and Derry, S. M., "An AOTV Aeroheating and Thermal Protection Study," AIAA Paper 84-1710, 1984.

19. Slanger, T. G., "Energy Transfer Reactions of Excited Atoms and Molecules," SRI International, Final Report, Contract No. DAAG 29-77-C-0018, 1980.

20. Slanger, T. G., "Generation of O_2 (C^1 $^-$, C^3 , A^3 $^+$) From Oxygen Atom Recombination," J. Chem. Phys. Vol. 69, 1978, pp. 4779-4791.

21. Stewart, D. A. and Leiser, D. B., "Catalytic Surface Effect on Ceramic Coatings for an Aeroassisted Orbital Transfer Vehicle," in Ceramic Engineering and Science Proceedings, Vol. 5., March 1984, pp. 491-505.

22. Swann, R. T., Wood, G. M., and Brown, R. D., "Non-Catalytic Surfaces for Metallic Heat Shields," AIAA Paper 84-1734, 1984.

23. Young, R. A. and Black, G., "Excited-State Formation and Destruction in Mixtures of Atomic Oxygen and Nitrogen, "J. Chem. Phys., Vol. 44, 1966, pp. 3741-3751.

TABLE 1

EXPERIMENT TEST ARTICLES AND GAS MIXTURES

TEST ARTICLE	SIZE	MOUNTING DETAILS	GAS MIXTURES EXAMINED
Free Stream			O_2/N_2 (Air)
RCC Puck	7.1 cm in diameter	In a 10.16 cm diameter graphite-silicon carbide holder which was in a 12.70 cm diameter copper holder	O_2/N_2 (Air) N_2 O_2/Argon Argon
HRSI Wedge	0.4m X 0.6m	-15^{o} angle with respect to the camber line	O_2/N_2 (Air) N_2 O_2/Argon
RCC Wedge	0.4m X 0.6m	-15^{o} angle with respect to the camber line	No tests as of 9/4/84

TABLE 2

CALIBRATION CONSTANTS FOR PLATE WAVELENGTH CALIBRATION EQUATIONS

Plate Equation:

$$Y = b_0 + b_1 x + b_2 x^2$$

where

Y = Wavelength in angstroms/100

$$x = \frac{\text{micron location} - 50000}{5000}$$

PLATE CENTERLINE WAVELENGTH, cm	CONSTANTS b_0	b_1 ($X10^{-}$[illegible])	b_2 ($X10^{-4}$)	PLATE USED	EXPOSURE #
260	2.589955	7.852731	-2.285499	32	1
380	3.790448	7.485376	-1.627544	42	6
500	5.001239	7.187476	-2.042028	43	1
620	6.179126	6.824881	-2.21267	15	6
740	7.392686	6.388521	-2.487615	31	1

TABLE 3

EXCITED SPECIES IDENTIFIED

EXCITED ATOMS	WAVELENGTH, nm	TRANSITION	CONDITIONS[1]	PLATE	EXP. SEQ. NO. ON PLATE
O Oxygen	394.7330		Ar/O_2 Sh	32	4
	394.751		Ar/O_2 Sh	32	4
	436.8300		Ar/O_2 Sh	30	3
	532.8561		Air Su	34	3
	645.607	$5S^5S^0 \text{-->} 3p^5P$	Ar/O_2 Sh	30	5
	700.2202	$3S^3D^0 \text{-->} 3p^5P$	Ar/O_2 Sh	31	4
	715.6380		Ar/O_2 Sh	31	4
	777.1928	$3p^5P \text{-->} 3S^5S^0$	Air Sh	16	4
	777.4139	$3p^5P \text{-->} 3S^5S^0$	Air Sh	16	4
	777.5433	$3p^5P \text{-->} 3S^5S^0$	Air Sh	16	4
N Nitrogen	491.4900		Air Su	34	3
	493.5030		Air Su	34	3
	517.008 (N II)		Air Su	34	3
	518.146 (N II)		Air Su	34	3
	528.1180		Air Su	34	3
	530.9480		Air Su	34	3
	535.6770		Air Su	34	3
	537.2660		Air Su	34	3
	566.6640 (N II)		Air Su	34	3
	567.9560 (N II)		Air Su	34	3
	742.3880		N_2 Sh	25	3

TABLE 3

EXCITED SPECIES IDENTIFIED (Continued)

EXCITED ATOMS	WAVELENGTH, nm	TRANSITION	CONDITIONS[1]	PLATE	EXP. SEQ. NO. ON PLATE
	744.2560		N_2 Sh	25	3
	746.8790		N_2 Sh	25	3
Cu Copper	324.7540	$4p\,^2P^0 \text{-->} 4s\,^2S$	Air Su	33	3
	327.3962	$4p\,^2P^0 \text{-->} 4s\,^2S$	Air Su	33	3
	510.5541	$4p\,^2P^0 \text{-->} 4s\,^2S$	Air Su	34	3
	515.3235	$4d\,^2D \text{-->} 4p\,^2P^0$	Air Su	34	3
	521.8202	$4d\,^2D \text{-->} 4p\,^2P^0$	Air Su	34	3
	529.2517		Air Su	34	3
	578.2130	$4p\,^2P^0 \text{-->} 4s\,^2D$	Air Su	34	5
Na Sodium	588.9953		Air Su	34	5
	589.5923		Air Su	34	5
H Hydrogen	656.2790	H	Ar Sh	43	3
	486.1327	H	Ar Sh	43	3
	434.0465	H	Ar Sh	43	3
	410.1735	H	Ar Sh	42	5
Ca Calcium	393.3666		Air Su	33	4
	396.8468		Air Su	33	4
Ba Barium	455.4042		Air Sh	15	3
	493.4086		Air Sh	15	3

TABLE 3

EXCITED SPECIES IDENTIFIED (Continued)

EXCITED ATOMS	WAVELENGTH, nm	TRANSITION	CONDITIONS[1]	PLATE	EXP. SEQ. NO. ON PLATE
Si Silicon	250.6899		Air Su	33	3
	251.6123		Air Su	33	3
	252.8516		Air Su	33	3
	288.1578		Air Su	33	3
K Potassium	766.4907		Air Su	35	2
	769.8978		Air Su	35	2
Calibration lamps (atomic lines identified on photographs) and argon)					
Hg	260 nm Centerline	Wavelength	Ar Sh	42	1
	380 " "	"	Air Sh	14	6
	500 " "	"	Ar/O_2 Sh	30	1
Ne	620 " "	"	Ar/O_2 Sh	30	6
	740 " "	"	Ar/O_2 Sh	31	2
A	380 " "	"	Ar Sh	42	5
	500 " "	"	Ar Sh	43	3
	620 " "	"	Ar Sh	43	5
	740 " "	"	Ar Sh	48	3

TABLE 3

EXCITED SPECIES IDENTIFIED (Continued)

EXCITED ATOMS	WAVELENGTH, nm OF STRONGEST BAND HEAD	TRANSITION	CONDITIONS[1]	PLATE	EXP. SEQ. NO. ON PLATE
N_2 1st Positive	645.58	$B^3 \dashrightarrow A^3$	Air Sh	15	3
	750.39		Air Sh	16	4
N_2 2nd Positive	315.93 V	$C^3 \dashrightarrow B^3$	Ar SH	42	5
	337.13				
N_2^+ 1st Negative	358.21 V	$B^2 \ ^+ \dashrightarrow X^2 \ g^+$	Air Sh	14	4
	391.44				
	427.81				
NO, System	247.11 V	$A^2 \ ^+ \dashrightarrow X^2$	Air F	45	3
	247.81				
	258.55 V				
	259.57				
OH 306.4 nm System	306.36 R	$A^2 \ ^+ \dashrightarrow X^2$	Ar Sh	42	3
	306.72				

[1]Air F — Air Free Stream
Air Sh — Air Shock Layer of RCC Puck
Air Su — Air Surface Layer of RCC Puck
Ar Sh — Argon Shock Layer of RCC Puck
Ar/O_2 — Argon/Oxygen Mixture
N_2 Sh — Nitrogen Shock Layer of RCC Puck

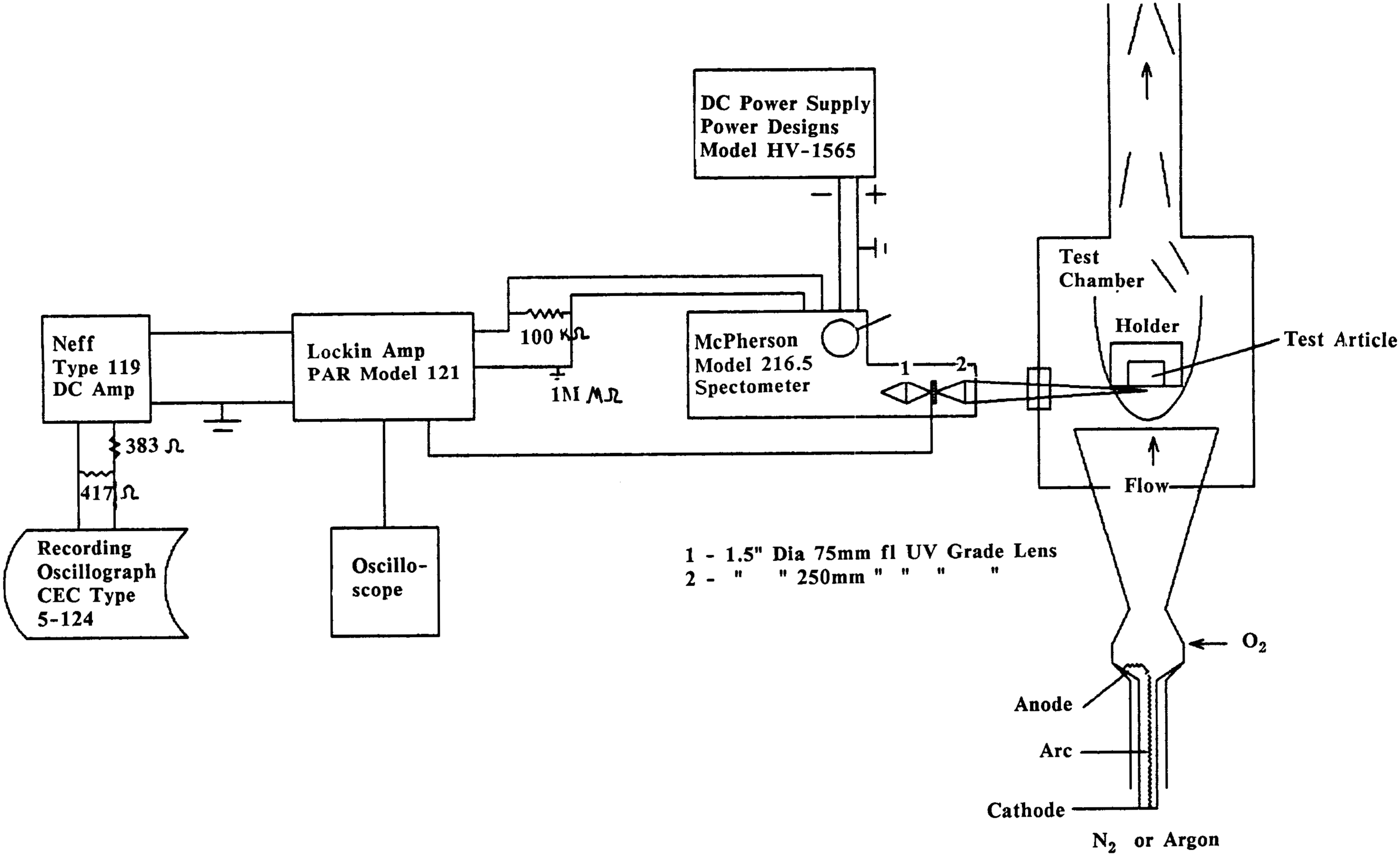


Figure 1. Arc Jet Flow Sheet and Spectrographic Equipment Diagram

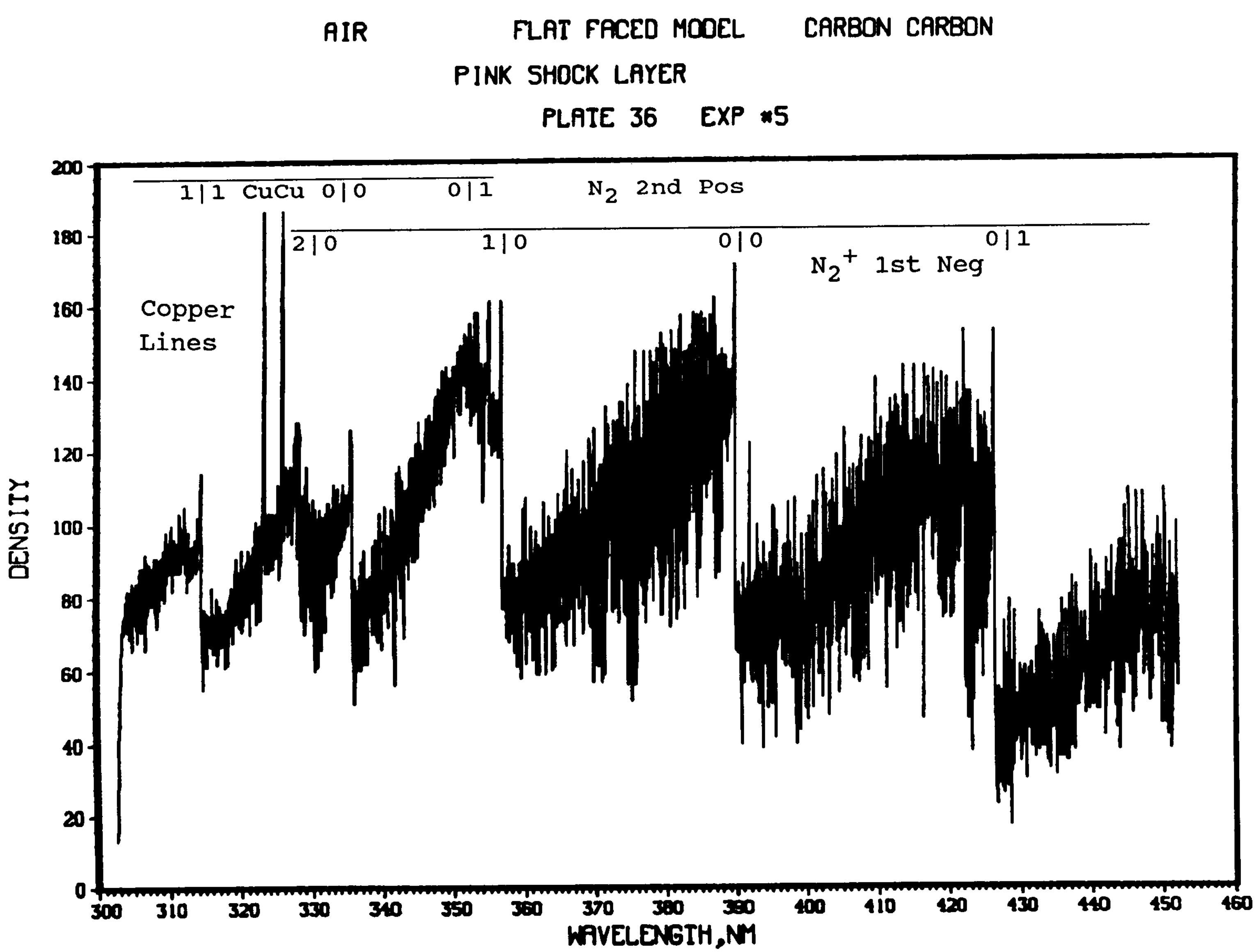


Figure 2. Spectrum of Shock Layer before RCC Puck at 380 nm Centering Wavelength - Air

