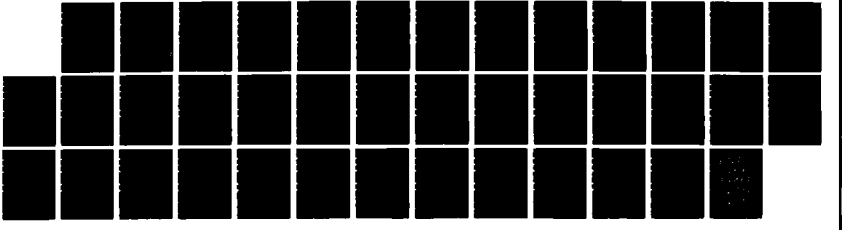
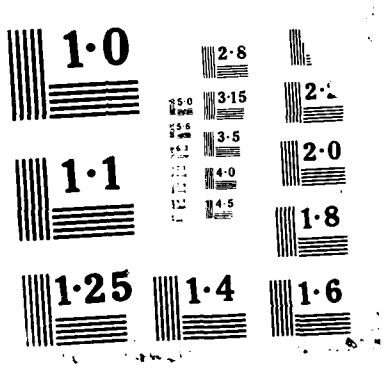
AD-A192 501 CHEMICALLY-PRODUCED N2(A) TO NO(X) ENERGY TRANSFER IN A SUPERSONIC FLOW(U) AIR FORCE WEAPONS LAB KIRTLAND AFB NM Y D JONES NOV 87 AFWL-RR-87-25 1/1

UNCLASSIFIED F/G 7/2 NL




1·0
1·1
1·25
2·8
3·15
3·5
4·0
4·5
2·0
1·8
1·4
1·6

AFWL-TR-
87-25

(2)

CHEMICALLY-PRODUCED $N_2(A)$ TO NO(X) ENERGY TRANSFER IN A SUPERSONIC FLOW

Y. D. Jones

November 1987

Final Report

AIR FORCE WEAPONS LABORATORY
Air Force Systems Command
Kirtland Air Force Base, NM 87117-6008

This final report was prepared by the Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico, Job Order 33260385. Dr. Yolanda D. Jones (AWYW) was the Laboratory Project Officer-in-Charge.

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely Government-related procurement, the United States Government incurs no responsibility or any obligation whatsoever. The fact that the Government may have formulated or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication, or otherwise in any manner construed, as licensing the holder, or any other person or corporation; or as conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

This report has been authored by an employee of the United States Government. Accordingly, the United States Government retains a nonexclusive, royalty-free license to publish or reproduce the material contained herein, or allow others to do so, for the United States Government purposes.

This report has been reviewed by the Public Affairs Office and is releasable to the National Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

If your address has changed, if you wish to be removed from our mailing list, or if your organization no longer employs the addressee, please notify AFWL/AWYW Kirtland Air Force Base, NM 87117-6008 to help us maintain a current mailing list.

This report has been reviewed and is approved for publication.

Yolanda D. Jones

YOLANDA D. JONES, PhD
Project Officer

FOR THE COMMANDER

Gerald A. Hasen

GERALD A. HASEN
Maj, USAF
Ch, Advanced Chemical Laser Branch

HARRO ACKERMANN
Lt Col, USAF
Ch, Laser Science & Technology Office

DO NOT RETURN COPIES OF THIS REPORT UNLESS CONTRACTUAL OBLIGATIONS OR NOTICE ON A SPECIFIC DOCUMENT REQUIRES THAT IT BE RETURNED.

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) AFWL-TR-87-25	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Air Force Weapons Laboratory 6b. OFFICE SYMBOL (If applicable) AWYW	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) Kirtland Air Force Base, NM 87117-6008	7b ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING / SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10 SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. 62601F; PROJECT NO. 3326; TASK NO. 03; WORK UNIT ACCESSION NO 85

11 TITLE (Include Security Classification)
CHEMICALLY-PRODUCED $N_2(A)$ TO NO(X) ENERGY TRANSFER IN A SUPERSONIC FLOW

12. PERSONAL AUTHOR(S)
Jones, Yolanda D.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
Final	FROM Jul 84 TO Feb 86	1987, November	38

16. SUPPLEMENTARY NOTATION

17 COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Nitrogen fluoride, Excited nitrogen, Metastable nitrogen, Energy transfer, Chemical laser
07	02		

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

A supersonic nozzle has been used to produce $N_2(A)$ by the reaction of NF_2 and H. The NO has been added to the flow via a hypersonic wedge. Excited state NO has been observed from energy transfer. The importance of showing chemically-produced $N_2(A)$ transfer of energy to NO is for possible use as a purely chemical ultraviolet laser. The densities observed here are not sufficiently high for use as a laser; however, these experiments indicate that in principle the transfer occurs with good efficiency in a chemical system.

20 DISTRIBUTION / AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Yolanda D. Jones	22b. TELEPHONE (Include Area Code) (505) 844-1786 22c. OFFICE SYMBOL AFWL/AWYW

DD FORM 1473, 84 MAR 83 APR edition may be used until exhausted
All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

PREFACE

The author would like to thank Capt Nanette D. Founds for her computational support; Mr. Ted Lane and Mr. Michael L. Orbock for their computer operation and electronics support; and Mr. Roman L. Martinez and TSgt James E. Garrett for their facility support.

The author would also like to thank Dr. Miles R. Palmer for his useful discussions.

CONTENTS

FIGURES

INTRODUCTION

The $N_2F_4 + H_2$ scheme for production of $NF(a^1\Delta)$, $NF(b^1\Sigma)$ and $N_2(A^3\Sigma_u^+)$ is well-known from flow tube studies at low pressure and low temperature (Refs. 1-4). The $N_2(A)$ is a good energy storage molecule with 6.2 eV of energy and a 2.0 s lifetime (Ref. 5). Because of the long lifetime of the species, $N_2(A)$ does not make a good laser candidate. Transfer of the energy in the $N_2(A)$ molecule to NO is well-documented (Refs. 6-8). The transfer is efficient, but has been demonstrated only in small-scale systems such as flow tubes and with nonchemically produced $N_2(A)$. This set of experiments was designed to demonstrate efficient NO excitation by $N_2(A)$ in a purely chemical system as produced via the following reactions:

$$N_2F_4 \xrightarrow{\Delta} NF_2 \qquad (1)$$

$$F + H_2 \longrightarrow H + HF \qquad (2)$$

$$H + NF_2 \longrightarrow NF(a^1\Delta) + HF \qquad (3)$$

$$H + NF(a^1\Delta) \longrightarrow N(^2D) + HF \qquad (4)$$

$$N(^2D) + NF(a^1\Delta) \longrightarrow N_2(B) + F \qquad (5)$$

$$N_2(B) \longrightarrow N_2(A) + h \qquad (6)$$

$$N_2(A) + NO \longrightarrow N_2 + NO(A) \qquad (7)$$

Although, the $N_2(A)$ to NO transfer is efficient, when NO is added to the excited nitrogen system, the kinetics become complicated. A basic set of the $N_2(A)$ + NO reactions and rates is given in the Appendix. The transition of interest in NO is the $A \rightarrow X$. The $NO(A^2)$ state has a lifetime of 2.0×10^{-7} s (Ref. 9). The Franck-Condon factor for the $NO(A^2\Sigma, v' = 0)$ to NO $(X^2\Pi, v' = 1)$ transition is the largest at 0.26 (Ref. 10). The NO(A-X) spectrum is complex with 8 branch bands (Refs. 11 and 12). The A-state rotational constant is

1.9965 and the Boltzmann rotational distribution is centered about J = 7 (Ref. 13). The stimulated emission cross section can be calculated as 1.03 X 10^{-16} cm^2. The NO molecule is a promising laser candidate and has been lased by optical pumping (Ref. 14).

Early work by Setser (Ref. 15) and Collear (Ref. 16) showed that the $N_2(A^3\Sigma, v' = 1)$ to NO $(X^2\Pi, v'' = 0)$ transfer resulted in $NO(A^2\Sigma)$ in the ratio of v = 1 to v = 0 of 1:10 (Ref. 15) and 1:2 (Ref. 16). This is the dominant process since $N_2(A)$ in $v > 1$ rapidly relaxes by V-V processes with $N_2(X)$ (Ref. 15). The most desirable NO(A-X) transitions for lasing are the strong emission lines of $v' = 0$ to $v'' = 1, 2$.

DEVICE DESCRIPTION

OVERVIEW

The overall system consisted of a 316L stainless steel chamber with viewing ports on four sides and has been previously described (Ref. 17). Figure 1 shows a top view of the chamber with positions shown for the gas input plumbing. The chamber was exhausted into a cooled diffuser in the transition section and two heat exhangers. The device was evacuated using two Kinney 850 cfm pumps with two M & D Pneumatics 2700 cfm blowers for a system total of 7,100 cfm.

The BCL - 16 nozzle was positioned in the chamber wall with the gas inputs. The BCL - 16 nozzle cross section is shown in Figure 2. The BCL - 16 nozzle was developed for HF/DF laser application (Ref. 18) and studied for those same systems (Ref. 19). For the $N_2F_4 + H_2$ system the combustor portion of the assembly nozzle was operated as it had been designed to produce F atoms. The hydrogen or deuterium and fluorine were injected into the combustor along with helium diluent at a molar ratio of F_2:D_2:He of approximately 1:2:50.

