AD-A106 090 SPACE SCIENCES INC MONROVIA CA F/G 7/4
MASS SPECTROMETRIC STUDIES OF THE THERMAL DECOMPOSITION OF SOME--ETC(U)
SEP 81 M FARBER, R D SRIVASTAVA N00014-80-C-0711
UNCLASSIFIED NL

1 of 1
AD A
106090

END
DATE
FILMED
11-81
DTIC

SPACE SCIENCES, INC.

135 WEST MAPLE AVENUE • MONROVIA, CALIFORNIA 91016 • (213) 357-3879

LEVEL ②

AD A106090

6

MASS SPECTROMETRIC STUDIES OF THE THERMAL DECOMPOSITION OF SOME AZIDO POLYMERIC BINDERS

10 Milton Farber ~~and~~ R. D. Srivastava

9 ANNUAL SUMMARY REPORT, 1 Aug 80 - 31 Jul 81

Department of the Navy
Office of Naval Research
Arlington, Virginia 22217

15 Contract N00014-80-C-0711

11 Sept~~ember~~ 1981

12 36

DTIC
ELECTE
OCT 26 1981
S D
E

DTIC FILE COPY

81 10 26 025

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER

2. GOVT ACCESSION NO. AD-A106

3. RECIPIENT'S CATALOG NUMBER 090

4. TITLE *(and Subtitle)* MASS SPECTROMETRIC STUDIES OF THE THERMAL DECOMPOSITION OF SOME AZIDO POLYMERIC BINDERS

5. TYPE OF REPORT & PERIOD COVERED
Annual Summary
1 Aug 1980 - 31 July 1981

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
Milton Farber, R. D. Srivastava

8. CONTRACT OR GRANT NUMBER(s)
N00014-80-C-0711

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Space Sciences, Inc.
135 W. Maple Ave.
Monrovia, Ca 91016

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS
Office of Naval Research
Code 413
Arlington, VA 22217

12. REPORT DATE
September 1981

13. NUMBER OF PAGES
24

14. MONITORING AGENCY NAME & ADDRESS *(if different from Controlling Office)*

15. SECURITY CLASS. *(of this report)*
UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT *(of this Report)*

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

18. SUPPLEMENTARY NOTES

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*
3,3,bis(azidomethyl) oxetane polymer (BAMO)
glycidyl azide polymer (GAP)
azido oxetane monomer (AZOX)
thermal decomposition
activation energies
mass spectrometry

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

Thermal decomposition studies were conducted on BAMO, GAP and AZOX. Decomposition was initiated at approximately 120 C, with activation energies for the three materials approximately 170 kJ/mol^{-1}. The primary mechanism for the decomposition is the release of molecular N_2. Secondary decomposition occurring at temperatures above 150 C included the fracturing of the three-carbon backbone of both the polymers and the monomer. Higher decomposition temperature species included HCN, HCO, and smaller amu fragments.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

1. INTRODUCTION

During the past twelve months thermal decomposition studies were performed on several energetic azide monomers and polymers. These included 3,3,bis(azidomethyl) oxetane polymer (BAMO), glycidyl azide polymer (GAP), and azido oxetane monomer (AZOX). The materials were synthesized at various laboratories, which supplied samples: SRI International (BAMO), Edwards Air Force Base (GAP), and Fluorochem (AZOX).

The monomers and polymers all begin to decompose with the release of molecular nitrogen at approximately 120 C. Their activation energies for the primary mechanism of thermal decomposition, the breaking of the azido bond, were in the neighborhood of 170 kJ mol^{-1} (40 kcal/mole).

2. THERMAL DECOMPOSITION STUDIES ON AZIDO MONOMERS AND POLYMERS

2.1 Thermal Decomposition of BAMO-BDO, 3.2K

The thermal decomposition of BAMO,

$$H\left[O - CH_2 - C - (CH_2N_3)_2 - CH_2\right]_n OH$$

was studied by means of weight loss and mass spectrometry. The weight loss experiments involved placement of a capsule within an alumina effusion cell, as shown in Fig. 1. The cell was maintained at a constant temperature and products were released through the orifice into the vacuum chamber via an elongated orifice for molecular beam formation.