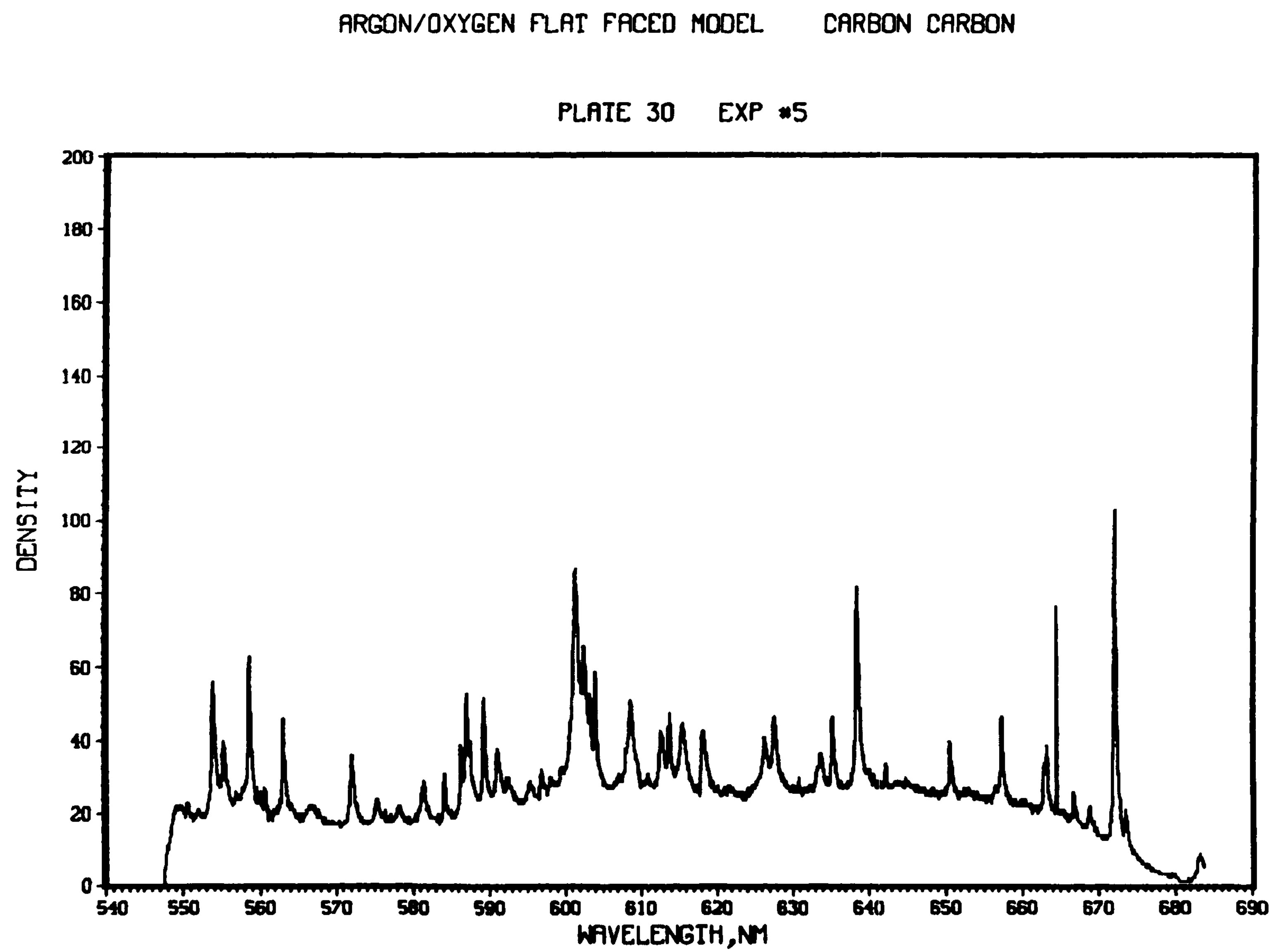


Figure 3. Spectrum of Shock Layer before RCC Puck at 620 nm Centering Wavelength - Oxygen in Argon

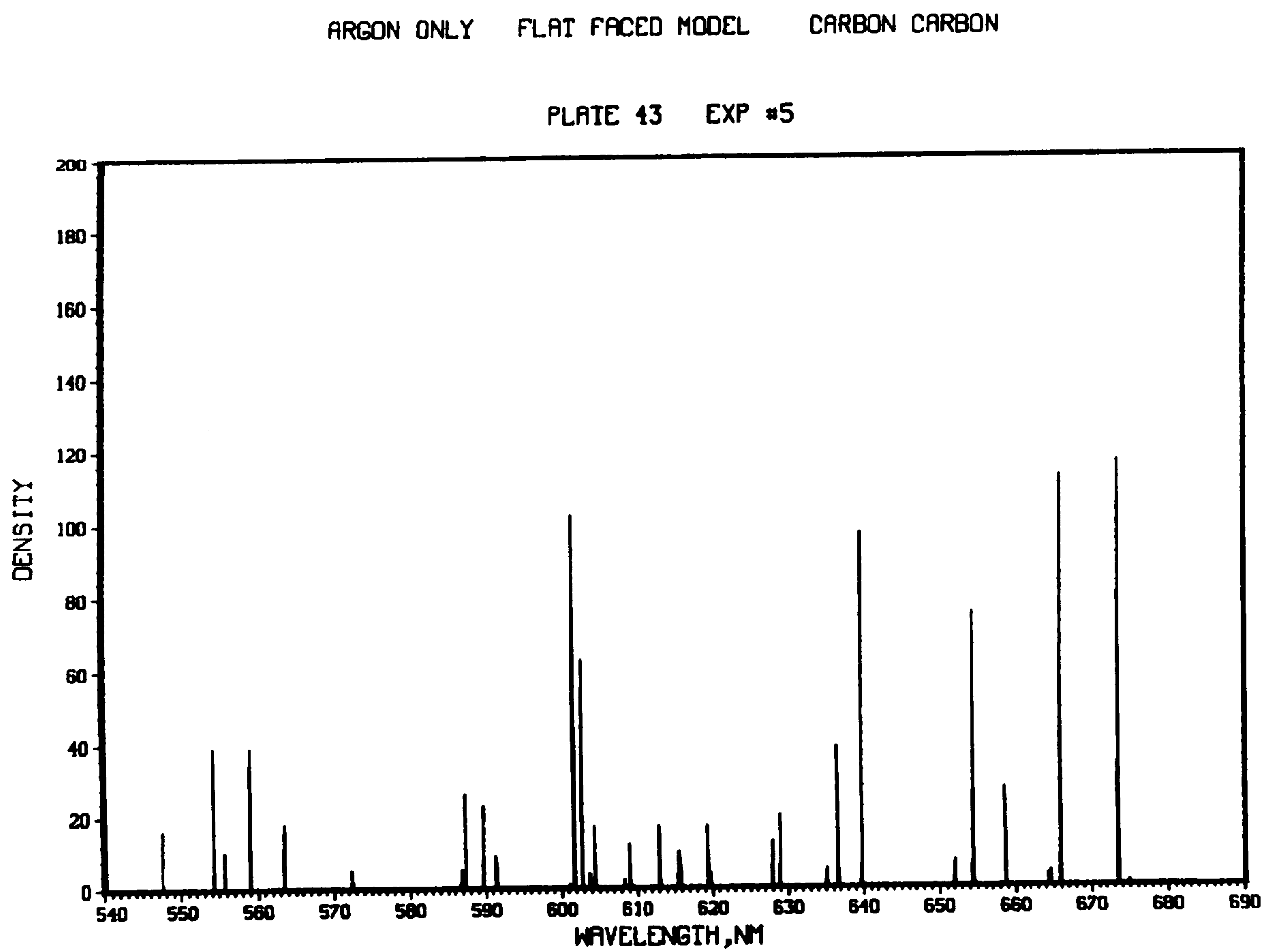


Figure 4. Spectrum of Shock Layer before RCC Puck at 620 nm Centering Wavelength - Argon Only

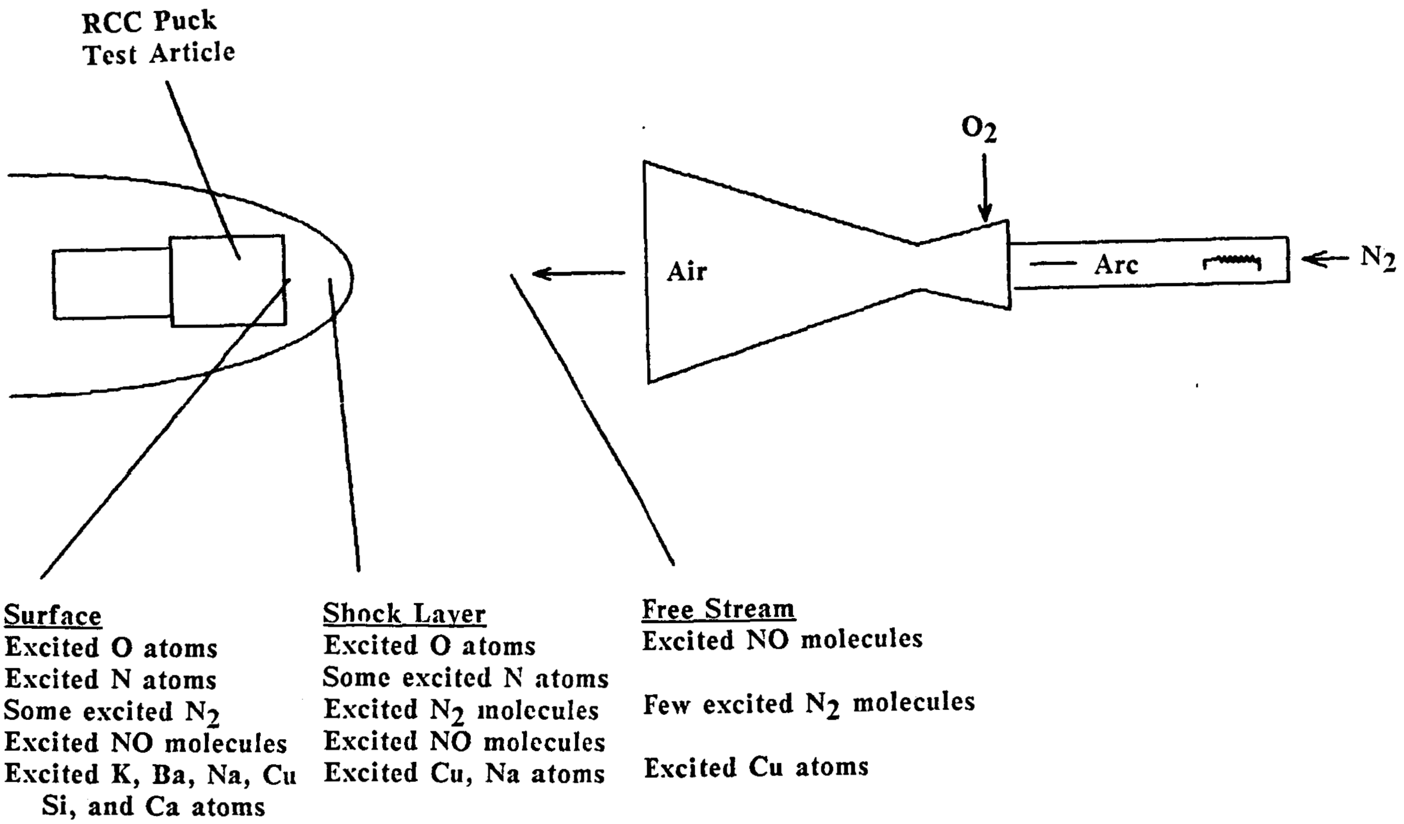


Figure 5. Excited Species Observed When the RCC Puck Test Article is in Air from the Arc Jet

APPENDIX A

MICRODENSITOMETER DETAILS

Location: USDA Forest Service
1050 Bay Area Blvd.
Houston, TX 77058

Start-Up

Follow lettered sequence of turning on equipment (Steps A-H).

Load tape in bottom tape drive.

Microprocessor Details

From a cold start load

Set half down

Enter 157744 (see p. 24 instruction manual)

Press Load Address

Enable halt up

Press Start

Type DIADS after 30 seconds

After DIADS is loaded

Type the following commands to scan a plate

Command	Description
1 TAPE-UNIT	Set lower tape drive to receive data
NEW-TAPE	Optional, use when starting with a fresh tape
PDS Parameters	Sets the PDS parameters
6000 UY	Sets Y step of 6000 microns
10 UX	Sets X step of 10 microns
6 5000 SIZE	Sets scan size of 6 lines by 5000 pixels
21 IO-UNIT	Sets automatic command mode
TAPE PDS P MOVE	Move PDS parameters to tape parameters
TAPE PARAMETERS SHOW	Shows tape parameters
Reset Set	Sets zero on densitometer at present table position
UL H Set	Sets upper left as home and horizontal scan mode
FLY-BACK	Scans in one direction only
SCAN	Begins automatic scan

Microdensitometer Adjustments

The microdensitometer has a dual optical system called upper and lower optics.

1. Mount plate(s)

2. With the photomultiplier tube off, select aperature size and pixel type for the upper and lower optical systems (both must match).

3. Focus the upper and lower optics.

4. Select a clear area and zero the density reading as shown in the instruction manual.

5. Check the density gain as shown in the instruction manual.

APPENDIX B

EXAMPLE OF LEAST SQUARES FIT OF PLATE CALIBRATION EQUATION TO KNOWN DATA SOURCE - PLATE 32, EXPOSURE 1 (Hg CENTERED AT 260 nm)

$$Y = b_0 + b_1 x + b_2 x^2$$

where Y = Wavelength/100

x = (microns-50000)/5000

DATA NUMBER	MICRONS MEASURED	ACTUAL WAVELENGTH, nm (Hg ATOMIC LINES)	PREDICTED WAVELENGTH, nm	RESIDUAL nm
1	53970	265.2042	265.2162	-0.0120
2	54060	265.3681	265.3569	0.0112
3	69550	289.3595	289.3503	0.0092
4	74380	296.7278	296.7421	-0.0143
5	77930	302.1499	302.1477	0.0022
6	78060	302.3476	302.3452	0.0023
7	84810	312.5663	312.5585	0.0078
8	85210	313.1546	313.1611	-0.0065

Constants found by least squares

b_0 = 2.589955

b_1 = 0.07852731

b_2 = -0.0002285499

APPENDIX C

PROGRAMS USED TO READ AND PROCESS MICRODENSITOMETER DATA

PROGRAM	DESCRIPTION	CONTROL PROGRAM WHICH MAPS IN PROGRAM AND REQUIRED SUBROUTINES
RW.START	Assign the necessry data files needed for plotting	
RW.READIN	Reads in information one word at a time from mass storage	RW.CONTROL12
RW.STORE	Stores information one word at a time into mass storage	RW.CONTROL13
RW.REDATA1	Reads data from 9-track tape. Stores it in mass storage.[1]	RW.CONTROL2
RW.LOCATELINE3	Finds maximum intensity versus micron (pixel) location	RW.CONTROL11
RW.FINDCONST	Finds plate offset for known wavelength and micron location	RW.CONTROL7
RW.BRINGIN	Sets up spectrum data for plots	RW.CONTROL10
RW.PLOTDAT	Plots density versus wavelength of a spectrum	RW.CONTROL5
RW.MASTER	Least squares fit of known wavelength versus micron location	RW.CONTROL
RW.END	Program which frees all assigned files after a run	

[1] Requires an address location in 1000K at the plate number address, i.e., Plate 14's 60,000 pieces of data were stored at a starting location of 3,000, thus mass storage location 14 had the number 3. New plates should start at mass storage location 1,131,000.

Example of how to create a plot of microdensitometer trace of plates using elements in file RW. under ES3-N03200

```
@ADD RW.START
     DATA IGNORED - IN CONTROL MODE
     I:002333 ASG complete.
     I:002333 USE complete.
     I:002333 ASG complete.
     I:002333 USE complete.
     I:002333 ASG complete.
     I:002333 USE complete.
>@ADD RW.CONTROL10
     DATA IGNORED - IN CONTROL MODE
     I:002333 FREE complete.
     I:002333 ASG complete.
     Collector 31R2B (841126 1925:45) 1987 Aug 11 Tue 1356:54
     END   MAP.     ERRORS:   0      TIME:   13.838     STORAGE:
     11308/6/021777/0107377
     I:002333 USE complete.
     WHAT PLATE NUMBER IS THIS ?
>36
     WHAT EXPOSURE DO YOU WISH TO LOOK AT ?
>5
     WHAT IS THE STARTING PIXEL YOU WISH TO LOOK AT?
>0
     WHAT IS THE ENDING PIXEL YOU WISH TO LOOK AT ?
>9999
     IS THE OFFSET TERM IN MASS STORAGE ?
>N
     IS THE OFFSET TERM KNOWN ?
>N
     IS PACKING REQUIRED?  MAX # OF POINTS PLOTTED =        2500
>Y
     WHAT IS THE PACKING  FACTOR ?   PCKNG  FCTR =  # PNTS
     DIVIDED BY 2500
>4
     DATA IS ON UNIT 7
     READY TO XQT PLOTDAT
     @@XQT RW.PLOTDAT
>@ADD RW.CONTROL5
     Collector 31R2B (841126 1925:45) 1987 Aug 11 Tue 1357:41
     END   MAP.     ERRORS:   0      TIME:  1:05.201    STORAGE:
     24940/30/034077/0127777
     WHAT WAVE LENGTH RANGE IS THIS ?
     TYPE 1 FOR 260 NM
     TYPE 2 FOR 380 NM
     TYPE 3 FOR 500 NM
     TYPE 4 FOR 620 NM
     TYPE 5 FOR 740 NM
>2
```

continued on the next page

Continued from the previous page....

```
     WHAT IS THE OFFSET TERM ?
     WHAT IS THE PIXEL STARTING POINT OF THE DATA ?
     NUMBER OF PIXELS YOU WISH TO PLOT ?
     WHAT IS THE PIXEL WIDTH ?
     PIXEL STARTING POINT   302.56349
     ENDING POINT   452.21375
     WHAT IS THE X ORIGIN AND X ENDING POINT ?
>300
>460
```