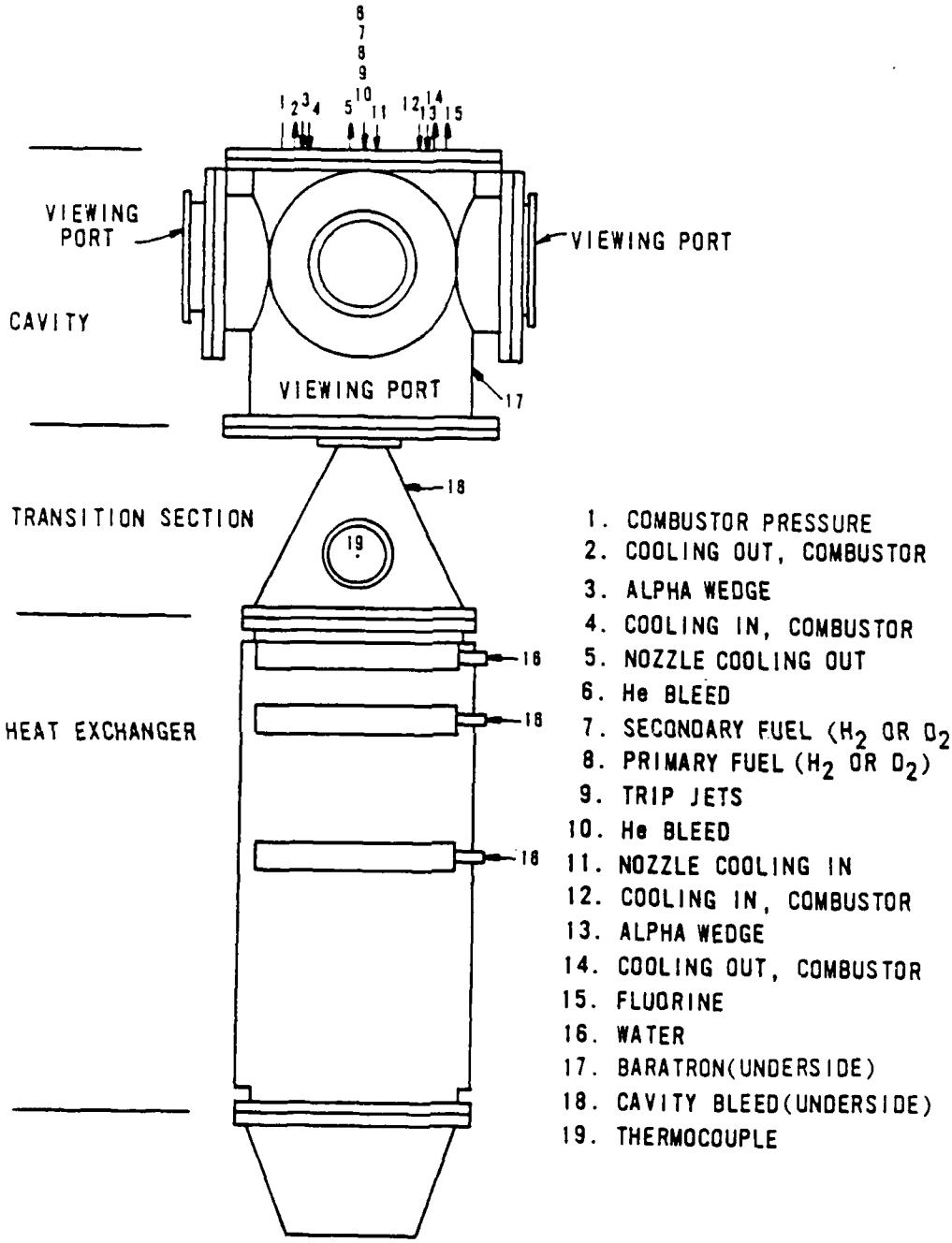


Figure 1. System overview.

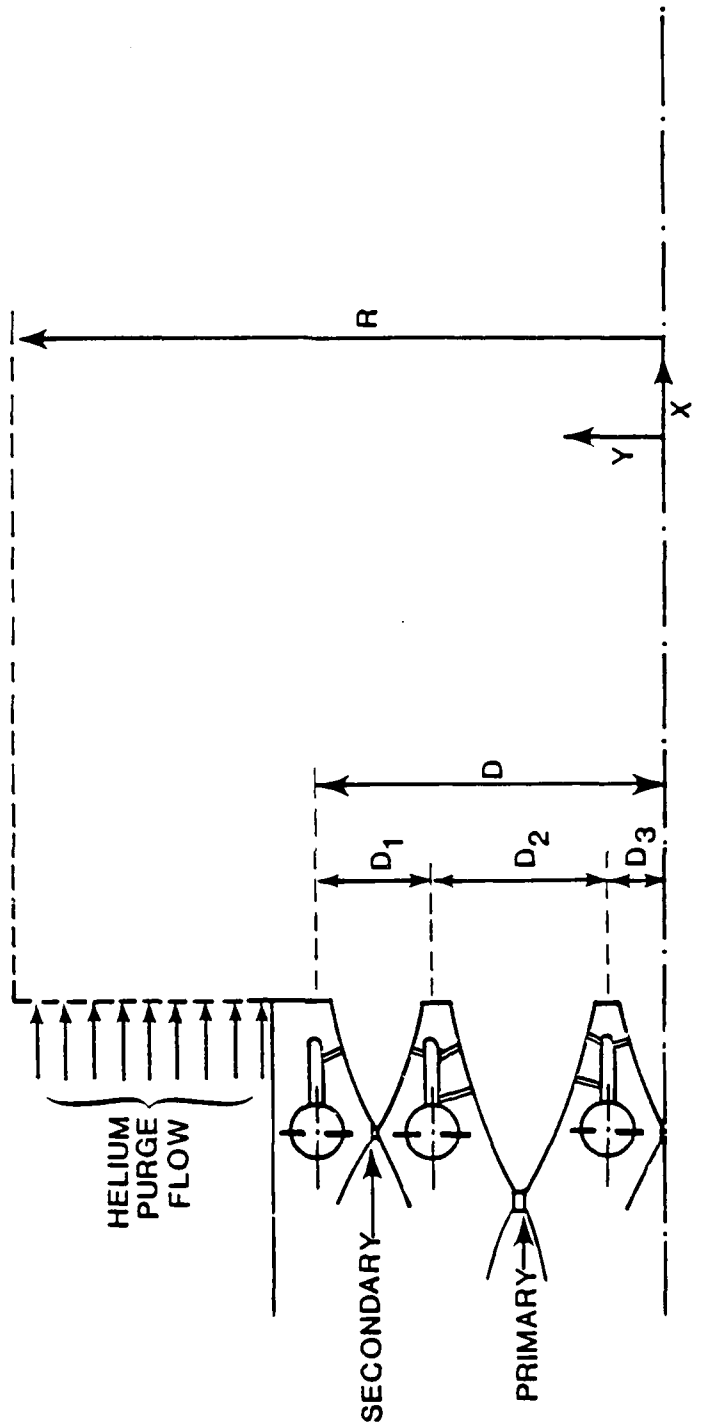


Figure 2. Cross section of the BCL-16 nozzle.

NO INJECTOR SYSTEM

The NO was delivered to the system via a hypersonic wedge constructed from aluminum (Fig. 3). The wedge was used for preliminary examination of the NO injection. The gas was fed to the wedge by two tubes which also served as supports. The tubing could be moved along the centerline (X_c) of the cavity. This allowed for optimization of the NO(A-X) emission by varying the injection position and the NO flow rate. The NO flow system is depicted in Fig. 4. The N_2 or He could be provided through the purge system. During testing only He was used as a diluent. The entire system was operated remotely. For safety, however, an NO detector (Ecolyzer, Model 412) was placed near the device.