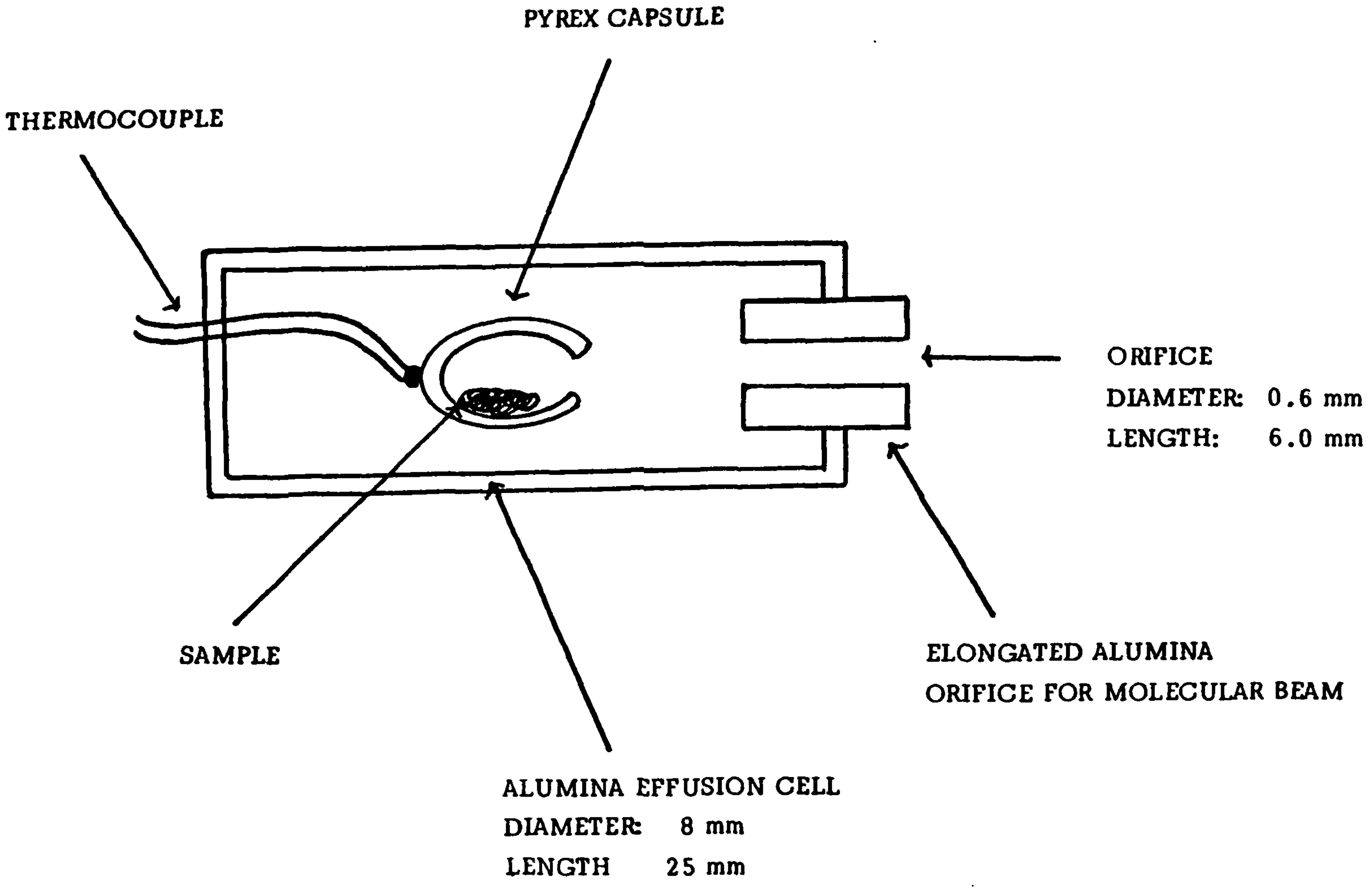


Fig. 1. Sample capsule within effusion cell with elongated orifice

Weight loss experiments on 25 mg samples of BAMO were performed for periods of 3 hours each at temperatures of 82, 100, 118, 130, 135, and 202 C. These data are presented in Table 1. No apparent decomposition occurred at 80, 100 or 120 C, although at 120 C the sample turned a slightly off-white, or cream, color from its original white. Slight decomposition began at 130 C, with nearly complete decomposition at 200 C, where the rate of decomposition was 20 times that at 130 C. A 25 mg sample maintained at 200 C for three hours lost 80% of its initial mass, leaving behind a carbonaceous tar residue. The melting point of the BAMO-BDO was found to be 75 C.

The release of molecular nitrogen can be seen as low as 130 C, and has a good temperature dependence above 160 C, depicted in Fig. 2., which shows the decomposition as a function of temperature quite clearly. At any given temperature the decomposition rate as a function of temperature is essentially constant, whether in a heating or cooling cycle. Figure 3 shows the decomposition