****

RW.START

****

```
ES3-N03200*RW(1).START(11)
.
.
. RW.START
.
.  THIS IS A CONTROL PROGRAM TO ASSIGN DATA FILES
.   FOR USE IN ANY PROGRAMS RELATED TO READING
.  MICRODENSITOMETER DATA FROM MASS STORAGE
.
.
.  TO EXECUTE TYPE @ADD RW.START
.
@ASG,A DATA1.
@USE 2.,DATA1.
@ASG,T DATAIN.
@USE 4.,DATAIN.
@ASG,T DATAOUT.
@USE 3.,DATAOUT.
```

```
*******************************

RW.CONTROL12

*******************************

ES3-N03200*RW(1).CONTROL12(2)
.
.
.   RW.CONTROL12
.
.
@PACK,P RW.
@MAP,N RW.READIN
IN RW.READIN
LIB JSC*FTN.
END
@XQT RW.READIN
*******************************

RW.READIN

*******************************

ES3-N03200*RW(1).READIN(11)
      DIMENSION A(100)
      REAL X(100)
C
C
C   RW.READIN
C
C
C  THIS PROGRAM WILL READ IN DATA LOCATED IN MASS STORAGE 1 WORD ATA TIME
C  THIS PROGRAM IS USEFUL FOR CHECKING STORAGE OF A NUMBER IN MASS STORAGE
C
C
      CHARACTER WORD(48)*1,QU*1
      INTEGER NA(100)
      CALL NTRAN$(2,10,22)
      WRITE(6,*)'AT WHAT POINT DO YOU WISH TO READ FROM ?'
      READ(5,6)NB
    6 FORMAT()
      CALL NTRAN$(2,6,NB)
      WRITE(6,*)'HOW MANY WORDS DO YOU WISH TO CHECK ?'
      READ(5,6)NW
      NW1=4*NW
      WRITE(6,*)'IS THIS AN INTEGER,CHARACTER,REAL,OR OCTAL ?'
      READ(5,7)QU
    7 FORMAT(A1)
      IF(QU.EQ.'I')CALL NTRAN$(2,2,NW,NA(1),JSTAT,22)
      IF(QU.EQ.'C')CALL NTRAN$(2,2,NW,WORD(1),JSTAT,22)
      IF(QU.EQ.'R')CALL NTRAN$(2,2,NW,X(1),JSTAT,22)
      IF(QU.EQ.'O')CALL NTRAN$(2,2,NW,A(1),JSTAT,22)
      IF(QU.EQ.'I')WRITE(6,8)(NA(I),I=1,NW)
    8 FORMAT(1X,I8)
      IF(QU.EQ.'C')WRITE(6,9)(WORD(I),I=1,NW1)
    9 FORMAT(1X,48A1)
      IF(QU.EQ.'R')WRITE(6,10)(X(I),I=1,NW)
   10 FORMAT(1X,E14.7)
      IF(QU.EQ.'O')WRITE(6,11)(A(I),I=1,NW)
   11 FORMAT(1X,O12)
      WRITE(6,*)'PRINT PROGRAM IS FINISHED'
      STOP
      END
```

****

RW.CONTROL13

****

ES3-N03200*RW(1).CONTROL13(5)

```
@PACK,P RW.
.
.
.  RW.CONTROL13
.
. THIS IS A CONTROL PROGRAM WHICH MAPS IN REQUIRED
. INFORMATION TO RUN RW.STORE.
.
.
@MAP,N RW.STORE
IN RW.STORE
LIB JSC*FTN.
END
@XQT RW.STORE
```

****

RW.STORE

****

ES3-N03200*RW(1).STORE(10)

```
      INTEGER NC
C
C
C   RW.STORE
C
C
C   THIS PROGRAM IS USEFUL FOR PLACEMENT OF PLATE
C   CALIBRATION CONSTANTS, PLATE LOCATION, AND PLATE
C  OFFSETS INTO MASS STOREGE
C
C  AN EXAMPLE IS TO STORE THE NUMBER 3 AT MASS STOREGE
C  LOCATION NUMBER 14.  THIS NUMBER REPRESENTS THE LOCATION
C  IN MASS STORAGE TIMES 1000 WHERE THE 60000 PIECES OF INFORMATION
C  FOR PLATE 14 IS LOCATED.
C
CC
      WRITE(6,*)'HOW MANY NUMBERS ARE YOU STORING ? '
      READ(5,21)IA
      DO 30 I=1,IA
      WRITE(6,*)'WHAT LOCATION DO YOU WISH TO STORE AT ?'
      READ(5,21)NB
      WRITE(6,*)'WHAT NUMBER DO YOU WISH TO STORE ? '
      READ(5,21)NC
       CALL NTRAN$(2,10,22)
      CALL NTRAN$(2,6,NB)
      CALL NTRAN$(2,1,1,NC,JSTAT,22)
      CALL NTRAN$(2,10,22)
   30 CONTINUE
   21 FORMAT()
      WRITE(6,*)'PROGRAM IS FINISHED'
      STOP
      END
```

****

RW.CONTROL2

****

```
ES3-N03200*RW(1).CONTROL2(47)
.
.
. RW.CONTROL2
.
.
. THIS PROGRAM IS USED TO MAP IN AND RUN
. RW.REDATA1
.
.
@MAP,N ,RW.REDATA1
IN RW.REDATA1
LIB JSC*FTN.
END
@USE 1.,TAPE1.
@USE 2.,DATA1.
@XQT RW.REDATA1
```

****

RW.REDATA1

****

```
ES3-N03200*RW(1).REDATA1(5)
      CHARACTER*1 CHRBUF(66),CHRID(64),QU(1),CHRID2(64)
C
C
C     RW.REDATA1
C
C
C      THIS PROGRAM READS A 9 TRACK TAPE WITH MICRO-
C      DENSITOMETER DATA STORES IT INTO MASS SOTRAGE
C
C
C
C  SCNNUM = SCAN NUMBER
C  CHRID  = 64 CHARACTER IDENTIFIER
C  SCNVEL = SCAN VELOCITY
C  XORG   = X-ORIGIN
C  YORG   = Y-ORIGIN
C  SSPACX = SCAN SPACING X (MICRONS)
C  SSPACY = SCAN SPACING Y (MICRONS)
C  NUMPXL = NUMBER OF PIXELS IN A LINE
C
      INTEGER IBUF1(32),IBUF2(1250,7),BINVAL(5000,7)
      EQUIVALENCE (CHRBUF(1),IBUF1(1))
      INTEGER SCNVEL,XORG,YORG,SSPACX,SSPACY,NUMPXL,NUMLIN
      INTEGER IOUNIT,XOFSET,YOFSET,NRATIO,DRATIO,BITPIX,APSIZE
C
C TRY TO OPEN A DEFINED FILE
C
      DO 50 NC1=2,46
C
C
C SET UP THE HEADER INTO LOGICAL FORM
C
C
C READ IN THE DATA
C
      WRITE(6,27)
   27 FORMAT(1X,'CHECK POINT ZERO HEADING INTO CALL NTRAN')
      CALL NTRAN$(1,2,32,IBUF1,JSTAT,22)
      WRITE(6,24)JSTAT
   24 FORMAT(1X,'CHECK POINT ONE ',I6)
   12 FORMAT(I32)
C
C CONVERSIONS
```

```
C
      SCNNUM=BITS(IBUF1(1),1,16)
      SCNVEL=SBITS(IBUF1(17),16,16)
      XORG=IBUF1(18)
      YORG=IBUF1(19)
      SSPACX=SBITS(IBUF1(20),1,16)
      SSPACY=SBITS(IBUF1(20),16,16)
      NUMPXL=BITS(IBUF1(21),1,16)
      NUMLIN=BITS(IBUF1(21),16,16)
      APSIZE=BITS(IBUF1(22),1,16)
      IOUNIT=BITS(IBUF1(22),1,16)
      BITPIX=BITS(IBUF1(29),16,16)
      DO 20 , I=1,64
       CHRID(I)=CHRBUF(I+2)
   20 CONTINUE
C
C RE-ARRANGE LETTERS
C
      DO 60 I=2,64,2
       K=I-1
      CHRID2(K)=CHRID(I)
      CHRID2(I)=CHRID(K)
   60 CONTINUE
      WRITE(6,14)(CHRID2(I),I=1,64)
      WRITE(6,*)'IS THIS THE CORRECT PLATE ? ANSWER YES BY TYPING 0'
      READ(5,21)IQU
      IF(IQU.NE.0)GO TO 50
C
C READ IN DATA FOR LA NUMBER OF SCANS
C
       WRITE(6,16)
   16  FORMAT(1X,'HOW MANY LINES ARE ON THIS PLATE?')
      READ(5,21)LA
      DO 15 L=1,LA
       CALL NTRAN$(1,2,1250,IBUF2(1,L),JSTAT,22)
   15 CONTINUE
   13 FORMAT(I32)
C
C
C
      XOFSET=((BITS(IBUF1(23),16,16)*256)+(BITS(IBUF1(24),1,16)))
      YOFSET=((BITS(IBUF1(24),16,16)*256)+(BITS(IBUF1(25),1,16)))
      NRATIO=((BITS(IBUF1(25),16,16)*256)+(BITS(IBUF1(26),1,16)))
      DRATIO=((BITS(IBUF1(26),16,16)*256)+(BITS(IBUF1(27),1,16)))
C
C TRANSLATE RAW DATA
C
      DO 30 L=1,LA
      DO 11,I=1,1250
      IA=((L-1)*1250+I)
       DO 10 J=1,4
      K=(I-1)*4+J
        BINVAL(K,L)=BITS(IBUF2(I,L),((J-1)*9+1),9)
   10 CONTINUE
   11 CONTINUE
   30 CONTINUE
C
C PRINT OUT DATA TO A DATA FILE
C
C
C  WRITE HEADER
C  TO FIRST DATA FILE
C
      WRITE(6,17)
   17 FORMAT(1X,'IS THIS AN A, B, C, OR D QUADRANT')
      READ(5,18)QU
   18 FORMAT(A1)
      WRITE(6,19)
   19 FORMAT(1X,'NUMBER OF LINES IN THIS QUADRANT')
      READ(5,21)LB
   21 FORMAT()
C
```

```
      WRITE(2,14)(CHRID2(I),I=1,64)
   14 FORMAT(1X,64A1)
      WRITE(2,22)QU
   22 FORMAT(1X,'QUADRANT ',A1)
      DO 25 L=1,LB
      DO 35 I=1,5000
      WRITE(2,23)I,BINVAL(I,L)
   23 FORMAT(1X,I6,2X,I6)
   35 CONTINUE
   25 CONTINUE
      ENDFILE 2
C
C
C WRITE DATA OUT
C TO SECOND DATA FILE
C
      WRITE(6,17)
      READ(5,18)QU
      WRITE(6,19)
      READ(5,21)LC
      WRITE(2,14)(CHRID2(I),I=1,64)
      WRITE(2,22)QU
      LD=LC+LB
      DO 45 L=(LB+1),LD
       DO 40 I=1,5000
      WRITE(2,23)I,BINVAL(I,L)
   40 CONTINUE
   45 CONTINUE
@MOVE TAPE1.,1
      ENDFILE 2
   50 CONTINUE
      STOP
      END
```

```
*******************************

           RW.CONTROL11

*******************************
ES3-N03200*RW(1).CONTROL11(4)
 .  R
 .
 .
 .  RW.CONTROL11
 .
 .
 .  THIS PROGRAMS MAPS AND CONTROLS RW.LOCATELINE3
 .
 .
@MAP,N ,RW.LOCATELINE3
IN RW.LOCATELINE3
LIB JSC*FTN.
END
@USE 2.,DATA1.
@XQT RW.LOCATELINE3

*******************************

          RW.LOCATELINE3

*******************************
ES3-N03200*RW(1).LOCATELINE3(11)
      INTEGER INTENS(10000),INTEN2(10000)
      CHARACTER QR(3),QS(3),Y(1)
C
C
C  RW. LOCATELINE3
C
C
C   THIS PROGRAM WILL LOCATE MAXIMUM
C   INTENSITY VERSUS MICRON PIXEL LOCATION
C
C  AN EXAMPLE WOULD BE TO @ADD RW.CONTROL11
C  ANSWER THE QUESTIONS AS THEY APPEAR
C
C  OUTPUT IS ON FILE 3.
C
       NEXP=6
      CALL NTRAN$(2,10,22)
      WRITE(6,*)'WHAT PLATE NUMBER IS THIS ? '
         Y(1)='Y'
      READ(5,21)LOC
       IF(LOC.EQ.16.OR.LOC.EQ.25.OR.LOC.EQ.31.OR.LOC.EQ.34.OR.LOC.
     1 EQ.35.OR.LOC.EQ.38)NEXP=4
       IF (LOC.EQ.44)NEXP=3
   21  FORMAT()
      CALL NTRAN$(2,6,LOC)
      CALL NTRAN$(2,2,1,NB,JSTAT,22)
      CALL NTRAN$(2,10,22)
      NB=NB*1000
      WRITE(6,*)'WHAT EXPOSURE DO YOU WISH TO LOOK AT ?'
      READ(5,21)NELOC
      LINE=NEXP-NELOC
      NB=NB+LINE*10000
      WRITE(6,*)'WHAT IS THE STARTING PIXEL YOU WISH TO LOOK AT? '
      READ(5,21)LPIX1
      NB=NB+LPIX1
      WRITE(6,*)'WHAT IS THE ENDING PIXEL YOU WISH TO LOOK AT ?'
      READ(5,21)LPIX2
      NPIX=LPIX2-LPIX1+1
      CALL NTRAN$(2,6,NB)
      CALL NTRAN$(2,2,NPIX,INTENS(LPIX1),JSTAT,22)
      CALL NTRAN$(2,10,22)
      WRITE(6,*)'IS THE OFFSET TERM IN MASS STORAGE ?'
      READ(5,12)QS(1)
      IF(QS(1).NE.Y(1))GO TO 30
```

```
      NB=LOC*12+LINE
      CALL NTRAN$(2,6,NB)
      CALL NTRAN$(2,2,1,NAO,JSTAT,22)
      CALL NTRAN$(2,10,22)
      AO1=NAO
      NB=LOC*12+LINE+6
      CALL NTRAN$(2,6,NB)
      CALL NTRAN$(2,2,1,NAO,JSTAT,22)
      AO2=NAO
      GO TO 40
   30 CONTINUE
      WRITE(6,*)'IS THE OFFSET TERM KNOWN ?'
      READ(5,12)QS(1)
      IF(QS(1).NE.Y(1))GO TO 35
      WRITE(6,*)'WHAT IS THE SIDE A OFFSET TERM ?'
      READ(5,21)NAO
      AO1=NAO
      AO2=0.0
      NB=LOC*12+LINE
      CALL NTRAN$(2,6,NB)
      CALL NTRAN$(2,1,1,NAO,JSTAT,22)
      CALL NTRAN$(2,10,22)
   11 FORMAT(1X,I6,2X,I6)
   33 CONTINUE
      WRITE(6,*)'WHAT IS THE SIDE B OFFSET TERM ?'
      READ(5,21)NAO
      AO2=NAO
      NB=LOC*12+LINE+6
      CALL NTRAN$(2,6,NB)
      CALL NTRAN$(2,1,1,NAO,JSTAT,22)
      CALL NTRAN$(2,10,22)
      GO TO 40
   35 AO1=0.0
      AO2=0.0
   40 WRITE(6,*)' IS PACKING REQUIRED ? '
      READ(5,12)QR(1)
      IF(QR(1).NE.Y(1))GO TO 60
      WRITE(6,*)'WHAT IS THE PACKING FACTOR ?'
      READ(5,21)NPACK
      KA=LPIX1/NPACK+1
      KK=NPIX/NPACK+KA
      DO 55 K=KA,KK
      DO 53 I=1,NPACK
      L=(K*NPACK-NPACK)+I
      INTEN2(K)=INTENS(L)+INTEN2(K)
   53 CONTINUE
      INTEN2(K)=INTEN2(K)/NPACK
   55 CONTINUE
      NPIX=NPIX/NPACK
      CALL LOCATE(INTEN2,AO1,AO2,LOC,NELOC,LPIX1,
     1LPIX2,NPACK)
      GO TO 70
   60 NPACK=1
      CALL LOCATE(INTENS,AO1,AO2,LOC,NELOC,LPIX1,
     1LPIX2,NPACK)
   12 FORMAT(A1)
   70 CONTINUE
      STOP
      END
      SUBROUTINE LOCATE(INTENS,AO1,AO2,IP,IR,IP1,IP3,IP4)
       INTEGER INTENS(10000),N,I,IA
       REAL INCHES
      REAL A(5),B1(5),B2(5)
      CALL NTRAN$(2,10,22)
      NB=100
      CALL NTRAN$(2,6,NB)
      CALL NTRAN$(2,2,5,A(1),JSTAT,22)
      CALL NTRAN$(2,2,5,B1(1),JSTAT,22)
      CALL NTRAN$(2,2,5,B2(1),JSTAT,22)
      IP4=IP4*10
      WRITE(6,*)'WHAT WAVE LENGTH RANGE IS THIS ?'
      WRITE(6,*)'TYPE 1 FOR 260 NM '
```

```
      WRITE(6,*)'TYPE 2 FOR 380 NM  '
      WRITE(6,*)'TYPE 3 FOR 500 NM '
      WRITE(6,*)'TYPE 4 FOR 620 NM '
      WRITE(6,*)'TYPE 5 FOR 740 NM '
      READ(5,6)IAV
      WRITE(3,9)IP,IR
    9 FORMAT(1X,'PLATE',2X,I3,1X,'EXPOSURE #',1X,I2,1X,'SIDE',1X,A1)
      WRITE(6,*)'WHAT IS THE MINIMUM INTENSITY YOU WISH TO PRINT OUT ?'
      READ(5,6)ID1
    6 FORMAT()
      AO=AO1
      DO 20 I=IP1,IP3,1
      IF(I.EQ.5001)GO TO 60
   28 IF(INTENS(I).LE.ID1)GO TO 20
      IF(INTENS(I).GE.INTENS(I-1))GO TO 30
      GO TO 20
   30 IF(INTENS(I).GE.INTENS(I+1))GO TO 35
      GO TO 25
   35 IF(INTENS(I).GT.INTENS(I+1))GO TO 37
      NCOUNT=NCOUNT+1
      GO TO 20
   37 IF(INTENS(I).GT.INTENS(I-1))GO TO 40
      K=I-(NCOUNT)/2
      INCHES=K/2540.
      N=N+1
      IA=K*IP4
      XA=(IA+AO-50000.)/5000.
      WAVE=A(IAV)+B1(IAV)*XA+B2(IAV)*XA*XA
      WAVE=WAVE*100.
      BI=IA/10000.
      WRITE(3,12)IA,BI,INCHES,INTENS(K),WAVE
      GO TO 25
   40 INCHES=I/2540.
      N=N+1
      IA=I*IP4
      XA=(IA+AO-50000.)/5000.
      WAVE=A(IAV)+B1(IAV)*XA+B2(IAV)*XA*XA
      WAVE=WAVE*100.
      BI=IA/10000.
      WRITE(3,12)IA,BI,INCHES,INTENS(I),WAVE
   12 FORMAT(1X,'THERE IS A LINE AT',1X,I6,1X,'MICRONS',1X
     1 ,F4.2,1X,'CM',1X
     1 ,F6.4,1X,'INCHES',2X,'OF INTENSITY OF',1X,I6
     1 ,1X,'WAVELENGTH',1X,F9.4,1X,'NM')
   25 NCOUNT=0
   20 CONTINUE
   50 CONTINUE
      WRITE(6,13)N
   13 FORMAT(1X,'THE NUMBER OF LINES = ',I3)
      WRITE(6,*)'END OF PROGRAM DATA IS ON FILE 3.'
      GO TO 70
   60 AO=AO2
      GO TO 28
   70 CONTINUE
      RETURN
      END
```

```
********************************

          RW.CONTROL7

********************************

ES3-N03200*RW(1).CONTROL7(3)
      .
      .
      .
      . RW.CONTROL7
      .
      .
      .  CONTROL PROGRAM TO MAP AND RUN RW.FINDCONST
      .
      .
     @MAP,N ,RW.FINDCONST
     IN RW.FINDCONST
     LIB JSC*FTN.
     END
     @XQT RW.FINDCONST
********************************

          RW.FINDCONST

********************************

ES3-N03200*RW(1).FINDCONST(14)
        REAL A(5),B1(5),B2(5)
      C
      C
      C  RW.FINDCONST
      C
      C
      C  THIS SIMPLE PROGRAM ASSISTS IN FINDING
      C  PLATE OFFSETS.  AN EXAMPLE WOULD BE TO
      C  EXAMINE PLATE 23 EXPOSURE 6 (TOP LINE)
      C  USING LOCATELINE3 AND COMPARE WITH KNOWN
      C  WAVELENGTHS SHOWN ON PLATE 14 EXPOSURE
      C  6 (HG CALIBRATION) .  THE OFFSET IS
      C  RETURN AN CAN BE STORED INTO MASS
      C  STORAGE BY RW.LOCATELINE3 OR RW.BRINGIN
      C
      C
        CALL NTRAN$(2,10,22)
        NB=100
        CALL NTRAN$(2,6,NB)
        CALL NTRAN$(2,2,5,A(1),JSTAT,22)
        CALL NTRAN$(2,2,5,B1(1),JSTAT,22)
        CALL NTRAN$(2,2,5,B2(1),JSTAT,22)
        WRITE(6,*)'HOW MANY LOCATIONS ARE YOU GOING TO CHECK ?'
        READ(5,6)NUM
        WRITE(6,*)'WHAT WAVE LENGTH RANGE IS THIS ?'
        WRITE(6,*)'TYPE 1 FOR 260 NM '
        WRITE(6,*)'TYPE 2 FOR 380 NM '
        WRITE(6,*)'TYPE 3 FOR 500 NM '
        WRITE(6,*)'TYPE 4 FOR 620 NM '
        WRITE(6,*)'TYPE 5 FOR 740 NM '
        READ(5,6)I
        DO 10 N=1,NUM,1
        WRITE(6,*)'WHAT IS THE KNOWN WAVELENGTH ?'
      6 FORMAT()
        READ(5,6)Y
          Y=Y/100.
          X=(-B1(I)+SQRT(B1(I)**2-4*B2(I)*(A(I)-Y)))/(2*B2(I))
          X=X*5000.+50000.
        WRITE(6,*)' KNOWN X PLATE IS ',X
        WRITE(6,*)' WHAT IS THE MICRON LOCATION ON THE PLATE ?'
        READ(5,6)Y1
        UY=X-Y1
        WRITE(6,*)'OFFSET TERM ',UY
     10 CONTINUE
```

```
      WRITE(6,*)'END OF PROGRAM'
      STOP
      END
```