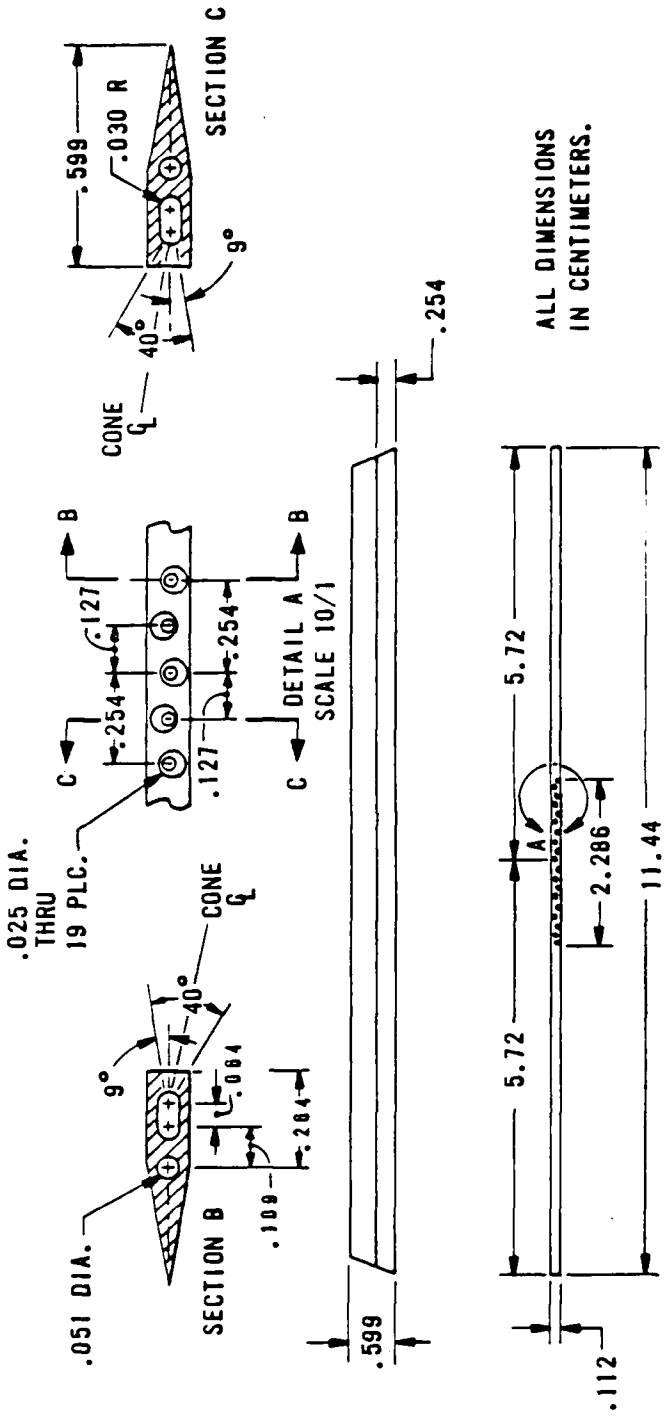


Figure 3. Detail of the NO injector.

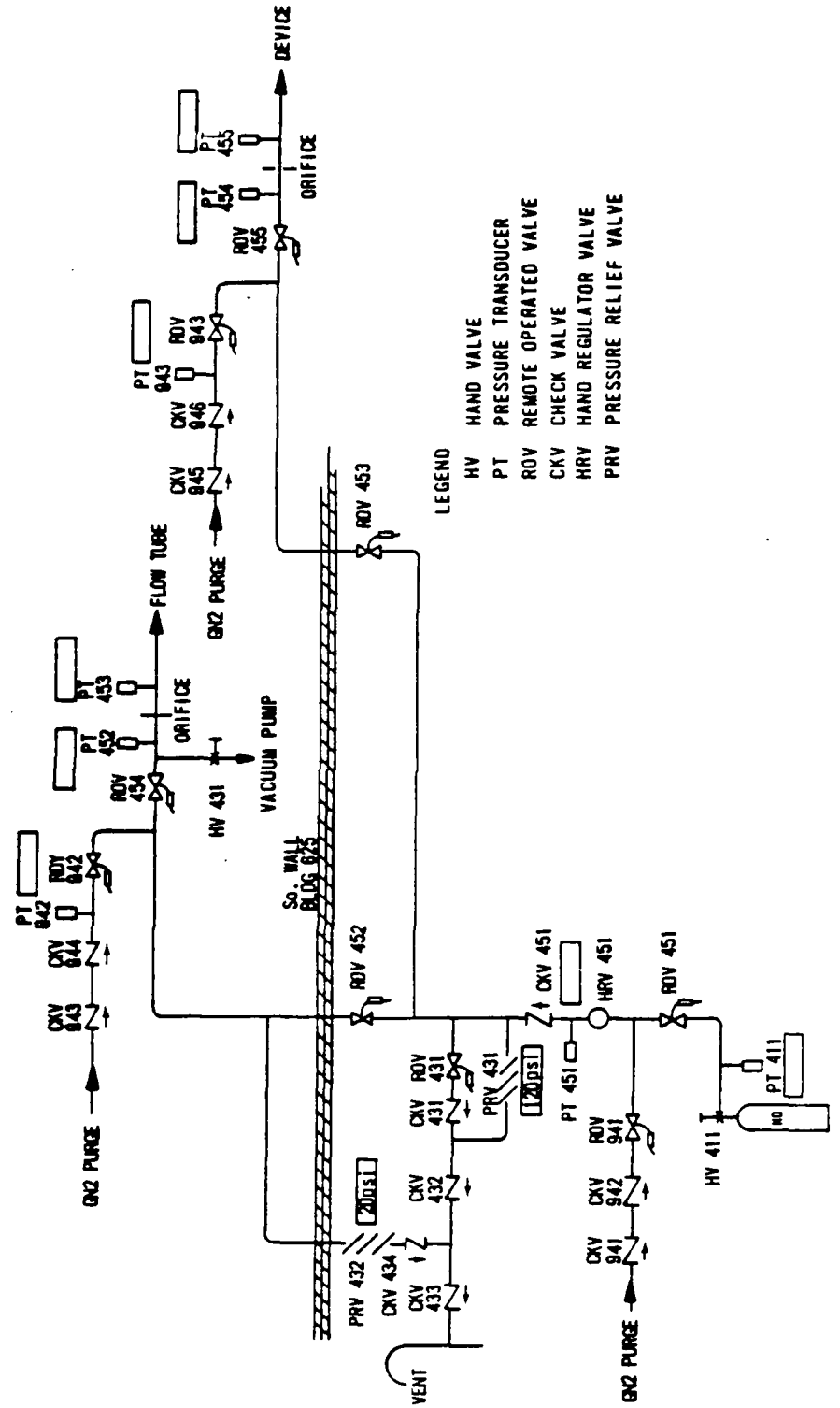


Figure 4. NO flow system.

DIAGNOSTICS

$NF(a^1\Delta)$ AND $NF(b^1\Sigma)$ DIAGNOSTICS

The $NF(a^1\Delta)$ diagnostic was an important part of the reaction analysis. The NF(a) and NF(b) diagnostics have been described (Ref. 20). The 874.2 nm emission from the NF(a-x) transition was detected via a 38.1 cm long spatial filter with 0.17 cm dia orifices coupled to a fused silica fiber optic. The fiber optic was bifurcated so that one end was fed into the NF(b) diagnostic. This allowed detection of NF(a) and NF(b) to be made within the same viewing volume. The diagnostic as applied to the device is shown in Fig. 5. The actual width of the flame was used to determine the volume viewed by the diagnostic. The NF(a) emission was filtered using an extremely narrow bandpass filter (FWHM 0.98 nm) centered at 874.29 nm which essentially eliminated interferences from the close-lying $N_2(B)$ and HF(v=3) emissions.

The NF(b) diagnostic used the same bifurcated fiber optic with the output of the other porting of the cable going to a narrow bandpass filter centered at 531.4 nm and FWHM of 9.8 nm. The 538.8 nm emission of the NF ($b^1\Sigma$-$X^3\Sigma$) transition was not masked by any near-lying emissions. The spatial filter was mounted on a remotely operated translation stage with a linear voltage displacement transducer (LVDT) to accomplish scans across the flow field of the device with a known position. Sample scans of the $NF(a^1\Delta)$ and $NF(b^1\Sigma)$ emissions are shown in Figs. 6 and 7.

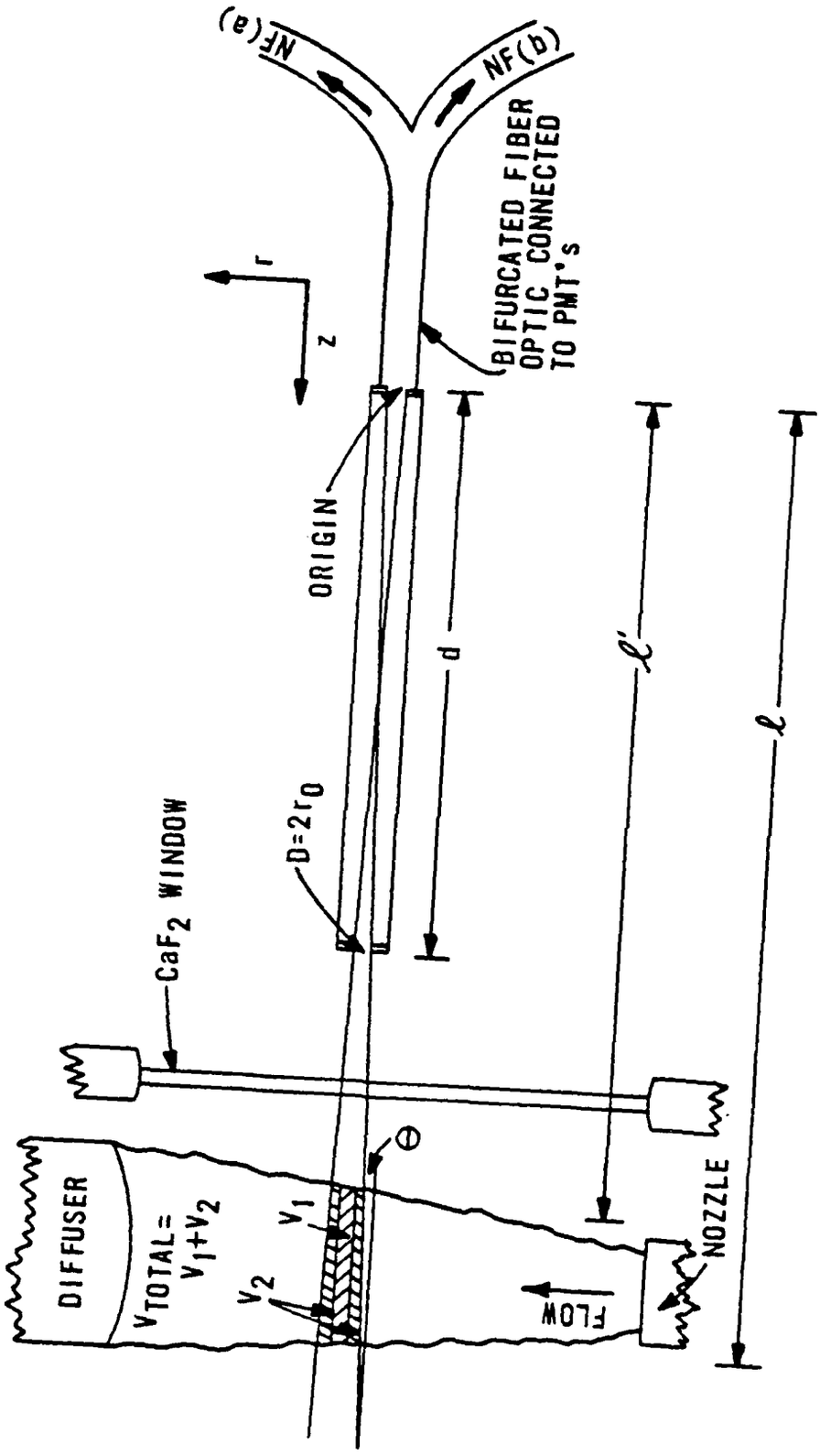


Figure 5. Diagnostic set-up.