of a 25 mg sample maintained at a temperature of 202 C over a two-hour period. As can be seen, for the first 1-1/2 hours the rate of N_2 evolution remains nearly constant, but as the sample becomes depleted during the last 30 minutes the N_2 concentration decays to a negligible amount.

An activation energy study of the primary decomposition path, the release of N_2 from the azide groups, was also completed. Figure 4 depicts the N_2 concentration as a function of temperature, while Fig. 5 is a plot of the N_2 intensity versus the reciprocal of the absolute temperature. The E_a for the BAMO-BDO, 3.2K, was determined as 178.7 kJ mol^{-1} (42.7 kcal/mole). From this study the primary mechanism for BAMO decomposition

Table 1

Thermal Decomposition of BAMO-BDO

Temp. (^oC)	Experiment Duration (hours)	Initial Sample Weight (gms)	Final Sample Weight (gms)	Rate of Decomposition (g/sec)	Appearance
82	3	0.0226	0.0226	0	No color change; sample melted
100	3	0.0226	0.0226	0	" "
118	3	0.0226	0.0226	0	Slightly off-white
130	3	0.0248	0.0235	1.2×10^{-7}	Cream colored
135	3	0.0347	0.0309	3.5×10^{-7}	" "
202	3	0.0252	0.0045	19.1×10^{-7}	Brownish-black char