****

RW.CONTROL10

****

```
ES3-N03200*RW(1).CONTROL10(11)
 .
 .
 . RW.CONTROL10
 .
 .
 . CONTROL PROGRAM TO RUN
 . RW.BRINGIN A PROGRAM TO SET
 . UP THE PLOT HEADER
 .
@FREE TPF$.
@ASG,T TPF$.,F///300
@MAP,N ,RW.BRINGIN
IN RW.BRINGIN
LIB JSC*FTN.
END
@USE 2.,DATA1.
@XQT RW.BRINGIN
```

****

RW.BRINGIN

****

```
ES3-N03200*RW(1).BRINGIN(34)
      INTEGER INTENS(10000),INTEN2(10000)
      CHARACTER QR(3),QS(3),Y(1)
      CHARACTER PLATE(1)*6,LINE1(6)*1,DOLL(1)*1,TOPLIN(1)*48
      CHARACTER SELINE(1)*36,WORD4(1)*4,LINE2(1)*7
      DATA PLATE/'PLATE '/,LINE2/' EXP # '/,DOLL/'$'/
      DATA LINE1/'1','2','3','4','5','6'/
C
C
C    RW.BRINGIN
C
C
C   THIS PROGRAM SETS UP HEADERS AND
C DETAILS REQUIRED TO RUN RW.PLOTDAT
C
C AN EXAMPLE WOULD BE TO PLOT
C PLATE 43 EXPOSURE 5
C
C
C
      WRITE(6,*)'WHAT PLATE NUMBER IS THIS ? '
        Y(1)='Y'
      READ(5,21)LOC
      CALL NTRAN$(2,10,22)
      NB=601
      INDEX=(LOC-14)*22
      NB=NB+INDEX
      CALL NTRAN$(2,6,NB)
      CALL NTRAN$(2,2,12,TOPLIN(1),JSTAT,22)
      WRITE(7,14)TOPLIN(1)
   14 FORMAT(A48)
   16 FORMAT(A36)
   17 FORMAT(A6,A4,A6,A1,A1)
      CALL NTRAN$(2,2,9,SELINE(1),JSTAT,22)
      WRITE(7,16)SELINE(1)
      CALL NTRAN$(2,2,1,WORD4(1),JSTAT,22)
      CALL NTRAN$(2,10,22)
   21 FORMAT()
      CALL NTRAN$(2,6,LOC)
      CALL NTRAN$(2,2,1,NB,JSTAT,22)
      CALL NTRAN$(2,10,22)
      NB=NB*1000
```

```
      WRITE(6,*)'WHAT EXPOSURE DO YOU WISH TO LOOK AT ?'
      READ(5,21)NELOC
       NEXP=6
       IF(LOC.EQ.16.OR.LOC.EQ.25.OR.LOC.EQ.31.OR.LOC.EQ.34
     1 .OR. LOC.EQ.35.OR.LOC.EQ.38)NEXP=4
      IF(LOC.EQ.44)NEXP=3
       LINE=NEXP-NELOC
      WRITE(7,17)PLATE(1),WORD4(1),LINE2(1),LINE1(NELOC),DOLL(1)
      NB=NB+LINE*10000
      WRITE(6,*)'WHAT IS THE STARTING PIXEL YOU WISH TO LOOK AT? '
      READ(5,21)LPIX1
      NB=NB+LPIX1
      WRITE(6,*)'WHAT IS THE ENDING PIXEL YOU WISH TO LOOK AT ?'
      READ(5,21)LPIX2
      NPIX=LPIX2-LPIX1+1
      CALL NTRAN$(2,6,NB)
      CALL NTRAN$(2,2,NPIX,INTENS(LPIX1),JSTAT,22)
      CALL NTRAN$(2,10,22)
      WRITE(6,*)'IS THE OFFSET TERM IN MASS STORAGE ?'
      READ(5,12)QS(1)
      IF(QS(1).NE.Y(1))GO TO 30
      NB=LOC*12+LINE
      CALL NTRAN$(2,6,NB)
      CALL NTRAN$(2,2,1,NAO,JSTAT,22)
      CALL NTRAN$(2,10,22)
      AO1=NAO
      NB=LOC*12+LINE+6
      CALL NTRAN$(2,6,NB)
      CALL NTRAN$(2,2,1,NAO,JSTAT,22)
      AO2=NAO
      GO TO 40
   30 CONTINUE
      WRITE(6,*)'IS THE OFFSET TERM KNOWN ?'
      READ(5,12)QS(1)
      IF(QS(1).NE.Y(1))GO TO 35
      WRITE(6,*)'WHAT IS THE SIDE A OFFSET TERM ?'
      READ(5,21)NAO
      AO1=NAO
      AO2=0.0
      NB=LOC*12+LINE
      CALL NTRAN$(2,6,NB)
      CALL NTRAN$(2,1,1,NAO,JSTAT,22)
      CALL NTRAN$(2,10,22)
   11 FORMAT(1X,I6,2X,I6)
   33 CONTINUE
      WRITE(6,*)'WHAT IS THE SIDE B OFFSET TERM ?'
      READ(5,21)NAO
      AO2=NAO
      NB=LOC*12+LINE+6
      CALL NTRAN$(2,6,NB)
      CALL NTRAN$(2,1,1,NAO,JSTAT,22)
      CALL NTRAN$(2,10,22)
      GO TO 40
   35 AO1=0.0
      AO2=0.0
   40 WRITE(6,*)' IS PACKING REQUIRED?  MAX # OF POINTS PLOTTED =
     1 2500'
      READ(5,12)QR(1)
      IF(QR(1).NE.Y(1))GO TO 60
      WRITE(6,*)'WHAT IS THE PACKING FACTOR ?  PCKNG FCTR = # PNTS
     1 DIVIDED BY 2500'
      READ(5,21)NPACK
      KA=LPIX1/NPACK+1
      KK=NPIX/NPACK+KA
      DO 55 K=KA,KK
      DO 53 I=1,NPACK
      L=(K*NPACK-NPACK)+I
      INTEN2(K)=INTENS(L)+INTEN2(K)
   53 CONTINUE
      INTEN2(K)=INTEN2(K)/NPACK
   55 CONTINUE
      NPIX=NPIX/NPACK
```

```
      WRITE(7,21)AO1,AO2
      WRITE(7,21)LPIX1
      WRITE(7,21)NPIX
      WRITE(7,21)NPACK
      WRITE(7,11)(I,INTEN2(I),I=KA,KK)
      GO TO 70
   60 CONTINUE
      WRITE(7,21)AO1,AO2
      WRITE(7,21)LPIX1
      WRITE(7,21)NPIX
      NPACK=1
      WRITE(7,21)NPACK
      WRITE(7,11)(I,INTENS(I),I=LPIX1,LPIX2)
   70 CONTINUE
         WRITE(6,*)'DATA IS ON UNIT 7'
         WRITE(6,*)'READY TO XQT PLOTDAT'
         WRITE(6,*)'@@XQT RW.PLOTDAT'
   12 FORMAT(A1)
      STOP
      END
```

****

RW.CONTROL5

****

ES3-N03200*RW(1).CONTROL5(21)

```
@MAP,N ,RW.PLOTDAT
IN RW.PLOTDAT
LIB DISSPLA*AGEM.
LIB JSC*FTN.
END
@XQT RW.PLOTDAT
```

****

RW.PLOTDAT

****

ES3-N03200*RW(1).PLOTDAT(52)

```
      COMPILER (PROGRAM=BIG),(BANKED=ALL)
      INTEGER INTENS(5000)
C
C
C  RW.PLOTDATA
C
C
C   WITH RW.BRINGIN, THIS PROGRAM WILL PLOT MICRODENSITOMETER
C   DATA ON A TEKTRONIX 4014-1 TERMINAL
C
C
      CHARACTER WORD1*47,WORD2*31,WORD3*17,QU*1
      REAL XARAY(2500),YARAY(2500)
      REAL A(5),B1(5),B2(5)
      CALL REDC(A,B1,B2)
      WRITE(6,*)'WHAT WAVE LENGTH RANGE IS THIS ?'
      WRITE(6,*)'TYPE 1 FOR 260 NM '
      WRITE(6,*)'TYPE 2 FOR 380 NM '
      WRITE(6,*)'TYPE 3 FOR 500 NM '
      WRITE(6,*)'TYPE 4 FOR 620 NM '
      WRITE(6,*)'TYPE 5 FOR 740 NM '
      READ(5,6)IAV
    6 FORMAT()
      REWIND 1
      REWIND 7
      READ(7,14)WORD1
   14 FORMAT(A47)
      READ(7,16)WORD2
   16 FORMAT(A31)
      READ(7,17)WORD3
   17 FORMAT(A17)
      WRITE(6,*)'WHAT IS THE OFFSET TERM ?'
      READ(7,6)AO1,AO2
      WRITE(6,*)'WHAT IS THE PIXEL STARTING POINT OF THE DATA ?'
      READ(7,6)IP1
      WRITE(6,*)'NUMBER OF PIXELS YOU WISH TO PLOT ?'
      READ(7,12)IP5
      WRITE(6,*)'WHAT IS THE PIXEL WIDTH ?'
      READ(7,12)IP4
      IP4=IP4*10
      READ(7,11)(INTENS(I),I=1,IP5)
      YORIG=0
      YMAX=200
      YSTEP=20
      XSTEP=10.
      IB=IP1+IP5-1
       IC=IB-IP1
      AO=AO1
      DO 10 I=IP1,IB
         IBA=I*IP4/10
```

```
      IF(IBA.GE.5001)AO=AO2
      K=I-IP1+1
      IA=(I-IP1)*IP4+IP1*10
        XA=(IA+AO-50000.)/5000.
      XARAY(K)=A(IAV)+B1(IAV)*XA+B2(IAV)*XA*XA
        XARAY(K)=XARAY(K)*100.
      YARAY(K)=INTENS(K)
   10 CONTINUE
      WRITE(6,*)'PIXEL STARTING POINT ', XARAY(1)
      K=IB-IP1+1
      WRITE(6,*)'ENDING POINT ',XARAY(K)
      WRITE(6,*)'WHAT IS THE X ORIGIN AND X ENDING POINT ?'
      READ(5,12)XORIG,XMAX
   12 FORMAT()
   11 FORMAT(1X,6X,2X,I6)
      CALL TEKEGM(480,1,0)
      CALL SETDEV(10,10)
      CALL PAGE(11.0,8,5)
      CALL HWROT('AUTO')
      CALL HWSCAL('SCREEN')
      CALL NOBRDR
      CALL YTICKS(5)
      CALL YAXANG(0.)
      CALL AREA2D(9.35,6.00)
      CALL FRAME
       CALL XNAME('WAVELENGTH,NM',14)
      CALL YNAME('DENSITY',7)
      CALL HEADIN(WORD1,47,1.,3)
      CALL HEADIN(WORD2,31,1.,3)
      CALL HEADIN(WORD3,17,1.,3)
      CALL INTAXS
      CALL XTICKS(10)
      CALL GRAF(XORIG,XSTEP,XMAX,YORIG,YSTEP,YMAX)
      CALL CURVE(XARAY,YARAY,IC,0)
      CALL ENDPL(0)
      CALL DONEPL
      STOP
      END
      SUBROUTINE REDC(A,B1,B2)
      REAL A(5),B1(5),B2(5)
      CALL NTRAN$(2,10,22)
      NB=100
      CALL NTRAN$(2,6,NB)
      CALL NTRAN$(2,2,5,A(1),JSTAT,22)
      CALL NTRAN$(2,2,5,B1(1),JSTAT,22)
      CALL NTRAN$(2,2,5,B2(1),JSTAT,22)
      RETURN
      END
```

****

RW.CONTROL

****

ES3-N03200*RW(1).CONTROL(25)

```
.
.
. RW.CONTROL
.
.
. RW.CONTROL IS A CONTROL PROGRAM TO
. DETERMINE 2ND ORDER LINEAR LEAST SQUARES
.
.
@ASG,T DATAIN.
@ED RW.PLATE326B,DATAIN.
EXIT
@USE 4.,DATAIN.
@MAP,N RW.MASTER
IN RW.MASTER
LIB J*AIMSL
LIB JSC*FTN.
END
@XQT RW.MASTER
```