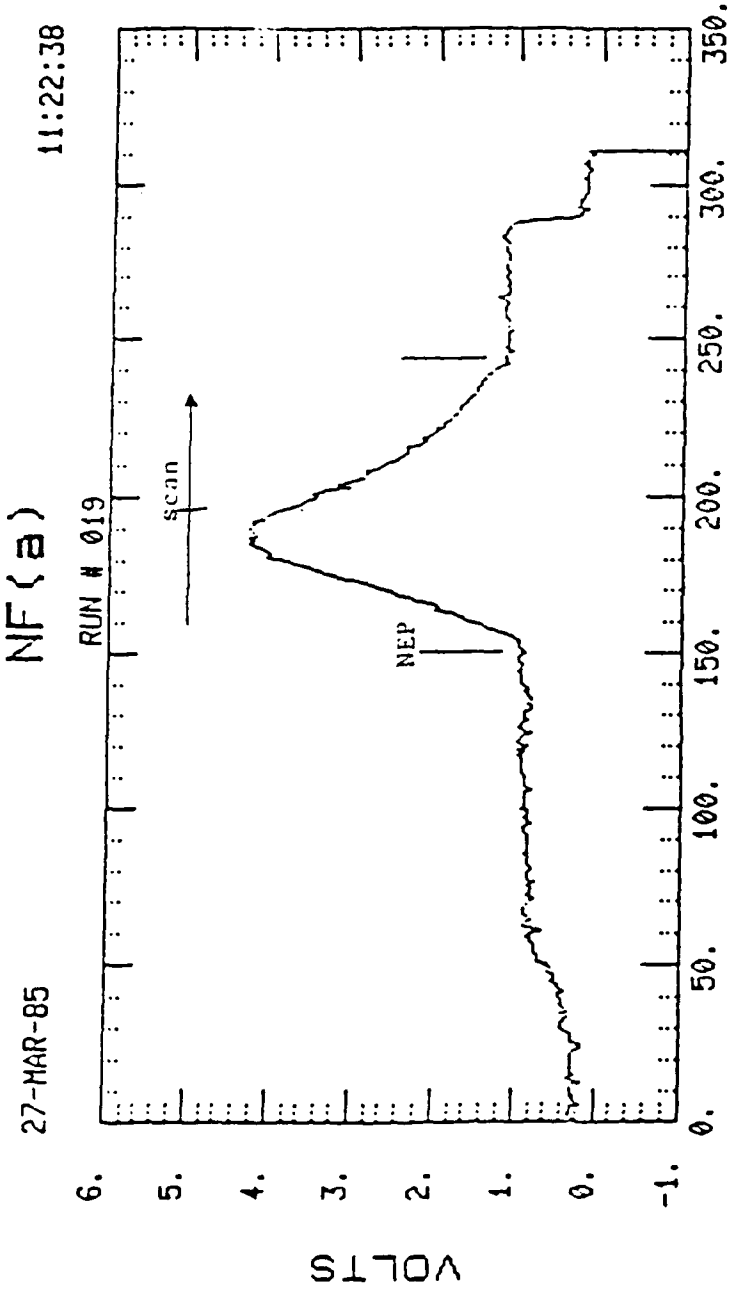


Figure 6. Sample NF(a) scan.

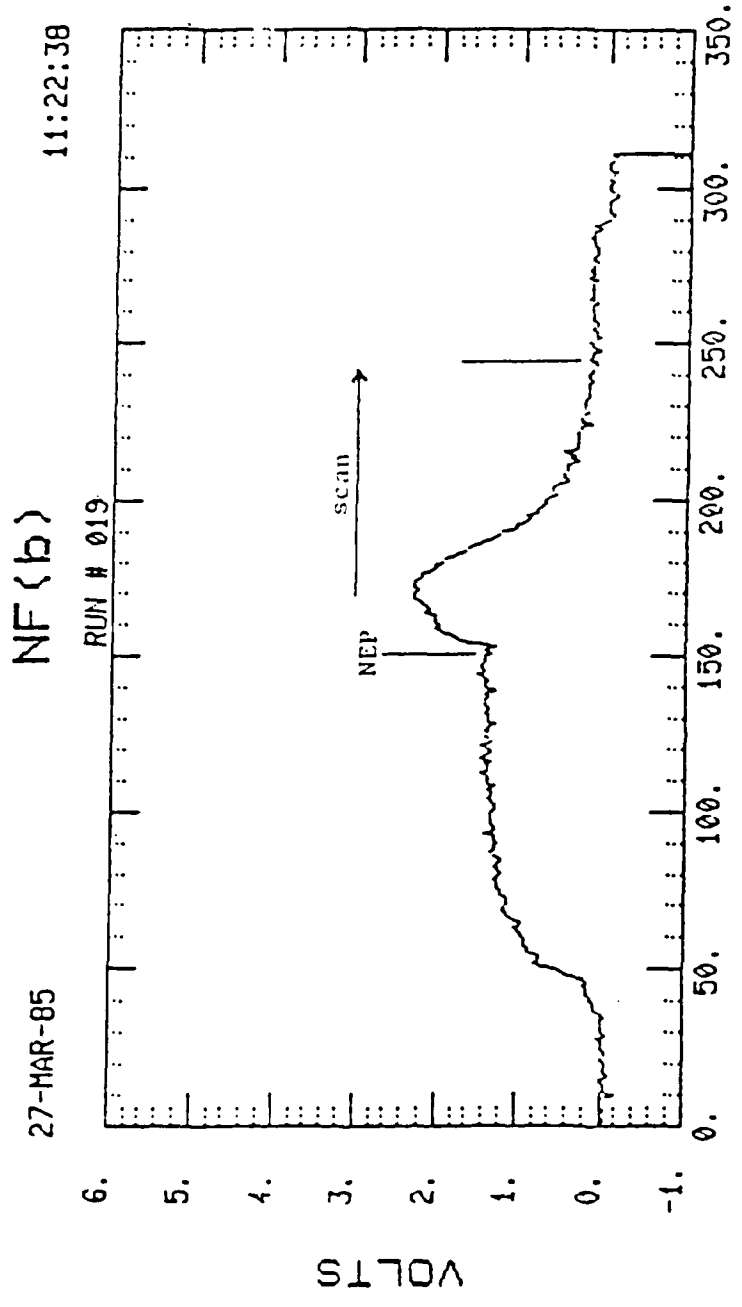


Figure 7. Sample NF(b) scan.

OPTICAL MUTICHANNEL ANALYZER (OMA)

The OMA III 1460R system (EG&G PAR) was used to monitor the change in emission over a wide wavelength range (usually 300-900 nm) at a fixed point within the device. The OMA III system consisted of a nonintensified diode array head (Model 1412) coupled to a Model 1233 polychromator.

$N_2(A)$ TO NO TRANSFER STUDIES

The system $N_2(A)$ production was optimized and has been described previously (Ref. 21). Maximum $N_2(A)$ production was found to occur when D_2 was used in place of H_2 due to better penetration of the higher molecular weight gas and fewer loss mechanisms for the $NF(a^1\Delta)$ (Ref. 22). The two effects cannot, at this time, be decoupled because of only preliminary flow studies. The $N_2(A)$ was monitored by the visible $N_2(B)$ emission in the flow. The $N_2(B)$ relaxes to $N_2(A)$ with the emission of a photon. The $N_2(A)$ may also be produced directly. Therefore, the $N_2(b)$ gave a lower limit to the actual $N_2(A)$ production. The additional $N_2(A)$ contribution was evaluated by examination of the $N_2(c)$ population in previous experiments (Ref. 23). The $N_2(b)$ was determined to be accurate to within a factor of 10. Without the hypersonic wedge in place, maximum $N_2(B)$ was about 2×10^{11} molecules/cm^3. The wedge interfered slightly with the flow field and, thus, mixing of the NF_2 and H_2 streams. The maximum $N_2(B)$ detected with the wedge in place was about 1×10^{11} molecules/cm^3. Variation of the injection point along the X_c was first performed. Figure 8 shows the variation of NO(A-X) emission (or γ-bands) with wedge position. The distance measured was from the backside of the wedge which had a width of 0.599 cm. The maximum NO(A-X) emission was at 1 to 2 cm from the nozzle exit plane (NEP).