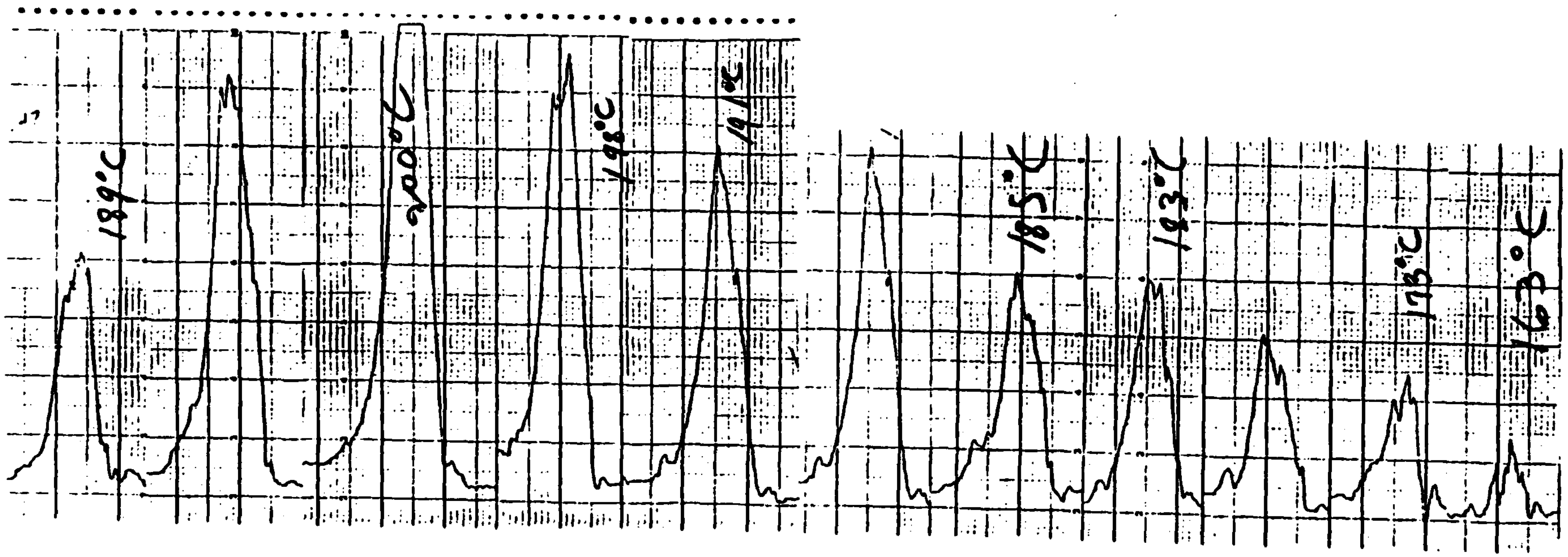


Fig. 2. Thermal Decomposition of BAMO-BDO as a Function of Temperature

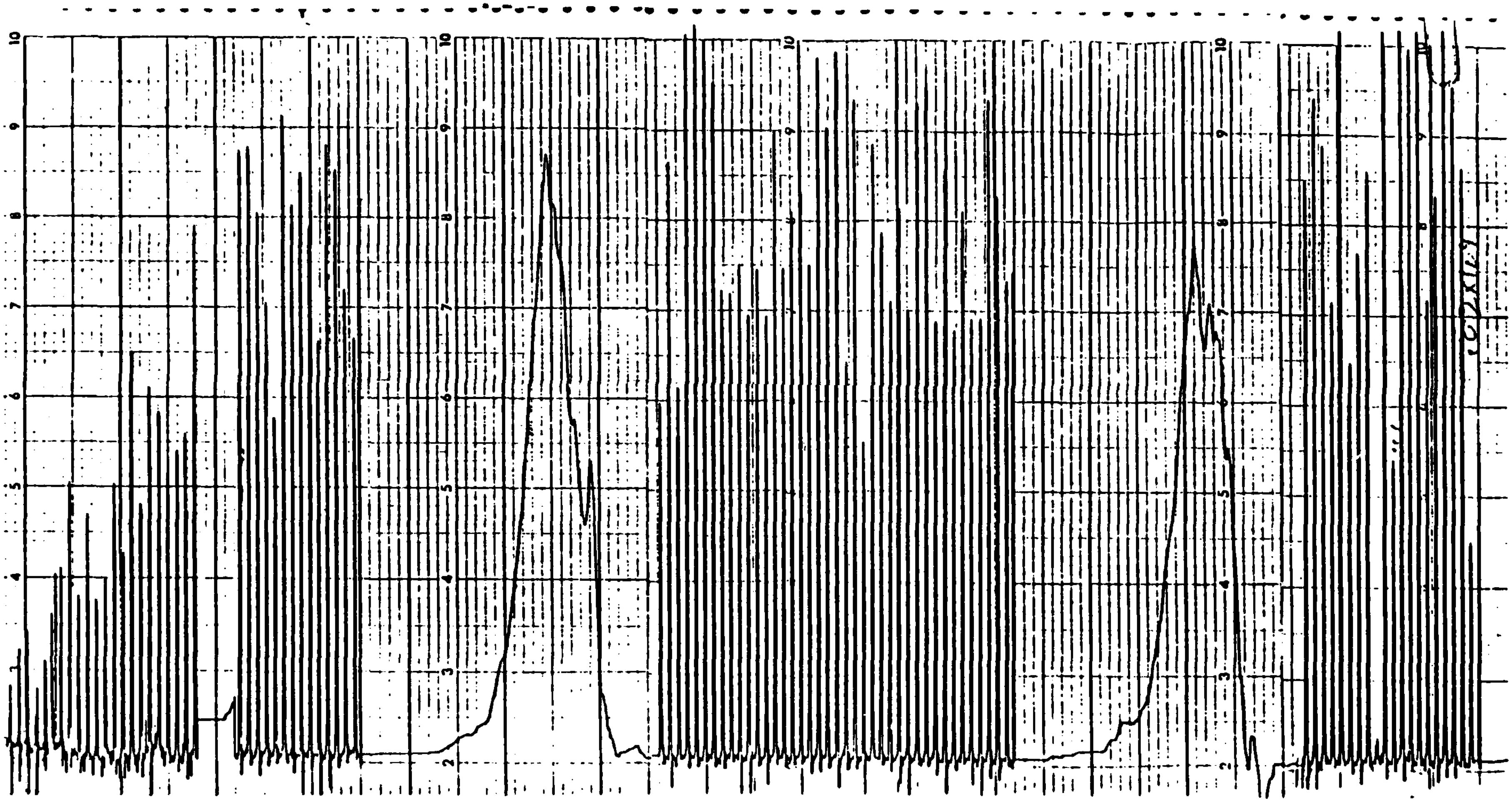


Fig. 3. Thermal Decomposition of BAMO-BDO. A 25 mg sample was heated at a constant temperature of 202 C for 2 hours. For the first 1-1/2 hours the rate of N_2 evolution was nearly constant (each line represents a time span of 1 minute). During the final 30 minutes the N_2 evolution showed a steady decline as the sample became depleted.