****

RW.MASTER

****

ES3-N03200*RW(1).MASTER(45)

```
      INTEGER IX,NBR(6),IER
C
C
C RW.MASTER
C
C
C PROGRAM TO FIND PLATE CONSTANTS FOR
C A 2ND ORDER LINEAR LEAST SQUARES
C FIT
C
C AN EXAMPLE   PLATE 32 IS SHOWN IN
C APPENDIX B
C
C REQUIRES FORMATTED DATA ON IN FILE
C 4  RW.LOCATELINE LOCATES THE MICRONS
C  WHERE THE LINES ARE LOCATED ON THE
C PLATE.
C
C
C FORMAT FILE
C
C FIRST NUMBER - NUMBER OF CALIBRATION POINTS
C
C COLUMN OF TWO NUMBERS X IN MICRONS AND 5 SIGN FIGURES + .
C AND SPACE FOLLOWED BY WAVELENGTH IN F8.4 FORMAT
C
C
      CHARACTER QU*1
C
C IX NUMBER OF DATA POINTS
C NBR 6 DIMENSION VECTOR 1=NUMBER OF VARIABLES
C 2=NUMBER OF OBSERVATION PER VARIABLES
C 3= NUMBER OF OBSERVATIONS IN THE SUBMATRIX X=
C MAKE THIS EQUAL TO NBR(2)
C 4=1 (DEALING WITH ONLY ONE SUBMATRIX) NBR(5)=1
C IF NBR(5)=0 MEANS YOU SUPPLY THE MEANS
C NBR(6)=1 ELSE NBR(6)=0 RETURNS VARIANCE-COVAR MATRIX
C IER ERROR PARAMETER
```

```
C
      REAL X(25,3),TEMP(3),XM(3),VCV(6),ANOVA(14),B(3,7)
      REAL VARB(3)
C
C X MATRIX OF VARIABLES SET UP AS X,X**2,Y WHERE X
C IS MEASUREMENT IN INCHES OR MICRONS AND Y IS THE KNOWN
C  WAVE LENGTH
C
C TEMP ARRAY WHICH CONTAINS MEANS WHEN SPECIFIED
C XM ARRAY WITH MEANS OF DATA
C VCV ARRAY WITH SUMS OF SQUARES CROSS-PRODUCTS
C ANOVA OUTPUT VECTOR OF RLMUL
C B OUTPUT VECTOR OF RLMUL B(I,1) CONTAINS THE PARAMETER
C ESTIMATES
C VARB
C
C
C CALL THE READ IN PROGRAM REQUIRES FORMATTED DATA
C
      CALL RED(X,NBR)
C
 13   FORMAT(I2)
CC IX NUMBER OF DATA POINTS EQUALS NUMBER OF ROWS
C
      IX=25
C
C CALL TO IMSL ROUTINE TO MAKE UP SUMS OF SQUARES MATRIX
C
      CALL BECOVM(X,IX,NBR,TEMP,XM,VCV,IER)
 12   FORMAT(1X,6E14.7)
      N=NBR(2)
      M=2
      IB=3
      ALFA=0.05
C
C IMSL SUBROUTINE TO FIND PARAMETERS B(I)
C
      CALL RLMUL(VCV,XM,N,M,ALFA,ANOVA,B,IB,VARB,IER)
C
C WRITE REGRESSION COEFFICIENTS
C
      WRITE(6,14)B(3,1),B(1,1),B(2,1)
 14   FORMAT(' INTERCEPT ',E14.7,' X COEFF ',E14.7,' Y COEFF ',E14.7)
C
C CALL PROGRAM TO CALCULATE UNKNOWN WAVELENGTHS
C
      CALL UNKNOW(B)
C
C RESIDUAL CALCULATION
C
      WRITE(6,16)
 16   FORMAT(' DO YOU WISH TO CALCULATE RESIDUALS TYPE 0 IF YES')
      READ(5,17)NRES
 17   FORMAT(I1)
      IF(NRES.NE.0)GO TO 20
C
C RE-READ X AND Y DATA
C
      CALL RED(X,NBR)
      WRITE(6,19)
      DO 20 I=1,NBR(2)
      YH=B(3,1)+B(1,1)*X(I,1)+B(2,1)*X(I,2)
      YH=YH*100.
      X(I,3)=X(I,3)*100.
      RES=X(I,3)-YH
      WRITE(6,18)I,X(I,3),YH,RES
 18   FORMAT(1X,I2,2X,'RESIDUAL',1X,3F9.4)
 19   FORMAT(15X,'ACTUAL',4X,'PREDICTED',1X,'RESIDUAL')
 20   CONTINUE
      WRITE(6,*)'DO YOU WISH TO STORE THESE CONSTANTS IN MASS STORAGE ?'
      READ(5,22)QU
 22   FORMAT(A1)
```

```
      IF(QU.EQ.'Y')CALL STOR(B(3,1),B(1,1),B(2,1))
      STOP
      END
C
C
C SUBROUTINE FOR READING IN DATA FORMATTED
C
C
      SUBROUTINE RED(X,NBR)
      DIMENSION X(25,3),NBR(6)
      REWIND 4
      NBR(1)=3
      READ(4,10)NBR(2)
      NBR(3)=NBR(2)
      NBR(4)=1
      NBR(5)=1
      NBR(6)=1
      DO 100 I=1,NBR(2)
      READ(4,11)X(I,1),X(I,3)
      X(I,1)=(X(I,1)-50000.)/5000.
      X(I,3)=X(I,3)/100.
      X(I,2)=X(I,1)*X(I,1)
  100 CONTINUE
   10 FORMAT(I2)
   11 FORMAT(F6.0,1X,F8.4)
      RETURN
      END
C
C
C
C SUBROUTINE FOR CALCULATING THE UNKNOWN Y
C
C
      SUBROUTINE UNKNOW(B)
      DIMENSION B(3,7)
      WRITE(6,8)
    8 FORMAT(' NUMBER OF UNKNOWNS')
      READ(5,11)N
      DO 100 I=1,N
      WRITE(6,10)
   10 FORMAT(' MICRONS MEASURED')
      READ(5,11)X
   11 FORMAT()
      X=(X-50000.)/5000.
      Y=B(1,1)*X+B(2,1)*X*X+B(3,1)
      Y=Y*1000.
      WRITE(6,12)Y
   12 FORMAT(' WAVELENGTH IS ',F10.4 ,1X,' NM')
  100 CONTINUE
      WRITE(6,13)
   13 FORMAT(' END OF INPUT')
      RETURN
      END
C
C  SUBROUTINE TO STORE CONSTANTS IN MASS STORAGE
C
      SUBROUTINE STOR(A,B1,B2)
      WRITE(6,*)'WHAT WAVE LENGTH RANGE IS THIS ?'
      WRITE(6,*)'TYPE 1 FOR 260 NM '
      WRITE(6,*)'TYPE 2 FOR 380 NM'
      WRITE(6,*)'TYPE 3 FOR 500 NM'
      WRITE(6,*)'TYPE 4 FOR 620 NM'
      WRITE(6,*)'TYPE 5 FOR 740 NM'
      READ(5,6)I
      NB=I+99
      CALL NTRAN$(2,10,22)
      CALL NTRAN$(2,6,NB)
      CALL NTRAN$(2,1,1,A,JSTAT,22)
      CALL NTRAN$(2,6,4)
      CALL NTRAN$(2,1,1,B1,JSTAT,22)
      CALL NTRAN$(2,6,4)
      CALL NTRAN$(2,1,1,B2,JSTAT,22)
```

```
      6 FORMAT()
        RETURN
        END
```

```
*******************************

          RW.END

*******************************
```

```
ES3-N03200*RW(1).END(2)
.
.
.
.   RW.END
.
.
.   THIS CONTROL PROGRAM FREES ALL DATA FILES USED
.   IN PLOTTING AND WORKING WITH MICRODENSITOMETER
.   PLATE DATA
.
.
@FREE DATA1.
@PACK,P RW.
@FREE DATAIN.
@FREE DATAOUT.
```

APPENDIX D
PHOTOGRAPHS OF SPECTRAL PLATES ANNOTATED WITH SPECIES IDENTIFICATION

Spectra of Pure Nitrogen

Shock Layer

Arc Jet Conditions:

Date	25 June 1984
Run Numbers	AC 881 to 883
Current	1,000 amps
Voltage	1,515 volts
Power	1.515 MW
Gas Flow Rate	0.0454 kg/sec nitrogen

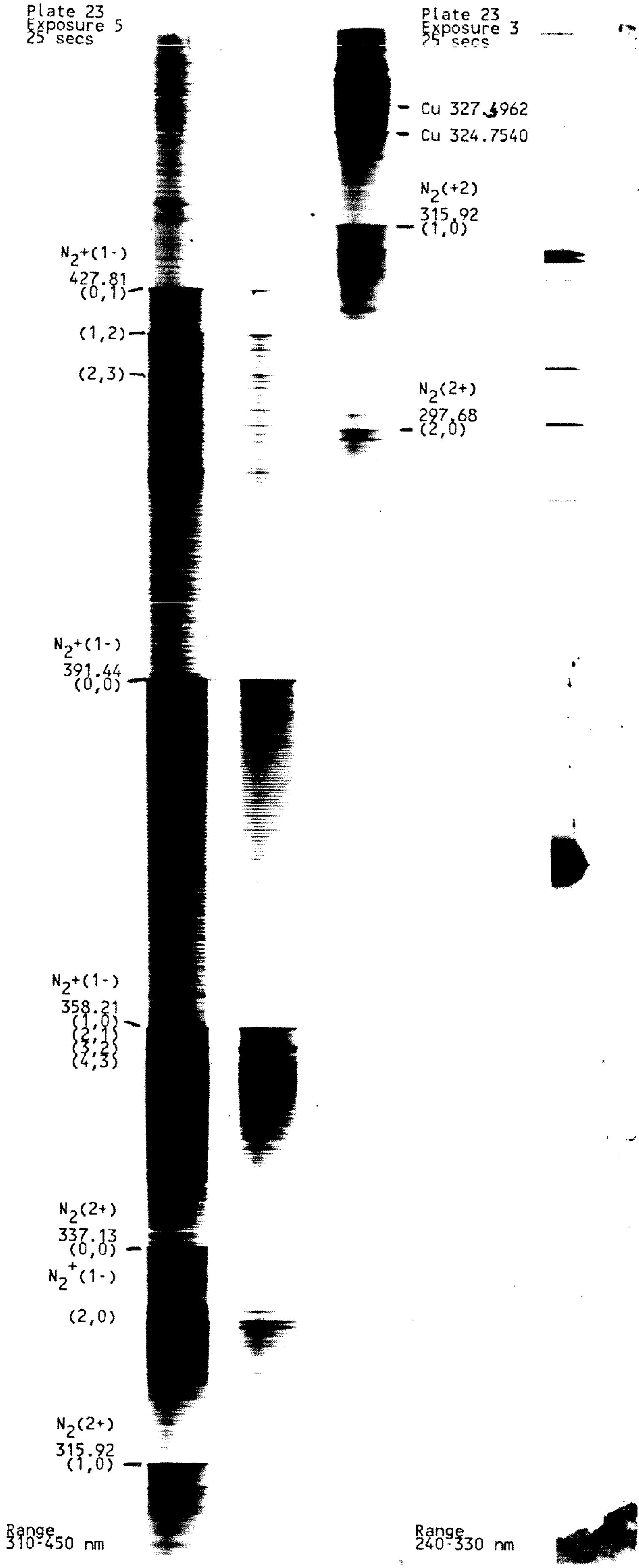


Plate 23
N_2-Shock Layer
Wavelength Range
240-450 nm
25 June 1984

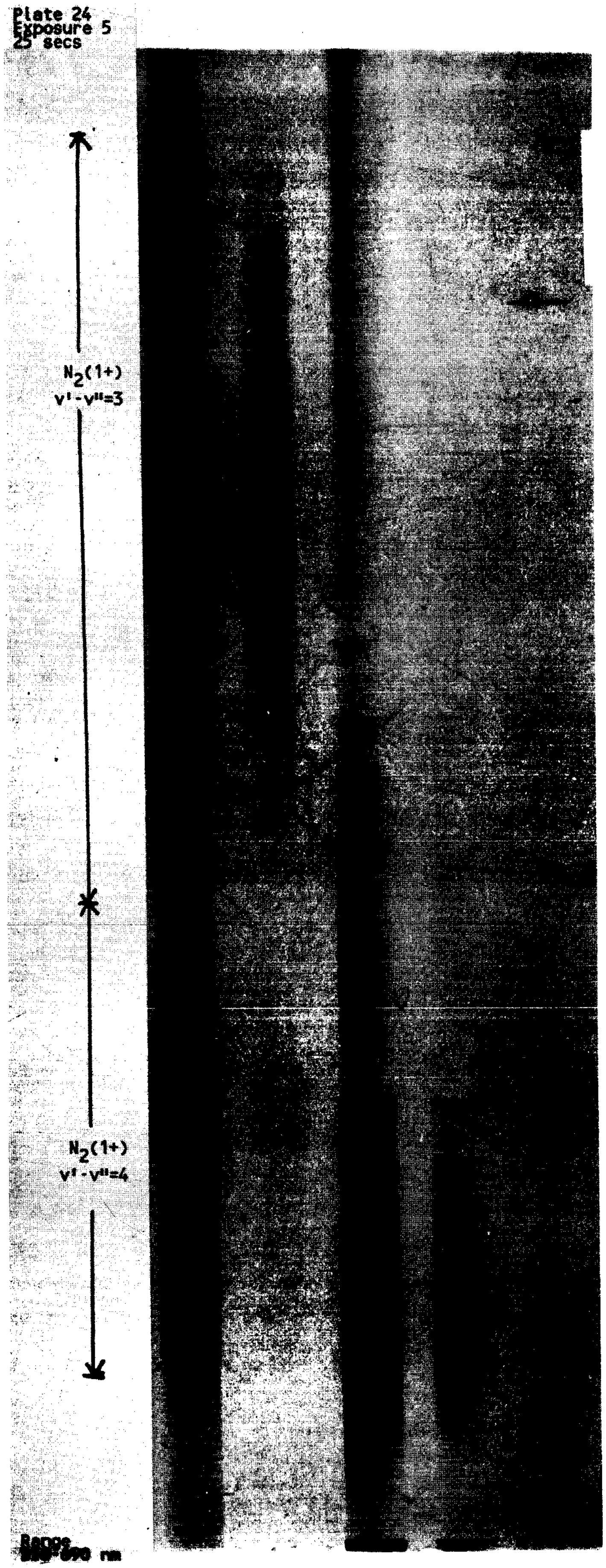


Plate 24
N_2-Shock Layer
Wavelength Range
430-690 nm
25 June 1984

Lyndon B. Johnson Space Center
Houston, Texas 77058

ORIGINAL PAGE IS
OF POOR QUALITY

S84-39730

National Aeronautics and
Space Administration

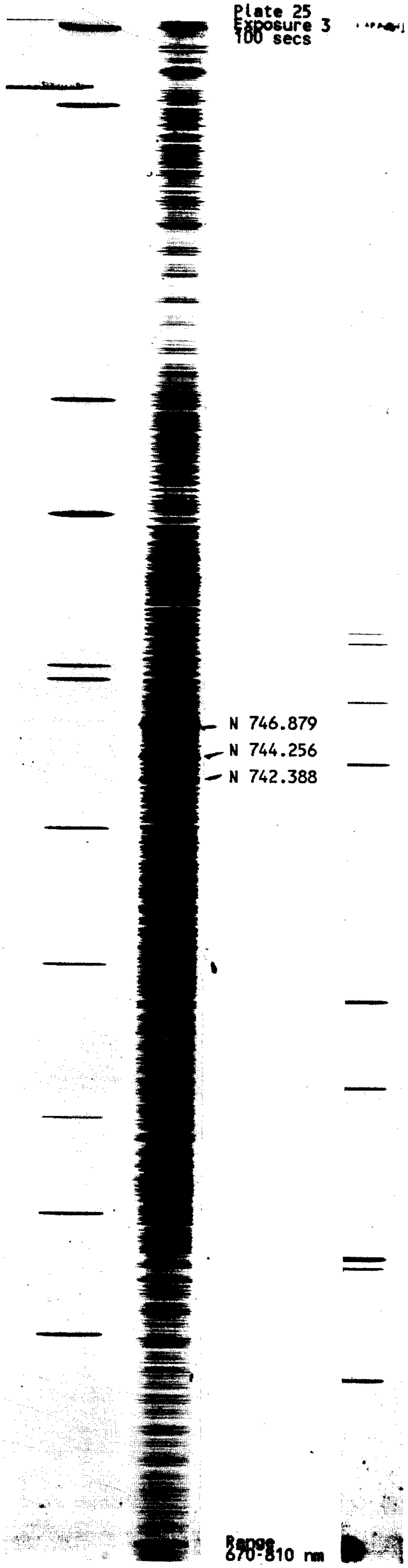


Plate 25
N_2-Shock Layer
Wavelength Range
670-810 nm
25 June 1984

Spectra of Pure Nitrogen

Free Stream

Arc Jet Conditions:

Date	25 June 1984
Run Number	AC 880
Current	1,000 amps
Voltage	1,515 volts
Power	1,515 MW
Gas Flow Rate	0.0454 kg/sec nitrogen