Flow rate variation is shown in Figs. 9 and 10. Figure 9 shows the NO(A-X) emission as a function of flow rate of NO. The NO emission decreased with increased NO flow rate. This is probably due to disturbance of the mixing of primary, secondary and trip jets by large flow rate injection. The flow rate range was limited by the flow control system. The NO can react with $N(^2D)$ rapidly (Ref. 23), $k = 7.0 \times 10^{11}$ cm^3/molecules-s, providing a competitive pathway for $N_2(A)$ formation. There is a definite decrease in $N_2(B)$ with increasing NO flow rate (Fig. 10). The decrease is most probably due to a combination of these effects in addition to self-quenching. The effect of He diluent is demonstrated by the data on the graph in Fig. 9 at 0.181 g/s NO. The He effectively dilutes the flow and does not aid mixing.

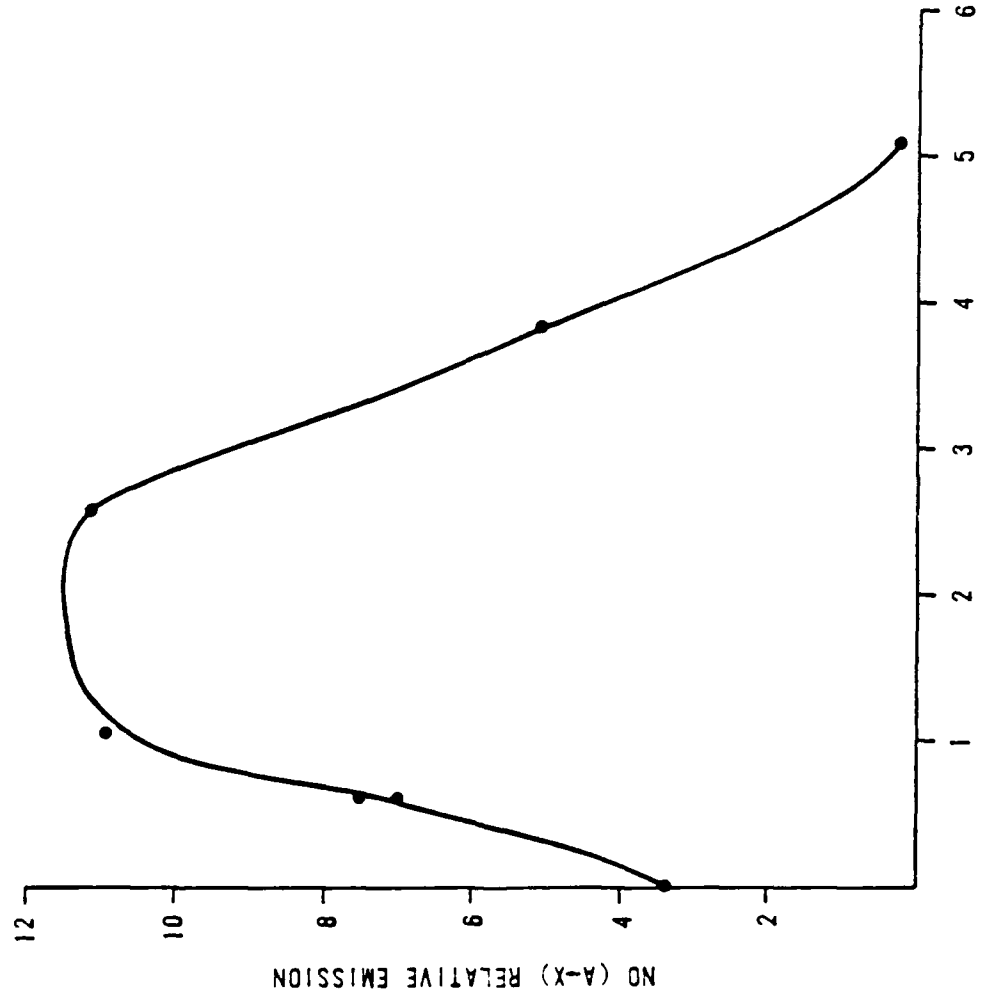


Figure 8. NO emission with variation in injector position.

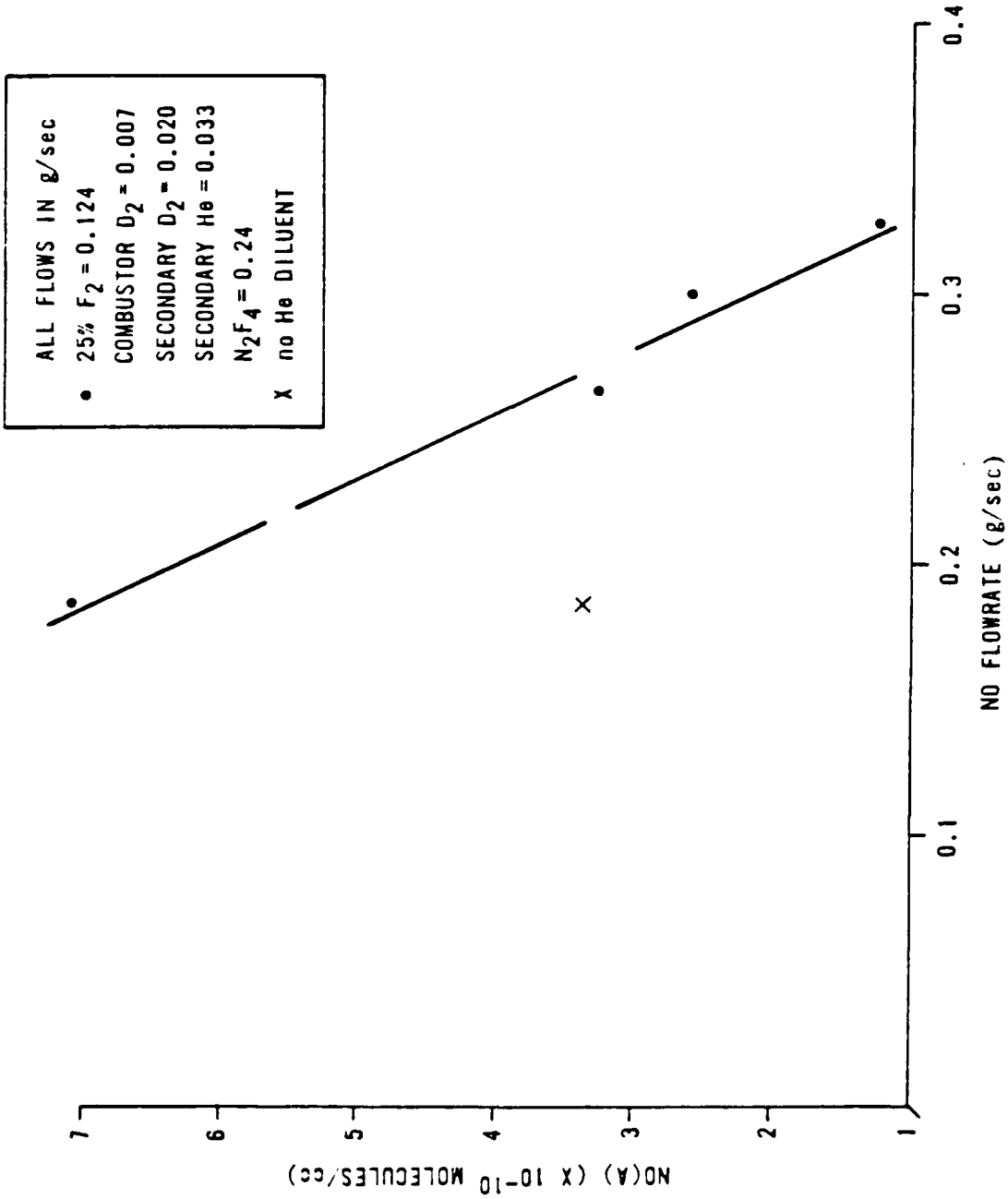


Figure 9 NO(A) emission as a function of NO flow rate.