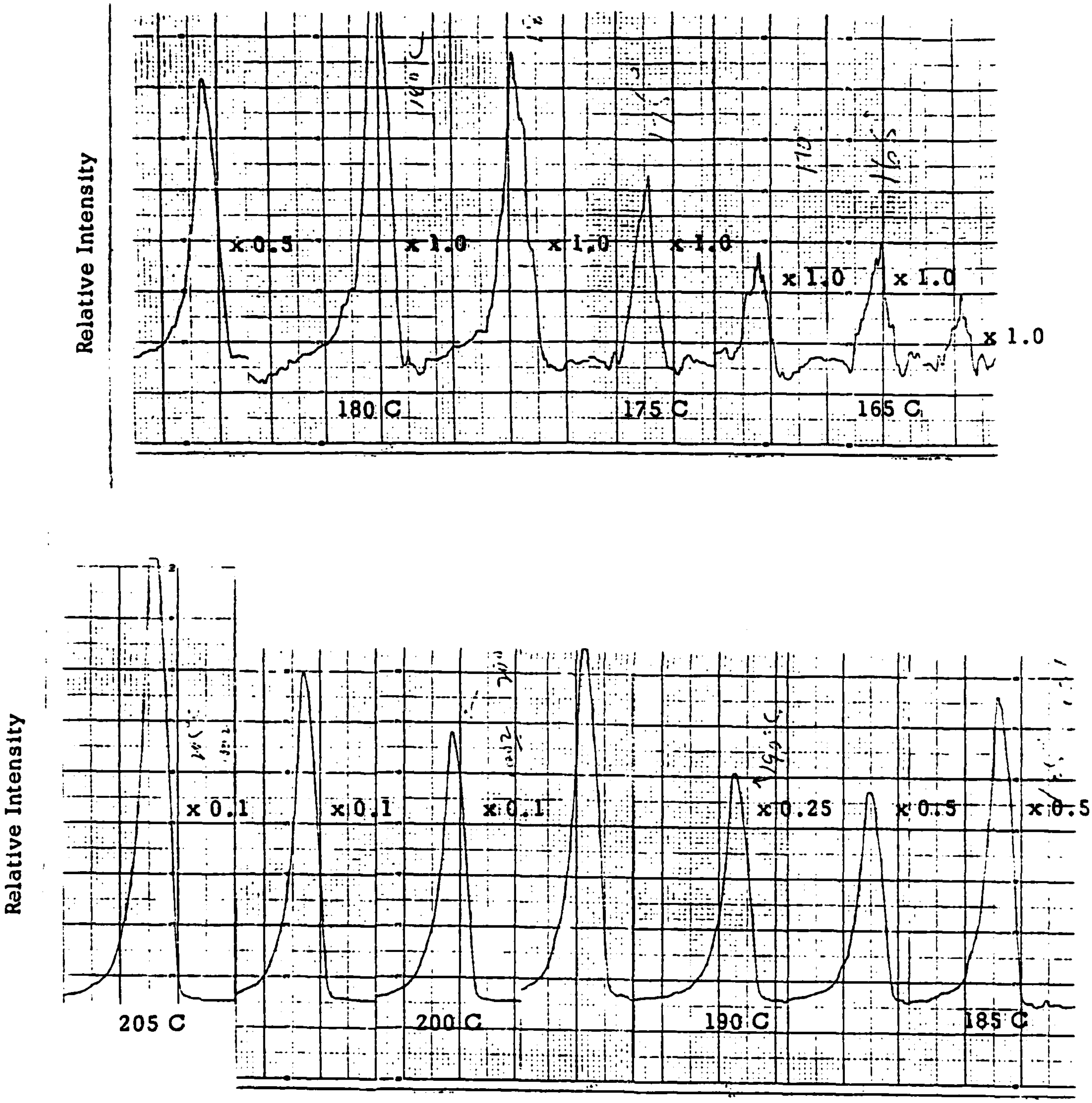


Fig.4. Decomposition of BAMO-BDO as a Function of Temperature. The peaks represent the release of molecular nitrogen. (These graphs are a composite of the individual peak heights and are not continuous as a function of temperature.)