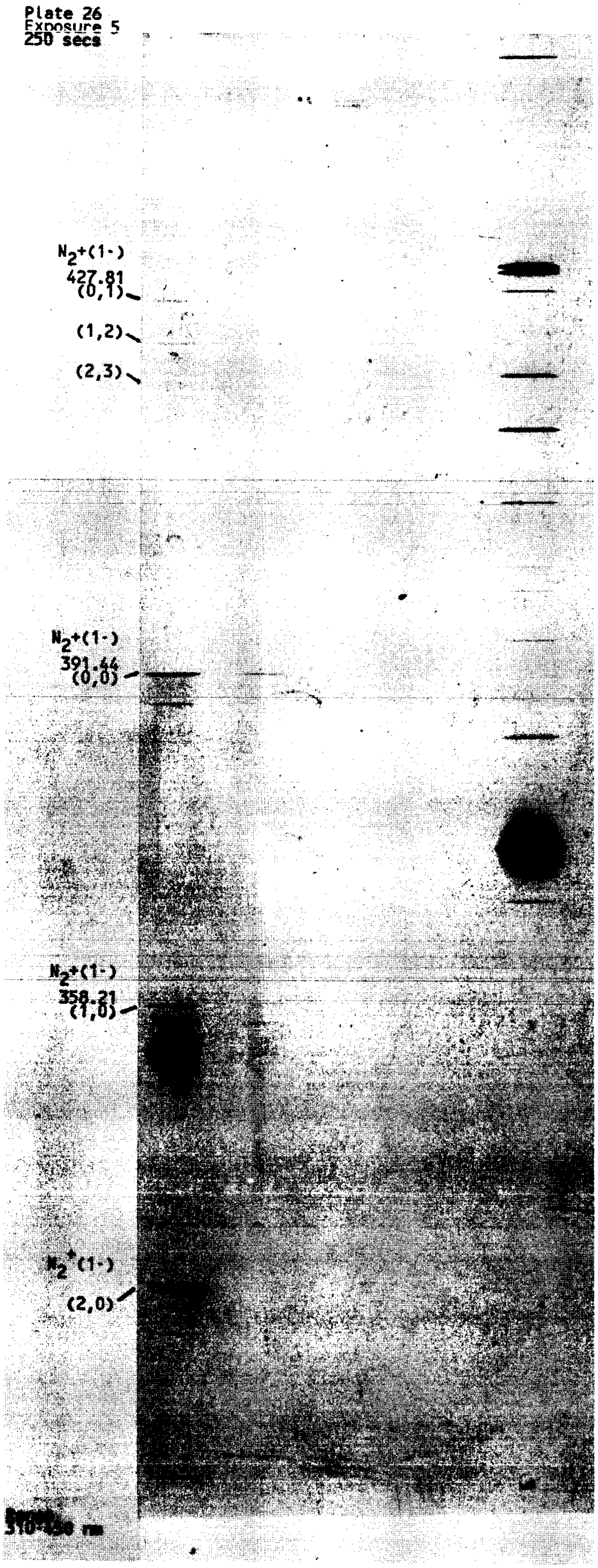


Plate 26
N_2 **Free Stream**
Wavelength Range
240-450 nm
25 June 1984

Spectra of Pure Argon

Shock

Arc Jet Conditions:

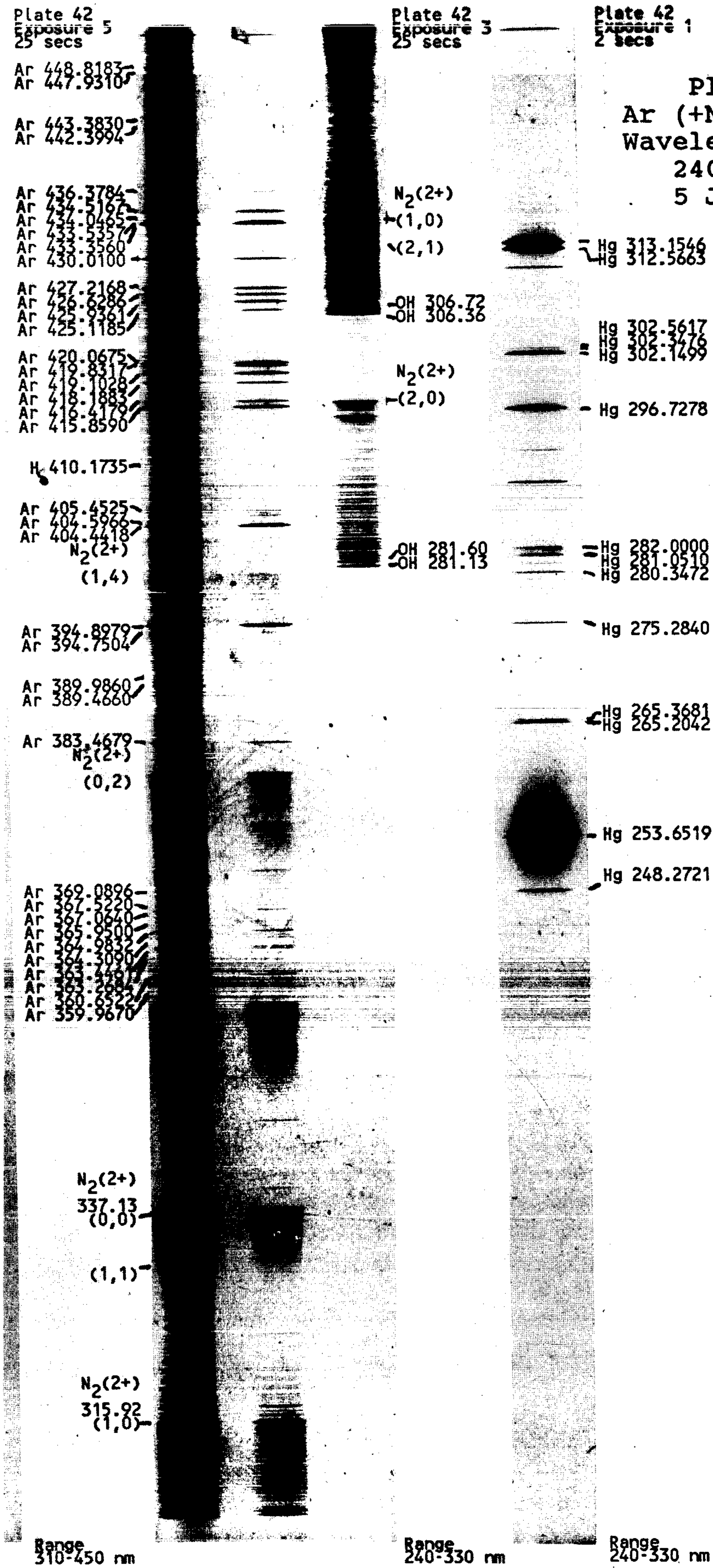
Date	5 July 1984
Run numbers	AC 893 to 894
Current	1,000 amps
Voltage	590 volts
Power	0.59 MW
Gas Flow Rate	0.0727 kg/sec argon

Lyndon B. Johnson Space Center
Houston, Texas 77058

National Aeronautics and
Space Administration

S84-39725

Plate 42
Ar (+N2 Contam.)
Wavelength Range
240-450 nm
5 July 1984



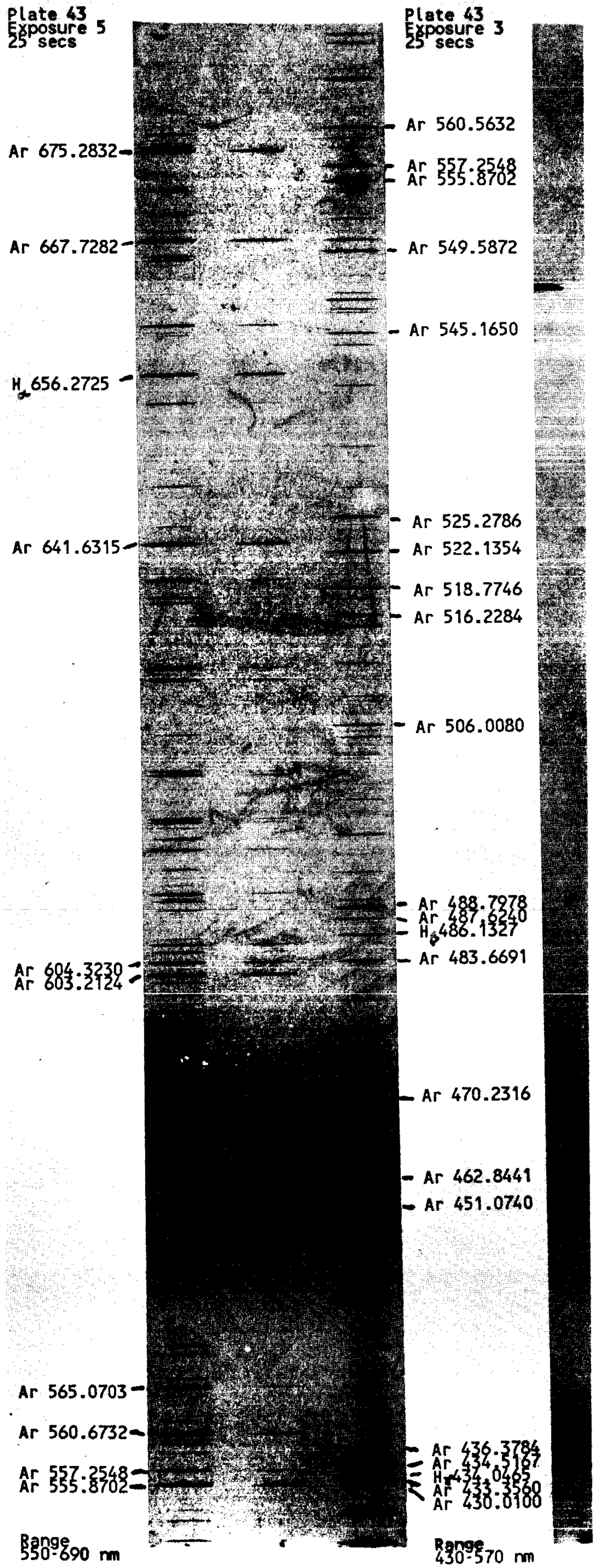


Plate 43
Argon-Shock Layer
Wavelength Range
430-690 nm
5 July 1984

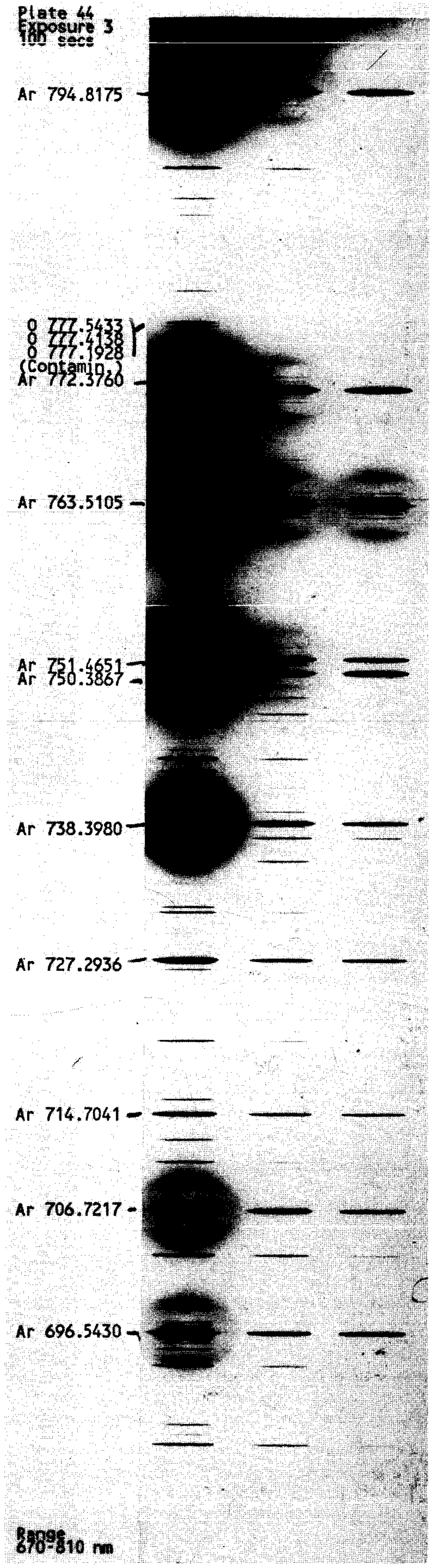


Plate 44
Argon-Shock Layer
Wavelength Range
670-810 nm
5 July 1984

Spectra of Argon-Oxygen Mixture

Shock Layer

Arc Jet Conditions:

Date	28 June 1984
Run Number	AC 886
Current	1,000 amps
Voltage	535 volts
Power	0.535 MW
Gas Flow Rate	0.03732 kg/sec argon
	0.00814 kg/sec oxygen