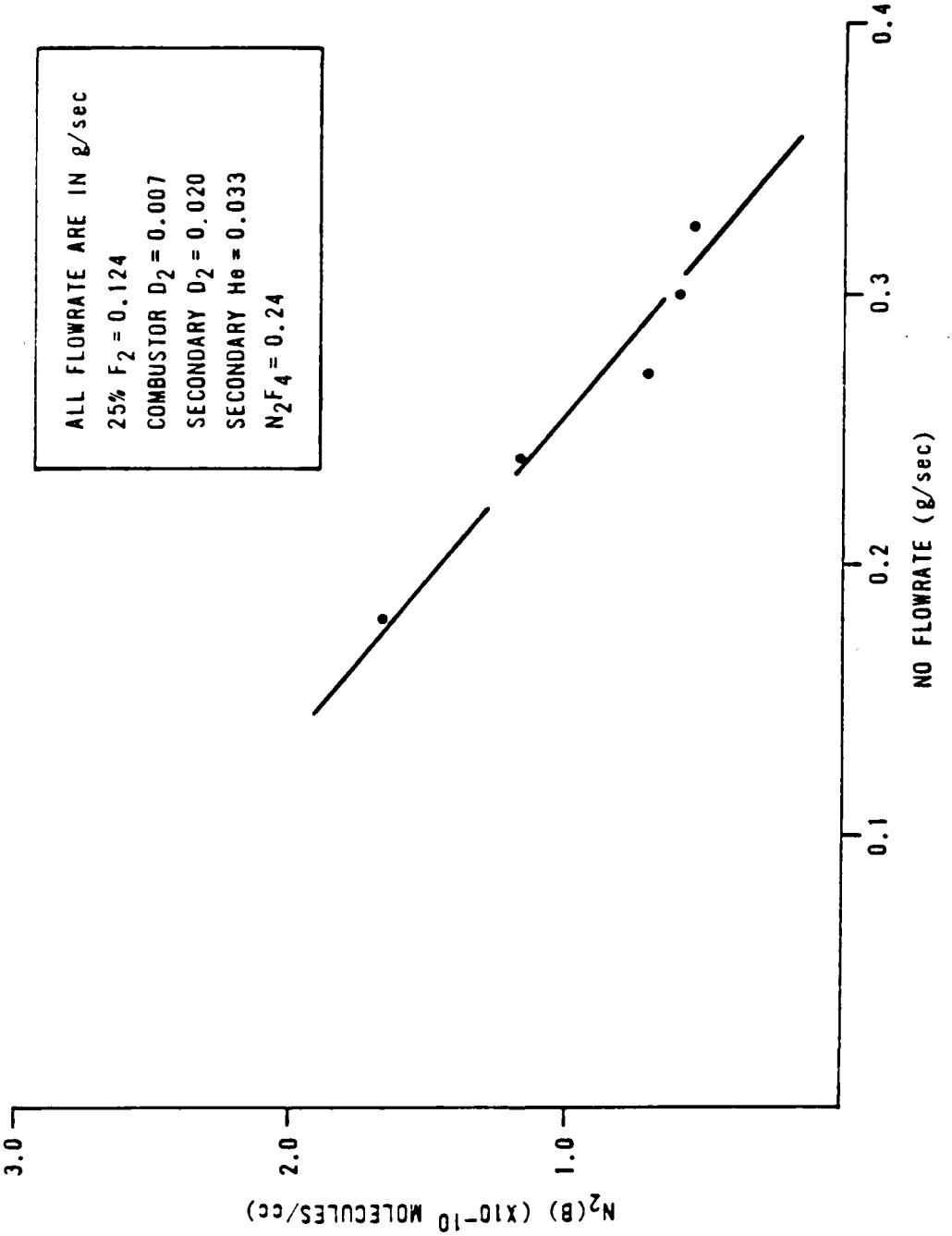


Figure 10. Variation of $N_2(B)$ emission as a function of NO flow.

A minimum number of runs were performed with trip jet injection of the D_2 and secondary injection of the N_2F_4. These were designed to determine if mixing could be improved in this configuration, providing greater number densities of NO(A). Table 1 contains information from the tests. There is some increase observed in the reversed configuration. The NO does not appear to interfere with $NF(a^1\Delta)$ or $NF(b^1\Sigma)$ production significantly as evidenced by the high concentrations in the tests.

Table 2 contains information from several tests where data was taken with and without NO flow. For the two high NO flow rate conditions, the efficiency is 30 to 50 percent due to the creation of turbulence in the flow. At the low flow rate, using the $N_2(B)$ emission yields a greater than 100 percent transfer. What is actually occurring is that not all of the $N_2(A)$ is accounted for by the $N_2(B)$ emission. This also implies that the $NF_2 + D_2$ reaction sequence forms some $N_2(A)$ directly instead of all $N_2(B)$ which then relaxes to $N_2(A)$. This is possible since the $N_2(A)$ is not detectable directly in this system because of interferences from NO emission from contaminants in the N_2F_4.

A typical OMA III spectra with NO is shown in Fig. 11. The NO(A-X, $V' = 0$) and NO(A-X, $V' = 1$) peaks were identified. Specifically, the (0-1), (0-2), (0-3), (0-4), (0-5), (0-6), (1-6), (1-7) and (1-8) peaks were detected. Possible β-band peaks are also identified in the figure. Figure 12 was taken on the same test with the NO flow turned off and is included for comparison. The OMA III scans shown are not corrected for wavelength response of the detector.

TABLE 1. D_2 Trip Jet Injection.

Wedge	Primary		Trip	Secondary		(Molecules/cm^3)			
NO[a] (at 0 position)	25% F_2 in He[a]	Combustor D_2[a]	D_2[a]	He[a]	N_2F_4[a]	$N_2(B)$ $\times 10^{10}$	NO(A) $\times 10^{10}$	NF($a^1\Delta$) $\times 10^{15}$	NF($b^1\Sigma$) $\times 10^{12}$
0.20	0.14	0.006	0.02	0.12	0.33	0.40	negl.	6.1	4.10
0.22	0.13	0.006	0.02	0.12	0.33	1.80	3.08	3.2	4.25
0.22	0.13	0.006	0.02	0	0.33	1.80	8.13	3.2	4.18
0.28	0.14	0.006	0.02	0.12	0.32	1.54	7.31	3.2	3.92
0.34	0.13	0.006	0.02	0.12	0.31	1.30	6.58	3.2	3.50
0.34[b]	0.13	0.006	0.02	0.12	0.28	1.39	6.25	2.0	3.34
0.34[b]	0.13	0.006	0.02	0	0.28	1.40	6.32	2.0	3.36

[a]All flow rates in g/s.

[b]Wedge at 0.64 cm position.

TABLE 2. $N_2(A)$ to NO Transfer Data .

Wedge	Primary		Trip	Secondary		(Molecules/cm^3)			
NO[a] (at 0 position	25% F_2 in HE[a]	Combustor D_2[a]	D_2[a]	He[a]	N_2F_4[a]	$N_2(B)$ $\times 10^{10}$	NO(A) $\times 10^{10}$	NF($a^1\Delta$) $\times 10^{15}$	NF($b^1\Sigma^+$) $\times 10^{12}$
0.183	0.12	0.007	0.02	0.03	0.21	2.23	9.23	5.2	2.71
0	0.12	0.007	0.02	0.03	0.21	6.00	0	5.2	2.85
0.238	0.13	0.007	0.02	0.03	0.24	1.30	2.31	4.0	1.12
0	0.13	0.007	0.02	0.03	0.24	4.31	0	4.0	2.15
0.33	0.12	0.007	0.02	0.03	0.23	0.54	1.22	3.9	0.73
0	0.12	0.007	0.02	0.03	0.23	4.11	0	3.9	1.96

[a]All flow rates in g/s.

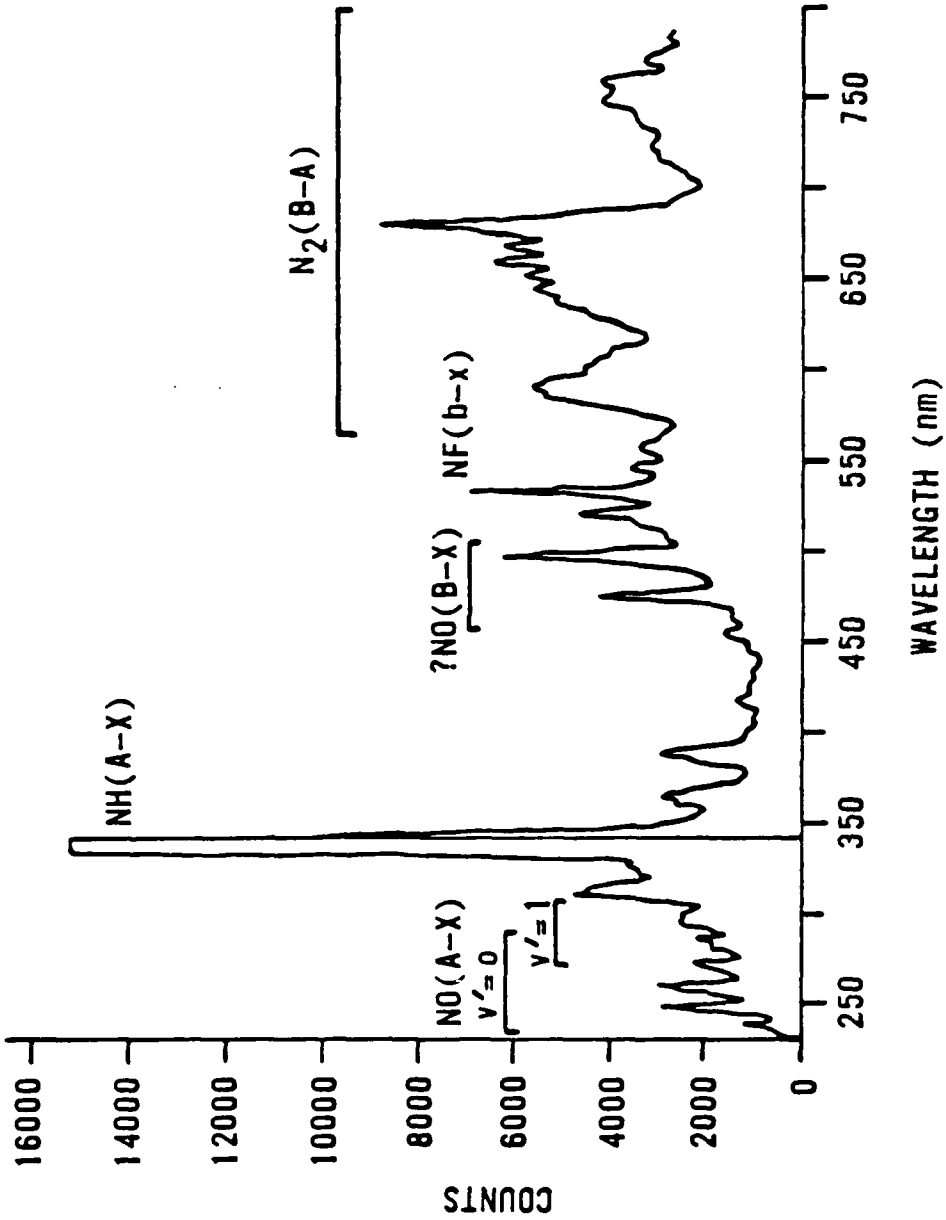


Figure 11. OMA III scan with NO flow on.