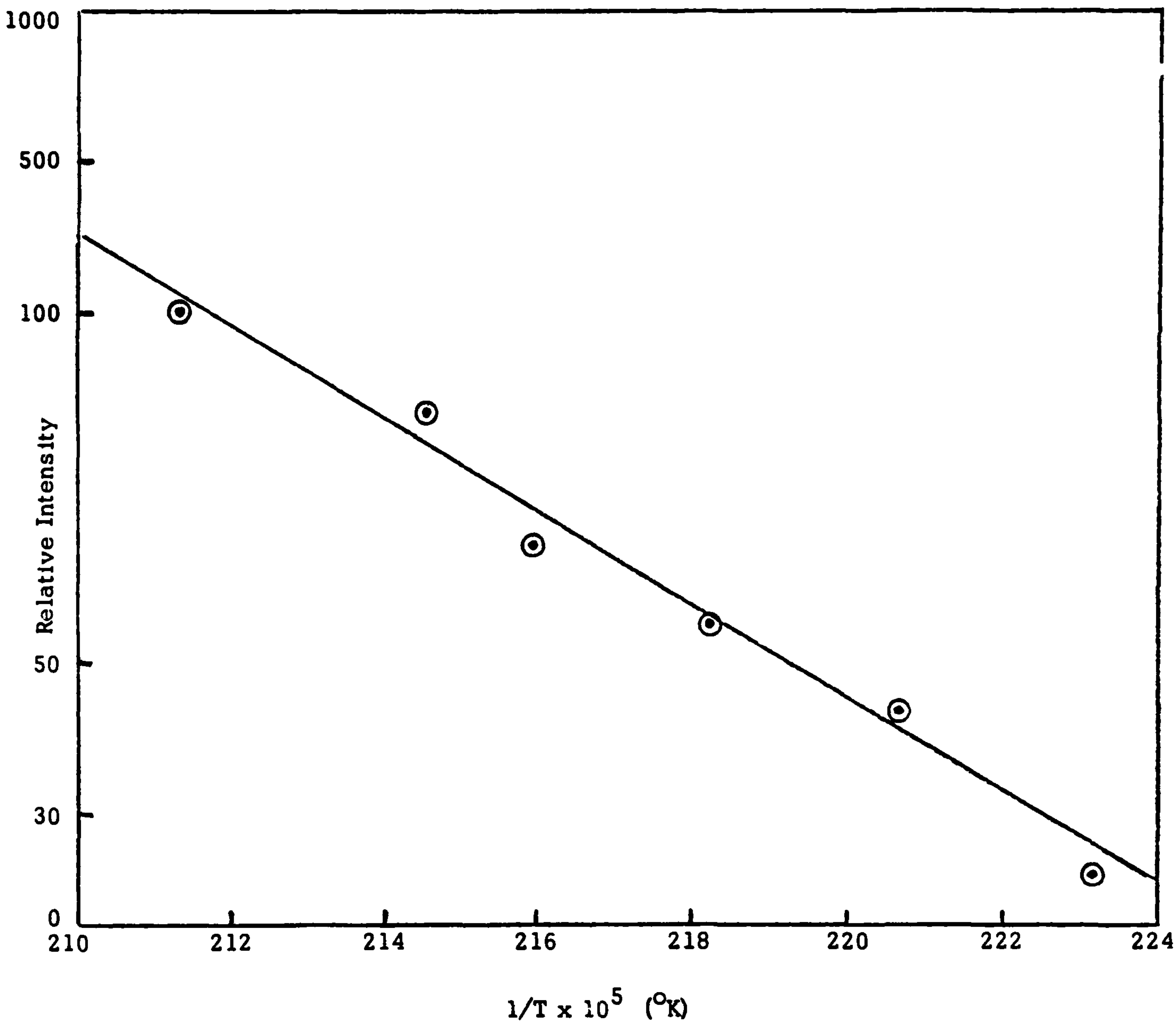


Fig. 5. Relative Intensity of N_2 from the Thermal Decomposition of BAMO-BDO plotted as a Function of the Recripocal of the Absolute Temperature ($1/T^{\circ}K$)

is the release of N_2 from the rupture of the azido bond. The three-carbon backbone of the polymer appears to remain intact initially since other gaseous species are not observed until the sample is heated to higher temperatures.

In addition to molecular N_2, the mass spectrometer showed peaks corresponding to HCN as well as peaks of amu 2, 14, 15, 16, 17, and 18 which may be attributed to H_2, CH_2, CH_3, O (fragment of O_2), OH and H_2O, respectively. Some low intensity peaks in the amu 40 to 46 range were also observed, indicating thermal decomposition of the hydrocarbon backbone. The temperature range of this secondary decomposition was 200 C. The intensities in Fig. 6 are only relative within the dashed lines. The intensity peaks in the 40 to 48 amu range are effusion cell reactions resulting in H, C, O, and N variations. The formation of NO_2, for example, may require cell reactions of the following type:

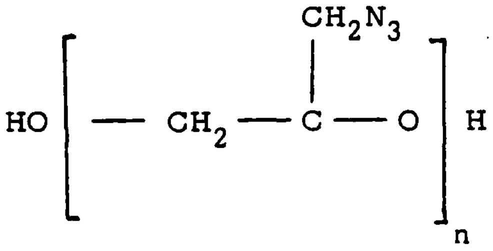
$$CH_2 = N\cdot + OH \longrightarrow CH_3\cdot + NO$$

and

$$NO + O \longrightarrow NO_2.$$

2.2 Thermal Decomposition of GAP

The initial investigation of the thermal decomposition of glycidyl azide polymer, GAP