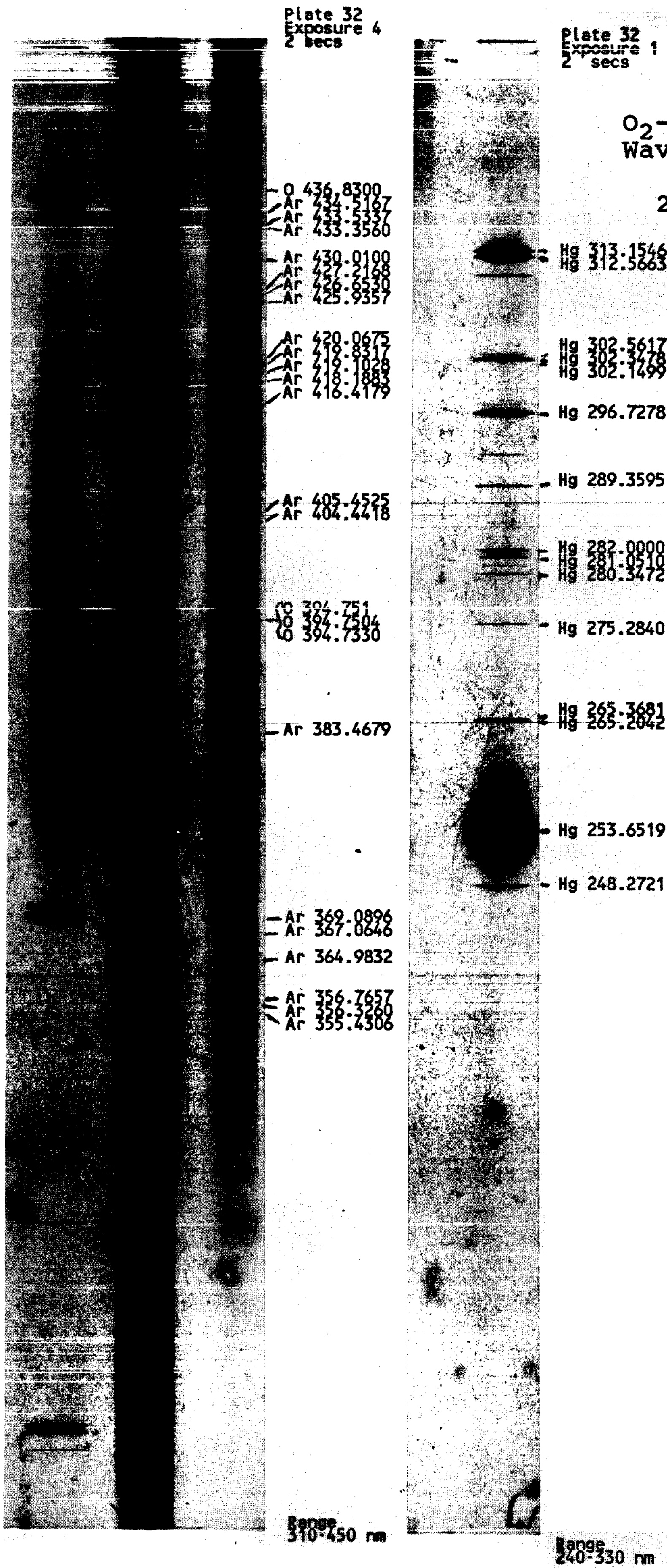


Plate 32
O_2-Ar Shock Layer
Wavelength Range
240-450 nm
28 June 1984

ORIGINAL PAGE IS
OF POOR QUALITY

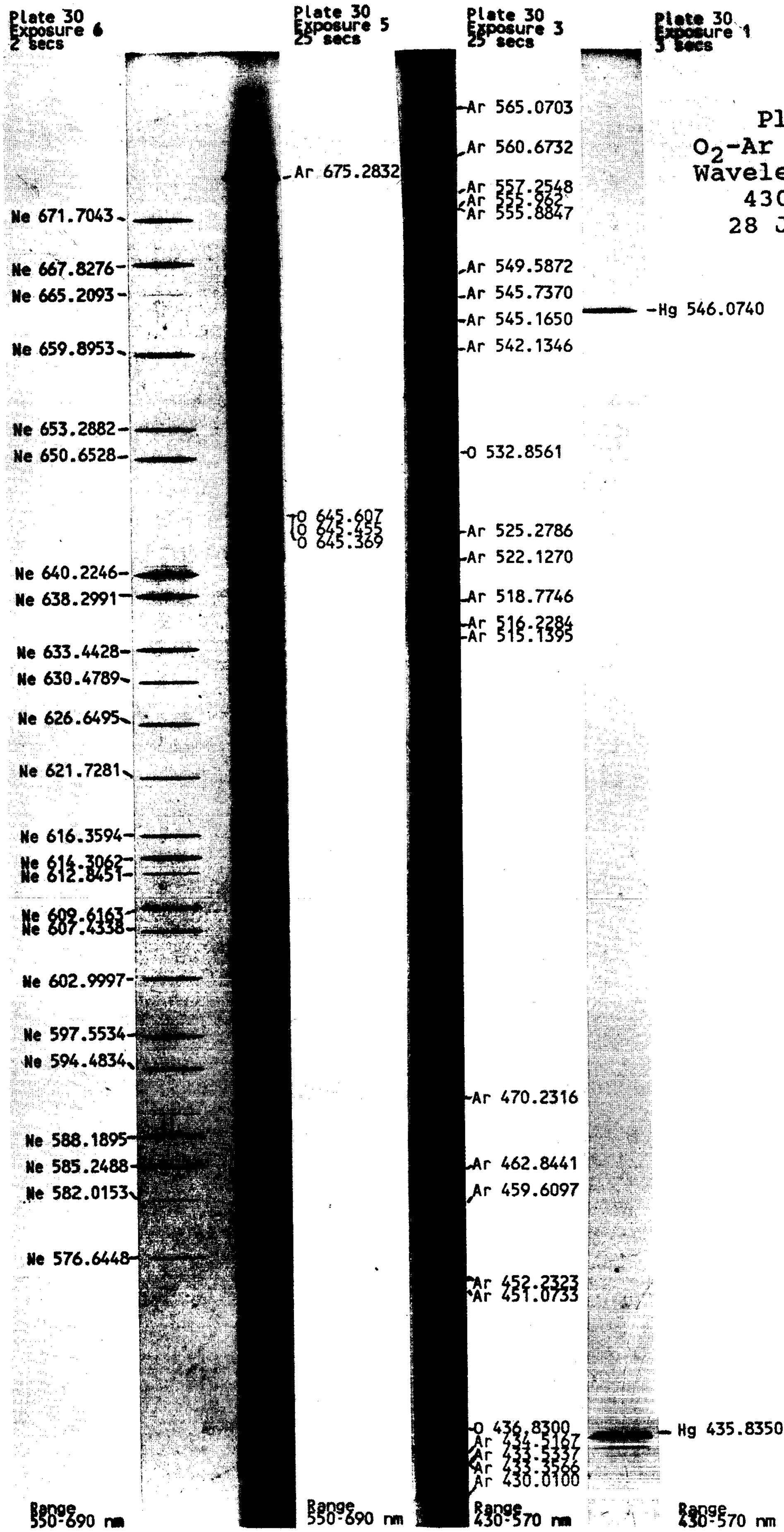
S84-39721

Lyndon B. Johnson Space Center
Houston, Texas 77058

S84-39727

National Aeronautics and Space Administration

Plate 30
O_2-Ar Shock Layer
Wavelength Range
430-690 nm
28 June 1984



S84-39726

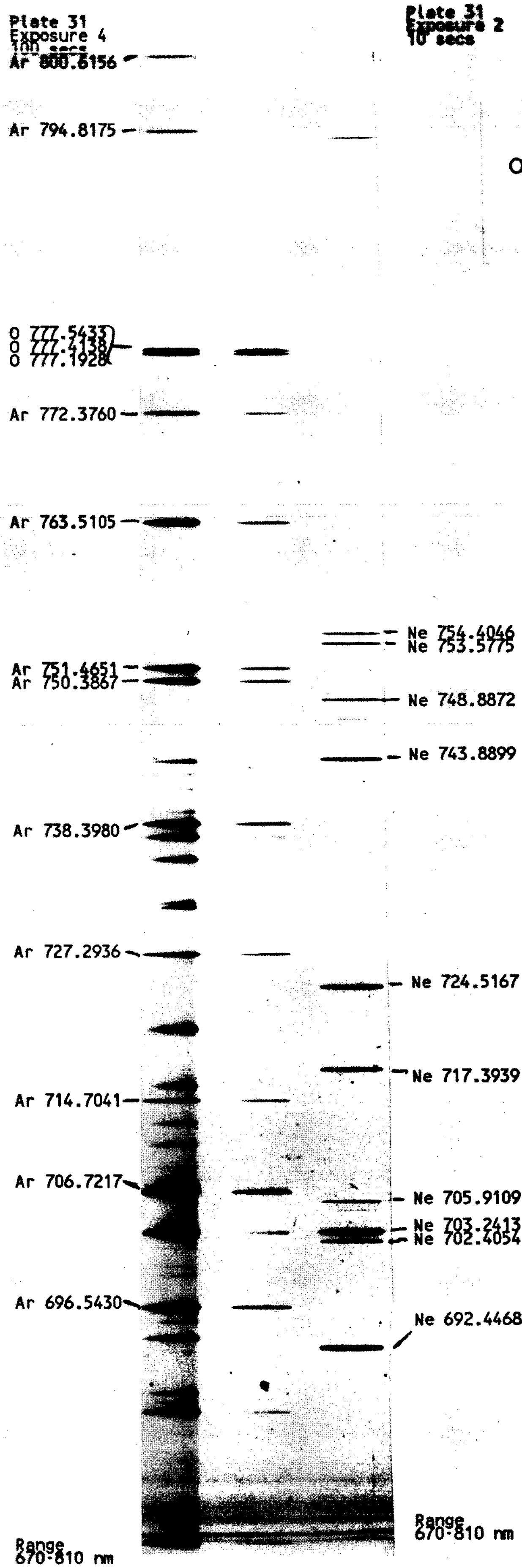


Plate 31
O_2-Ar Shock Layer
Wavelength Range
670-810 nm
28 June 1984

Spectra of Air (N_2 & O_2)

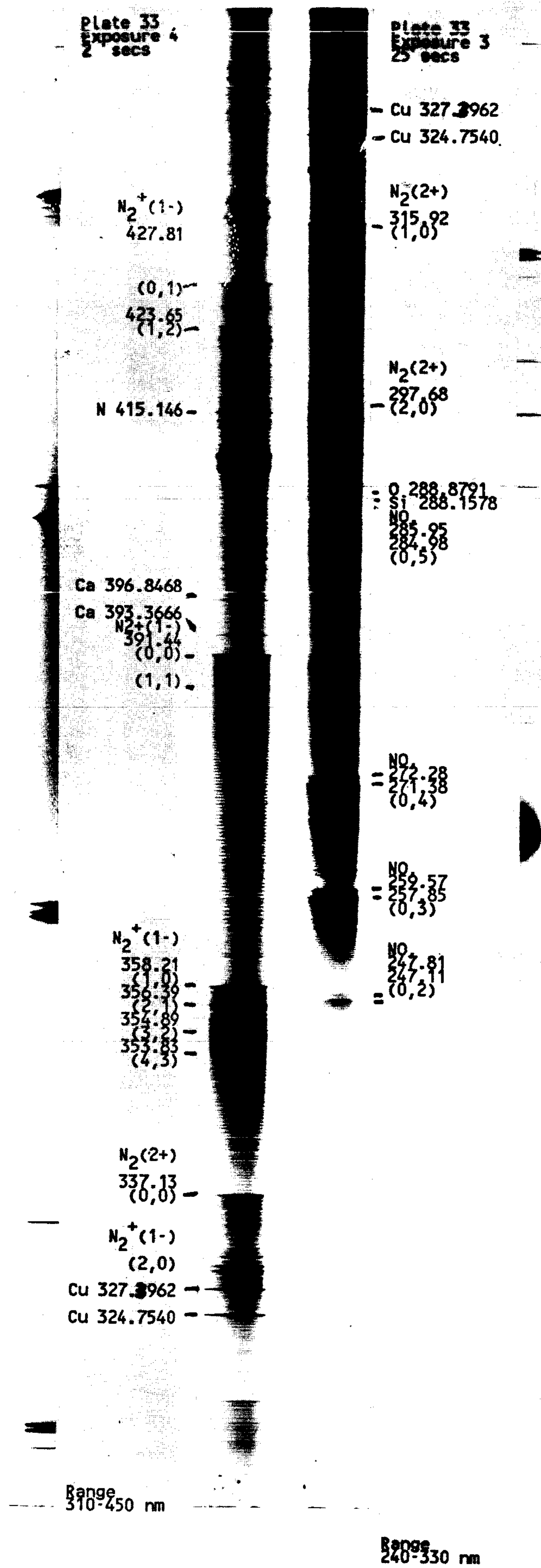
Surface

Arc Jet Conditions:

Date	28 June 1984
Run Number	AC 887
Current	1,000 amps
Voltage	1,430 volts
Power	1.43 MW
Gas Flow Rate	0.0355 kg/sec nitrogen
	0.0105 kg/sec oxygen

S84-39741

Plate 33
Air-Surface
Wavelength Range
240-450 nm
28 June 1984



NASA
National Aeronautics and Space Administration

Lyndon B. Johnson Space Center
Houston, Texas 77058

S84-39729

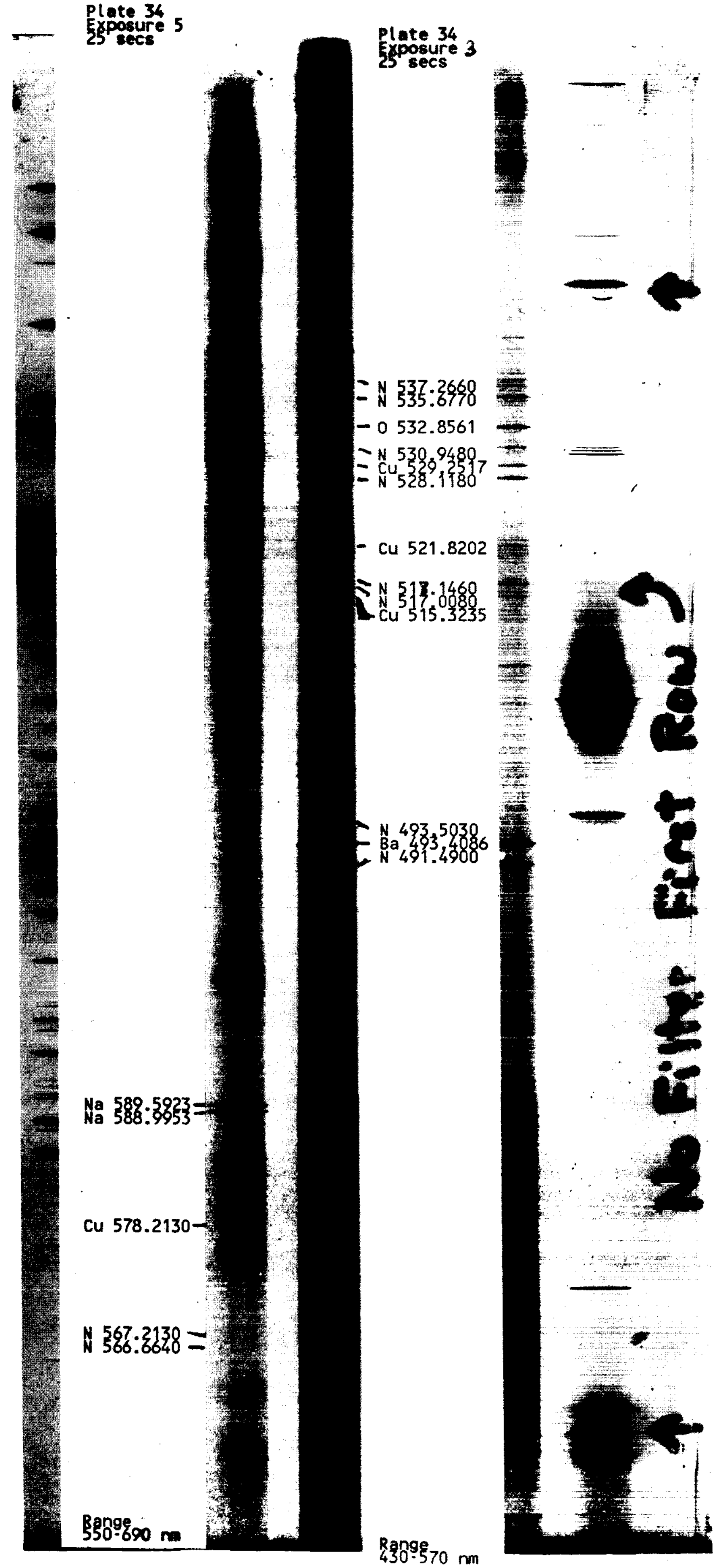


Plate 34
Air-Surface
Wavelength Range
430-690 nm
28 June 1984

Lyndon B. Johnson Space Center
Houston, Texas 77058

S84-39731

National Aeronautics and
Space Administration

ORIGINAL PAGE IS
OF POOR QUALITY

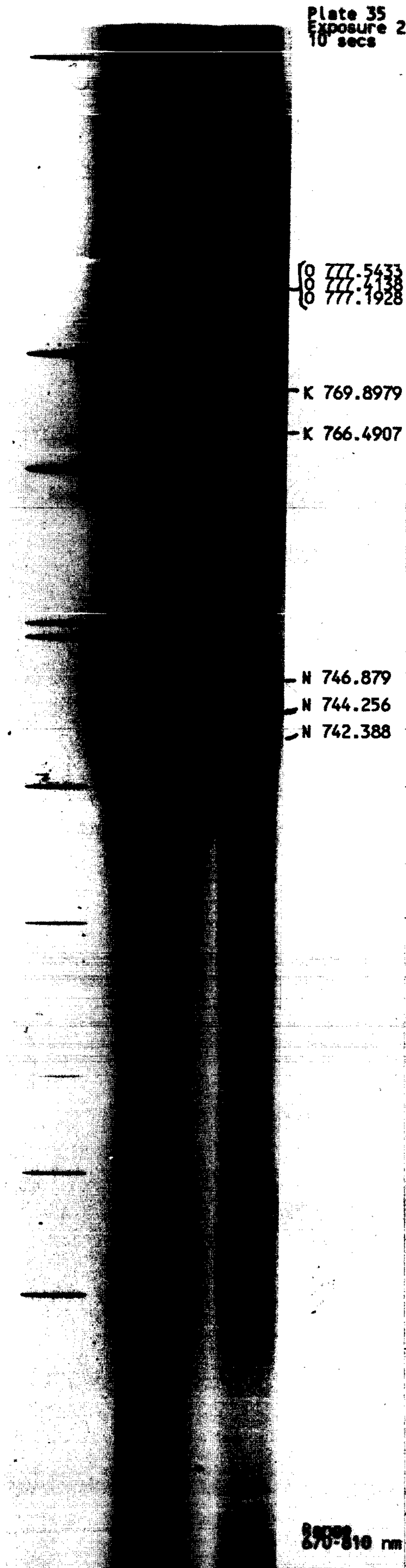


Plate 35
Air-Surface
Wavelength Range
670-810 nm
28 June 1984

Spectra of Air

Shock Layer

Arc Jet Conditions:

	Plates 14 to 16	Plates 36 to 38
Date	19 June 1984	28 June 1984
Run Numbers	AC 874 to 875	AC 887
Current	1,000 amps	1,000 amps
Voltage	1,420 volts	1,430 volts
Power	1.42 MW	1.42 MW
Gas Flow Rate	0.0355 kg/sec nitrogen	0.0355 kg/sec nitrogen
	0.0105 kg/sec oxygen	0.0105 kg/sec oxygen