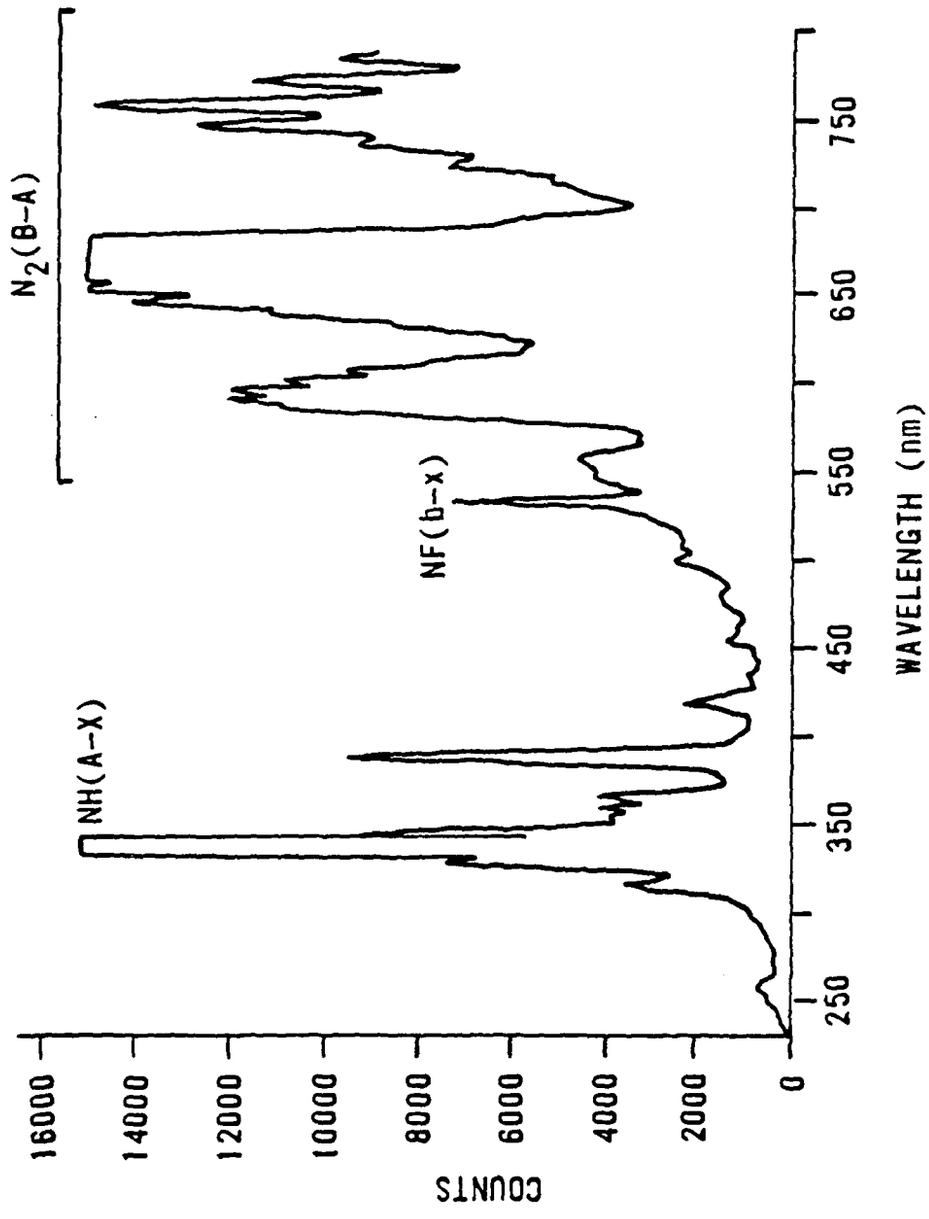


Figure 12. OMA III scan without NO flow.

CONCLUSIONS

Efficient $N_2(A^3\Sigma)$ to NO ($X^2\Pi$, $V'' = 0$) transfer has been demonstrated using a purely chemical production method for $N_2(A^3\Sigma)$. The $N_2(A)$ production system is complex and is not completely understood. Improvements in nozzle design could increase the $N_2(A)$ production which would allow for greater NO(A) densities. Improvements in the $N_2(A)$ production have been discussed in Reference 21. The maximum production level of NO(A) in these experiments was about 10^{11} molecules/cm^3. Levels on the order of 10^{14} are required to demonstrate gain over the short path length provided by this nozzle and system. Therefore, for nozzle development not only increased $N_2(A)$ production should be examined, but also gain path length. The $N_2(A)$ to NO(X) energy transfer system is promising for development into a chemical laser system.

REFERENCES

1. Herbelin, J. M. and Cohen, N., Chem. Phys. Lett. 20, 603 (1973).

2. Malins, R. J. and Setser, D. W., J. Chem Phys. 85, 1342 (1981).

3. Cheah, C. T., Clyne, M. A. A. and Whitefield, P. D., JCS Faraday II 76, 711-728 and 1543-1560 (1980).

4. Cheah, C. T. and Clyne, M. A. A., J. Photochemistry 15, 21 (1981).

5. Shemansky, D. E., J. Chem. Phys., 51, 689 (1969).

6. Young, R. A., Black, G., and Slanger, T. G., J. Chem Phys., 49, 4769 (1968).

7. Kaufman, F. and Kelso, J. R., J. Chem Phys, 28, 510 (1958) and 27, 1210 (1957).

8. Clark, W. G. and Setser, D. W., J. Chem Phys., 84, 2225 (1980).

9. Zacharias, H., Halpern, J. B. and Welge, K. H., Chem Phys. Lett., 43, 41 (1976).

10. Jarmain, W. R., Fraser, P. A. and Nicholls, R. W., Astrophys. J., 118, 228 (1955).

11. Mulliken, R. S., Phys. Rev., 32, 388 (1928).

12. Mulliken, R. S., Rev. Mod. Phys.,3, 89 (1931).

13. Molecular Spectra and Molecular Structure, IV. Constants of Diatomic Molecules, K. P. Huber and G. Hergberg, Van Nostrand Reinhold, New York (1979).

14. Burrows, M. D., Baughcum, S. L. and Oldenborg, R. C., Appl. Phys. Lett, 46, 22 (1985).

15. Stedman, D. H., and Setser, D. W., Chem. Phys. Lett. 2, 542 (1968).

16. Collear, A. B. and Wood, P. M., Trans Fara Soc 67, 272 (1971).

17. Jones, Y. D., NF($a^1\Delta$) Production in a Supersonic Flow Using N_2F_4+H_2 in a BCL-16 Nozzle, AFWL-TR-87-24, Kirtland AFB, NM, to be published.

18. Tregay, G. W. et. al., DF/HF Chemical Laser Technology, Bell Aerospace Textron Report No. D9276-9270003, Bell Aerospace Textron, Buffalo, NY January 1981.

19. Rapagnani, N. L., Ph.D Dissertation Universie Libre de Bruxellex Faculte des Sciences Appliquees, Brussels, Belgium, June 1983.

REFERENCES (Concluded)

20. Jones, Y. D., An Absolute Scanning NF($a^1\Delta$) and NF($b^1\Sigma$) Diagnostic for the N_2F_4+H_2 System, AFWL-TR-86-99, Kirtland AFB, NM, June 1987.

21. Jones, Y. D., Founds, N. D., Hibson, D. V. and Palmer, M. R., N_2(A) by Reaction of Tetrafluorohydrayine and Hydrogen in a Supersonic Flow, AFWL-TR-87-73, to be published.

22. Herbelin, J. M. and Cohen, N., Chem. Phys. Lett. 20, 605 (1973).

23. Lin, C. L. and F. Kaufman, J. Chem. Phys., 55, 3760 (1971).

24. Jones, Y. D., Founds, N. D. and Pchelkin, N. R., Preliminary Studies of NF_3 + H_2 Production of N_2(A) in a Supersonic Flow, AFWL-TR-87-71, to be published.

APPENDIX

$N_2(A)$ to NO(X)

KINETICS

TABLE A-1. Kinetic Rates.