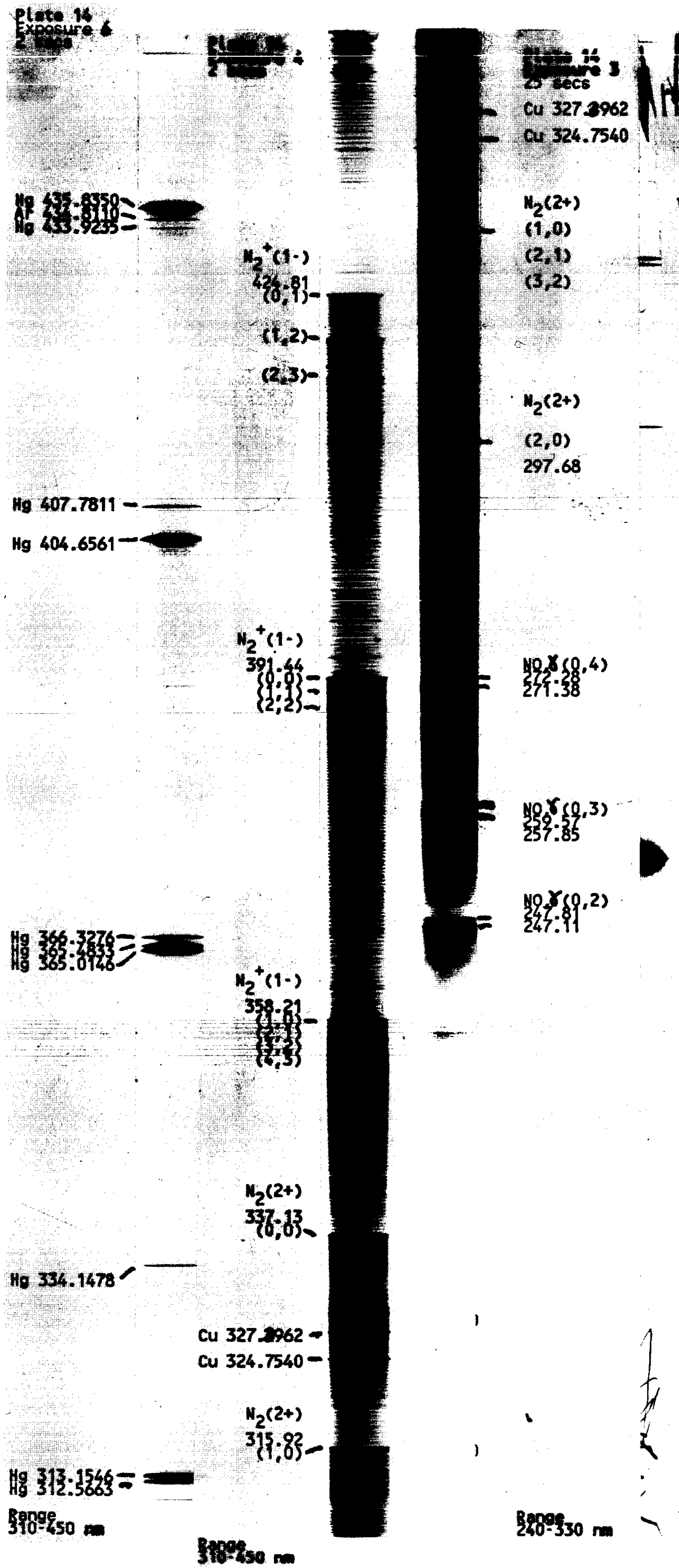


Plate 14
Air-Shock Layer
Wavelength Range
240-450 nm
19 June 1984

ORIGINAL PAGE IS
OF POOR QUALITY

Plate 15
Air-Shock Layer
Wavelength Range
430-690 nm
19 June 1984

Lyndon B. Johnson Space Center
Houston, Texas 77058

S84-39735

NASA
National Aeronautics and
Space Administration

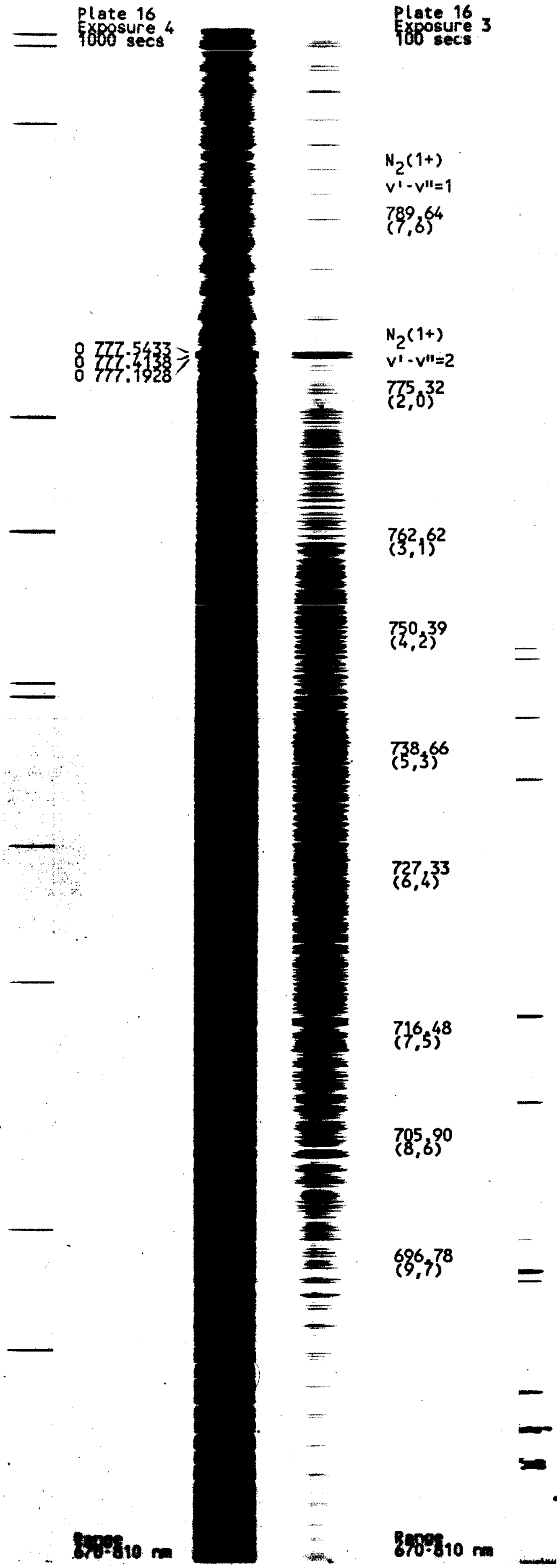
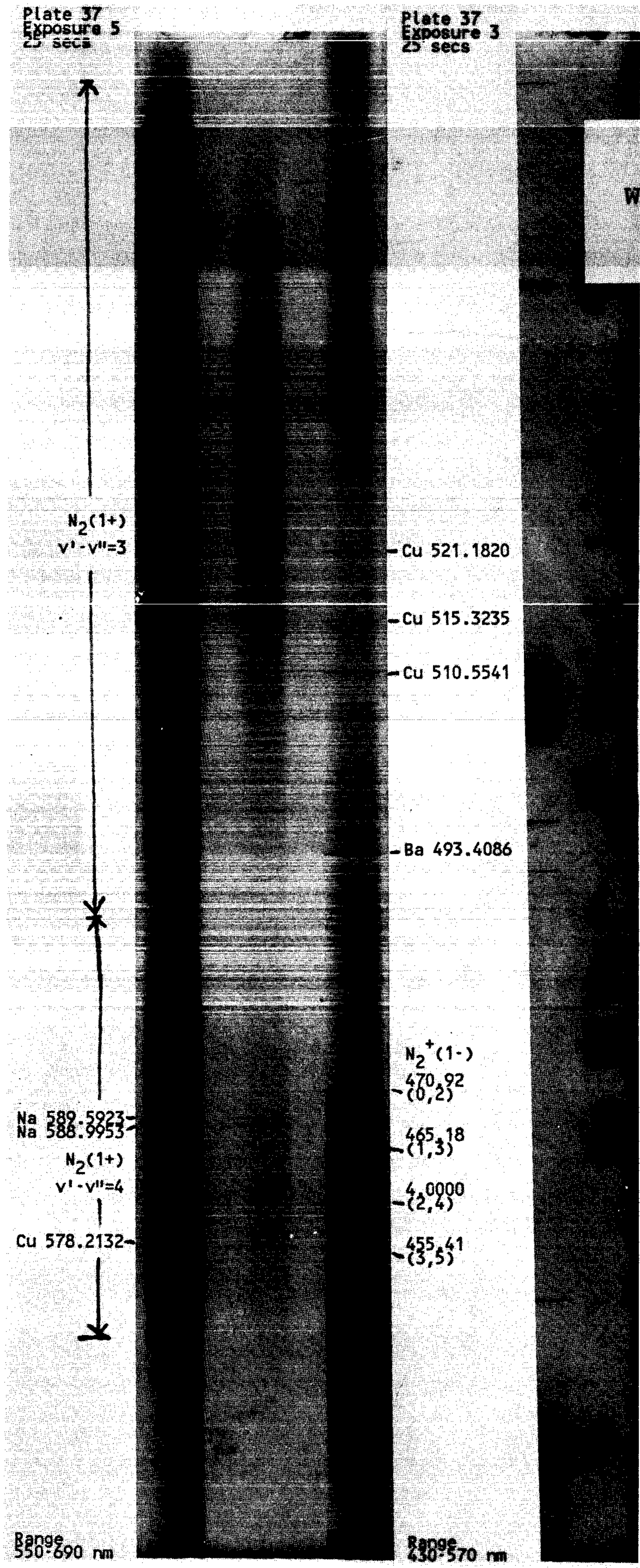


Plate 16
Air-Shock Layer
Wavelength Range
670-810 nm
19 June 1984

Plate 36
Air-Shock Layer
Wavelength Range
240-450 nm
28 June 1984

Plate 37
Air-Shock Layer
Wavelength Range
430-690 nm
28 June 1984



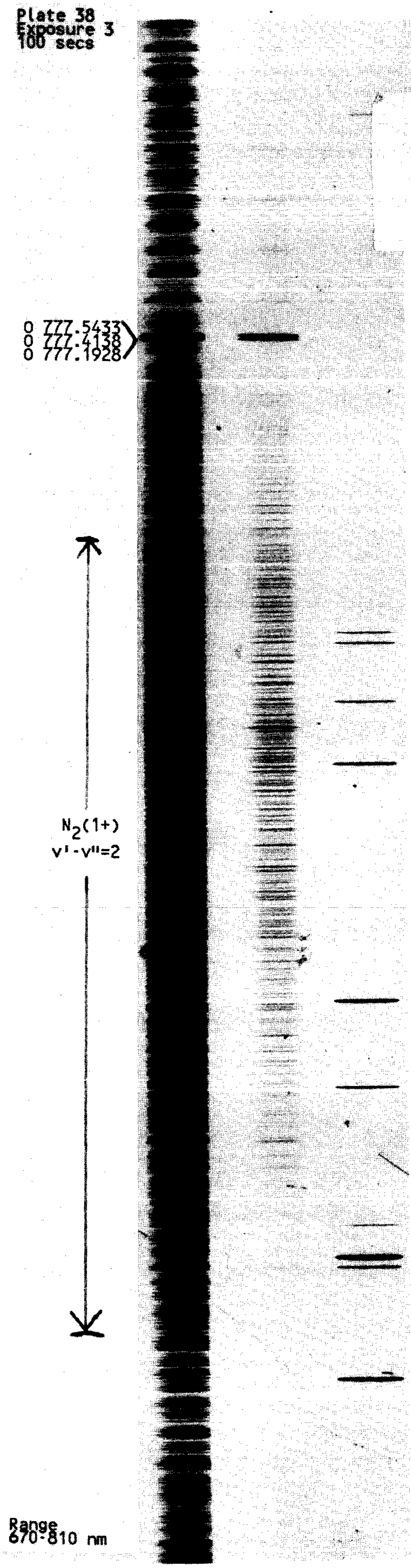


Plate 38
Air-Shock Layer
Wavelength Range
670-810 nm
28 June 1984

Spectra of Air

Free Stream

Arc Jet Conditions:

Date	5 July 1984
Run Number	AC 895
Current	1,000 amps
Voltage	1,475 volts
Power	1,475 MW
Gas Flow Rate	0.0553 kg/sec nitrogen
	0.0175 kg/sec oxygen

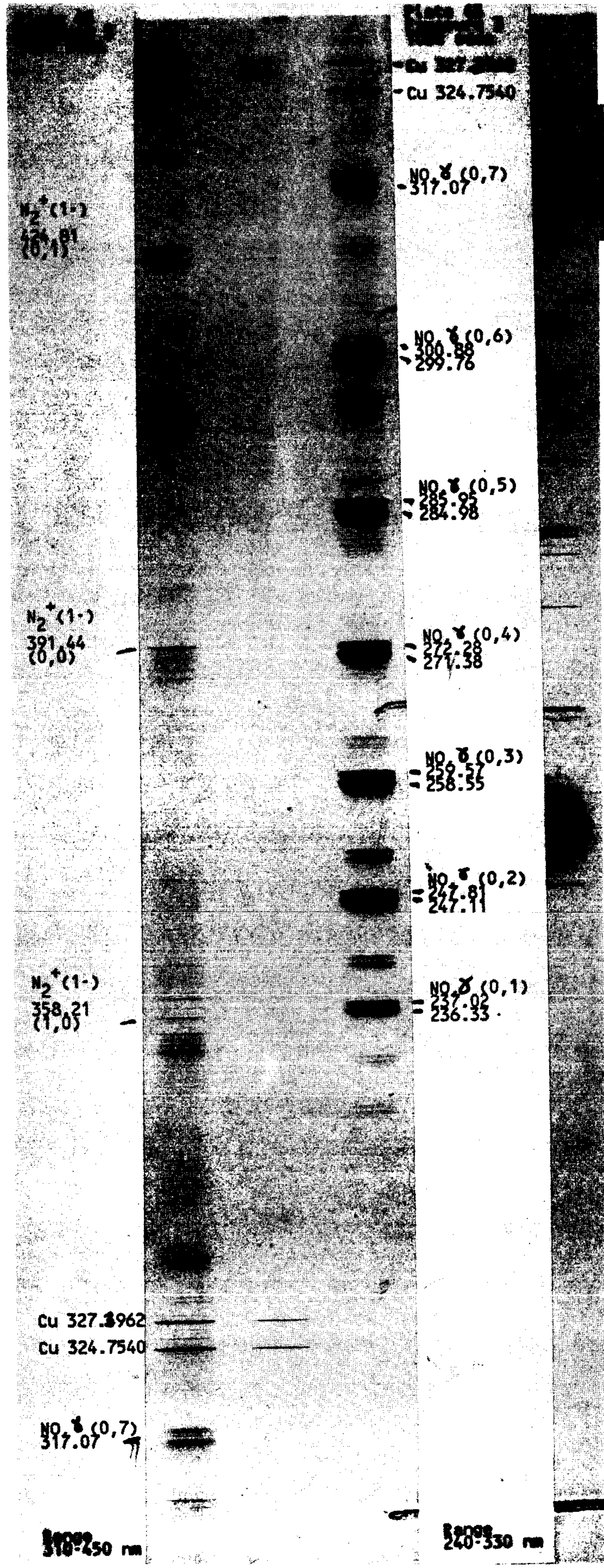
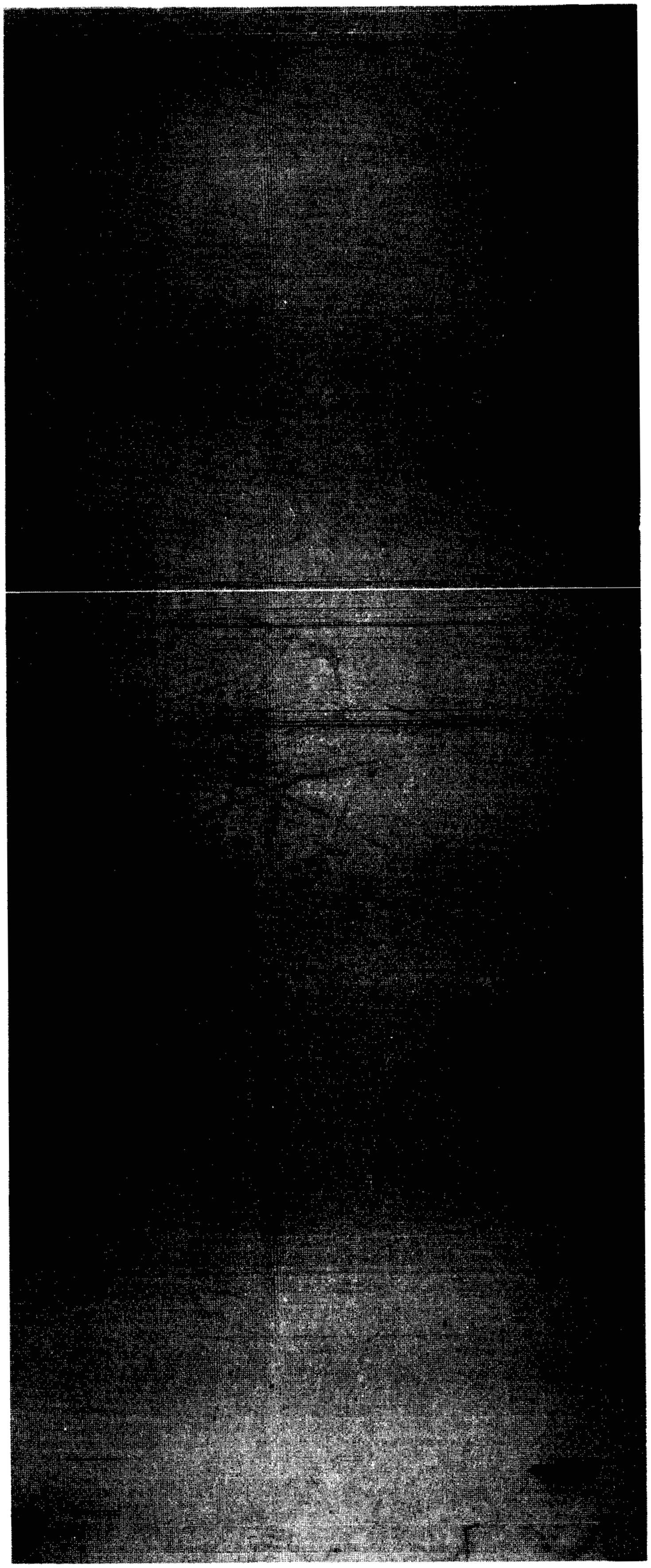


Plate 45
Air-Free Stream
Wavelength Range
240-450 nm
5 July 1984

National Aeronautics and
Space Administration

Plate 46
Air-Free Stream
Wavelength Range
430-690 nm
5 July 1984



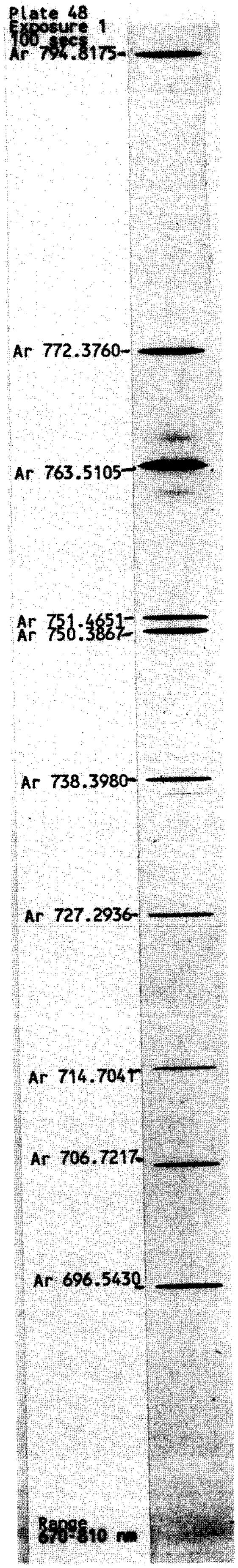


Plate 48
Air-Free Stream
Wavelength Range
670-810 nm
5 July 1984

☆ U.S. GOVERNMENT PRINTING OFFICE: 1987—761-013/60411