1.	$N_2(A) + NO(X) \rightarrow N_2(X) + NO(A)$	$k_1 = 1.5 \times 10^{-10}$	(Ref 1)
2.	$NO(A) + NO(X) \rightarrow NO(X) + NO(X)$	$k_2 = 1.7 \times 10^{-10}$	(Ref 2)
3.	$NO(A) + N_2(X) \rightarrow NO(X) + N_2(X)$	$k_3 = 1.1 \times 10^{13}$	(Ref 2)
4.	$NO(A) + N_2(B) \rightarrow NO(X) + N_2(A)$	$k_4 = 2.4 \times 10^{-10}$	(Ref 3)
4a.	$\rightarrow NO(X) + N_2(X)$		
5.	$N(^2D) + NO(X) \rightarrow N_2(X) + O(^3P)$	$k_5 = 7.0 \times 10^{-11}$	(Ref 4)
5a.	$\rightarrow N_2(X) + O(^1D)$		
5b.	$\rightarrow N_2(X) + O(^1S)$		
6.	$N(^4S) + NO(X) \rightarrow N_2(X) + O(^3P)$	$k_6 = 3.6 \times 10^{-11}$	(Ref 5)
6a.	$\rightarrow N_2(X) + O(^1D)$		
6b.	$\rightarrow N_2(X) + O(^1S)$		
7.	$N_2(A) + O(^3P) \rightarrow N_2(X) + O(^3P)$	$k_7 = 2.8 \times 10^{-11}$	(Ref 6)
7a.	$\rightarrow N_2(X) + O(^1D)$		
7b.	$\rightarrow N_2(X) + O(^1S)$	$k_{7b}/k_7 = .75$	(Ref 7)
7c.	$\rightarrow NO(X) + N(^4S)$		
7d.	$\rightarrow NO(X) + N(^2D)$		
8.	$O(^1D) + N_2(X) \rightarrow O(^3P) + N_2(X)$	$k_8 = 6.9 \times 10^{-11}$	(Ref 8)
9.	$O(^1S) + O(^3P) \rightarrow O(^1D) + O(^3P)$	$k_9 = 1.8 \times 10^{-11}$	(Ref 9)
9a.	$\rightarrow O(^3P) + O(^3P)$		
10.	$O(^1D) + NO(X) \rightarrow O(^3P) + NO$	$k_{10} = 8.5 \times 10^{-11}$	(Ref 10)
10a.	$\rightarrow N(^4S) + O_2(X)$		
11.	$O(^1S) + NO(X) \rightarrow O(^1D) + NO(X)$	$k_{11} = 4 \times 10^{-10}$	(Ref 11)
11a.	$\rightarrow O(^3P) + NO(X)$		
11b.	$\rightarrow N(^2D) + O_2(X)$		
11c.	$\rightarrow N(^4S) + O_2(a)$		
11d.	$\rightarrow N(^4S) + O_2(b)$		

All rates are in cm^3/molecule - s.

REFERENCES

A-1. Clark, W. G. and D. W. Setser, J Chem Phys 84, 2225 (1980).

A-2. Callear, A. B. and I. W. M. Smith, Trans Faraday Soc 59, 1720 (1963).

A-3. Young, R. A., G. Black and T. G. Slanger, J Chem Phys 50, 303 (1969).

A-4. Lin, C. L. and F. Kaufman, J Chem Phys 55, 3760 (1971).

A-5. Clyne, M. A. A., and B. A. Thrush, Proc. Roy. Soc. A261, 259 (1961)

A-6. Piper, L. G., et al, J Chem Phys 75, 2847 (1981).

A-7. Piper, L. F., J Chem Phys 77, 2373 (1982).

A-8. Heidner, R. F., D. Husain and J. R. Wiesenfeld, JCS Faraday II 69, 927 (1973).

A-9. Slanger, T. G., and G. Black, J Chem Phys 64, 3763 (1976).

A-10. Heidner, R. F., and D. Husain, Int. J. of Chem. Kinetics 5, 819 (1973).

A-11. Black, G., et. al., Can. J. Chem. 47, 1872 (1969).

DISTRIBUTION

AF Institute of Technology
Attn: LDEE, Tech Lib
Wright-Patterson AFB, OH 45433-5000

Aeronautical Systems Division
Attn: XR
Air Force Systems Command
Wright-Patterson AFB, OH 45433-5000

Air University Library
Department of the Air Force
Maxwell AFB, AL 36112-5000

Asst Sec of Defense (OUSDRE)
Directed Energy Weapons
Washington, DC 20301

AF Office of Scientific Research
Attn: NM
Bolling AFB, DC 20332-6600

Aerospace Corporation
Attn: MI-999, Library
P.O. Box 92957
Los Angeles, CA 90009

Arnold Engrg Development Center
Attn: Tech Rprts Files
Arnold Air Station, TN 37389-5000

Avco Research Lab
2385 Revere Beach Parkway
Everett, MA 02149

Bell Aerospace Textron Div
Attn: Library
P.O. Box One
Buffalo, NY 14240

Foreign Technology Division
Attn: SQSA
Air Force Systems Command
Wright-Patterson AFB, OH 45433-6508

Hughes Acft Co EO DS Group
ATTN: Tech Documentation Center
P.O. Box 902
El Segundo, CA 90245

Institute for Defense Analysis
Attn: Classified Lib, E. Bauer
1801 N. Beauregard St
Alexandria, VA 22311

Lockheed Missile Space Center, Inc.
Attn: Tech Info Center
3251 Hanover Street
Palo Alto, CA 94304-1187

Chief, Naval Operations
Attn: QP982F4
Depatment of the Navy
Washington, DC 20350

Frank J. Seiler Research Lab
Attn: NH
USAFA
Colorado Springs, CO 80840-6528

General Research Corporation
Attn: Tech Info Office
P.O. Box 6770
Santa Barbara, CA 93160-6770

Hughes Research Laboratories
Attn: Library
3011 Malibu Canyon Road
Malibu, CA 90265

Lawrence Livermore National Lab
Attn: Tech Info Dept L-3
P.O. Box 808
Livermore, CA 94550

Los Alamos National Laboratory
Attn: Tech Library
P.O. Box 1663
Los Alamos, NM 87545

Martin Marietta Aerospace Co.
Attn: Research Lib, 2655
P.O. Box 179
Denver, CO 80201

MIT Lincoln Laboratory
Attn: A-082, Library
P.O. Box 73
Lexington, MA 02137

DISTRIBUTION (Continued)

Naval Surface Weapons Center
Attn: Lib Code E432
White Oak Laboratory
Silver Spring, MD 20903

Perkin-Elmer Corporation
Attn: Central Library
Main Avenue
Norwalk, CT 06851

Rockwell International
Attn: GA06, Tech Info Center
P.O. Box 92098
Los Angeles, CA 90009

Science Applications, Inc.
2361 Jefferson Davis Highway, St 320
Arlington, VA 22202

Undersec'y of Def Rsch Engrg
Attn: Strat Space Sys (OS)
Department of Defense
Washington, DC 20301

US Air Force Academy
Attn: DFP
Colorado Springs, CO 80840

Naval Research Laboratory
Attn: Code 2627, Tech Lib
Washington, DC 20375

Physical Sciences Inc.
P.O. Box 3100, Research Park
Andover, MA 01810

SRI International
Attn: Lib
333 Ravenswood Ave
Menlo Park, CA 94025

McDonnell-Douglas Astro Co
Attn: AR-135, Library Services
5301 Bolsa Avenue
Huntington Beach, CA 92647

Naval Postgraduate School
Attn: Code 1424, Lib
Department of the Navy
Monterey, CA 93940

Nimitz Library
Attn: Rprts Off/Comp Search Ctr
U.S. Naval Academy
Anapolis, MD 21402

Rockwell Int'l, Rocketdyne Div
Attn: Dept 086-306, Library
6633 Canoga Avenue
Canoga Park, Ca 91304

Sandia National Laboratories
Attn: Div 3144, Tech Lib
P.O. Box 5800
Albuquerque, NM 87115

TRW Electronics & Defense Sector
Attn: Tech Info Center
One Space Park
Redondo Beach, CA 90278

United Technologies Research Corp
Attn: Library
400 Main Street
East Hartford, CT 06108

US Army Ballistic Missile Defense
Advanced Technical Center
P.O. Box 1500
Huntsville, AL 35807

KAMAN TEMPO
Attn: DASIAC/DETIR, Mr. Wimenitz
2560 Huntington Ave, Suite 500
Alexandria, VA 22303

KAMAN TEMPO
Attn: DASIAC/DETIR, D. Reitz
P.O. Drawer QQ
Santa Barbara, CA 93102

AUL
Attn: LSE
Maxwell AFB, AL 36112

Defense Technical Information Cen
Attn: FDAC
Cameron Station
Alexandria, VA 22314

DISTRIBUTION (Concluded)

AFWL/ARBI
Kirtland AFB, NM 87117-6008

Official Record Copy
AFWL/AWYW/Dr Jones
Kirtland AFB, NM 87117-6008

Institute for Modern Optics
Department of Physics Astronomy
University of New Mexico
800 Yale Boulevard NE
Albuquerque, NM 87131

General Dynamics, Convair Div.
Attn: Research Lib
P.O. Box 85357
San Diego, CA 92138

Naval Sea Systems Command
Attn: PMS-405 J
Directed Energy Weapons Prog Office
Washington, DC 20362

AFSC
Attn: XRTD
Andrews AFB, DC 20334

AFCSA
Attn: SAMI
Washington, DC 20330-5425

AFWL
Attn: SUL
Kirtland AFB, NM 87117-6008

AFWL
Attn: HO
Kirtland AFB, NM 87117-6008

AFSC
Attn: DWL
Andrews AFB, DC 20334

AFWL
Attn: AR1 (Lt Col Ackermann)
Kirtland AFB, New Mexico 87117-6008

END

DATE

FILMED

DTIC

6-88