$$HO\left[-CH_2-\overset{\displaystyle CH_2N_3}{\overset{|}{C}}-O\right]_n H$$

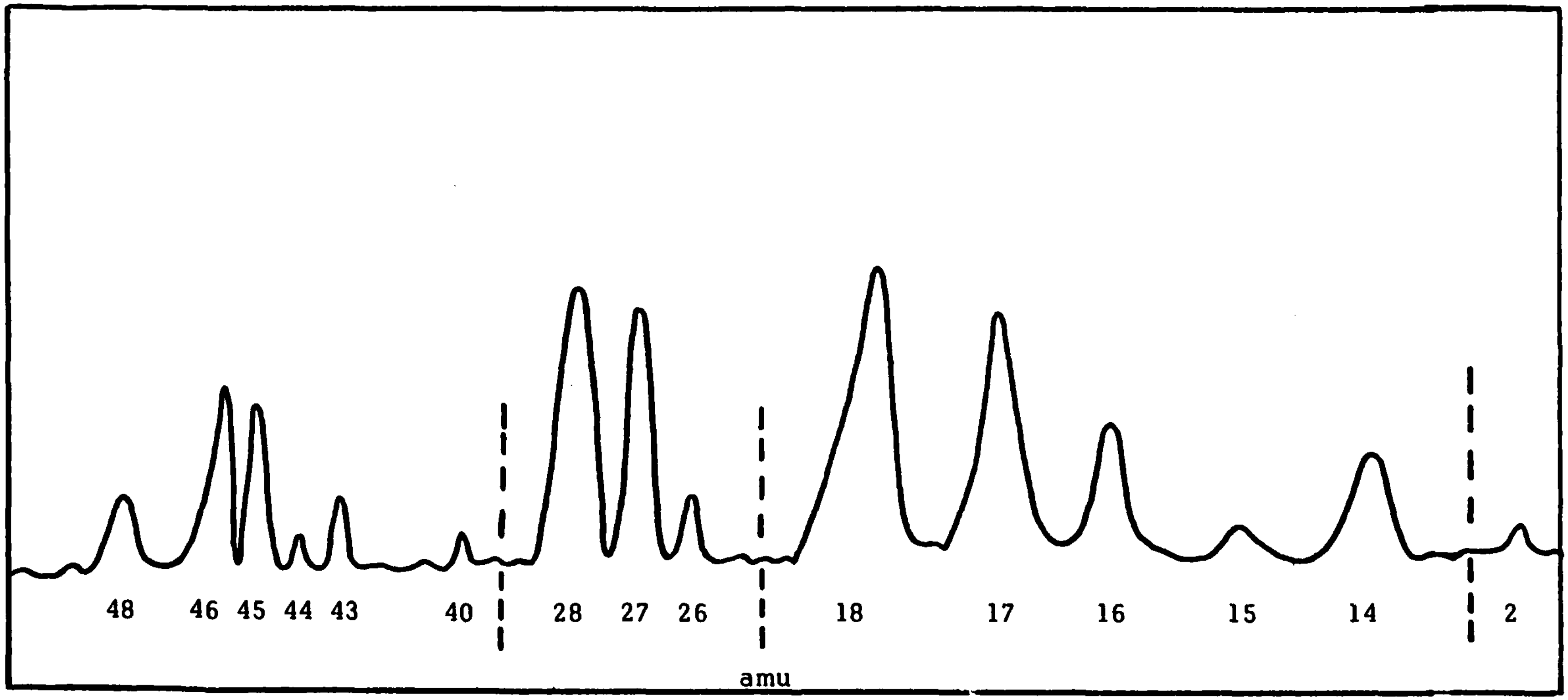


Fig. 6. PRODUCTS FROM THE THERMAL DECOMPOSITION OF BAMO

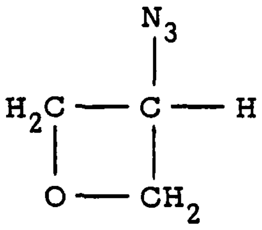
PEAK HEIGHTS ARE ONLY RELATIVE WITHIN DESIGNATED SECTIONS.

was a study of its primary decomposition as a function of temperature. As in the case of BAMO, the GAP appears to be fairly stable to 120 C, at which molecular N_2 is released.

The results of the decomposition study of this polymer as a function of temperature is shown in Fig. 7. For a 20 C rise in temperature the rate of N_2 evolution is increased by approximately a factor of 10. In the amu range 24 to 32 the major ion intensity constituent is molecular N_2. This appears to be the same pattern as found in the thermal decomposition of BAMO. However, at temperatures above 170 C a slight intensity of amu 27, HCN, is observed, approximately 1 to 2% of the N_2 intensity. It is likely that secondary decomposition begins at a slightly lower temperature for GAP than for BAMO. The primary decomposition mechanism for GAP is N_2 release. A plot of the log N_2 against 1/T, as shown in Fig. 8, yields an activation energy of 176.6 kJ mol^{-1} (42.2 kcal/mole), nearly identical to the E_a of BAMO.

2.3 Thermal Decomposition of AZOX Monomer

The thermal decomposition of azido oxetane monomer, AZOX



as a function of temperature was investigated by the double boiler-effusion technique. The AZOX was maintained in an ice bath and the vapor at 0 C was allowed to enter the effusion cell where it was heated to a

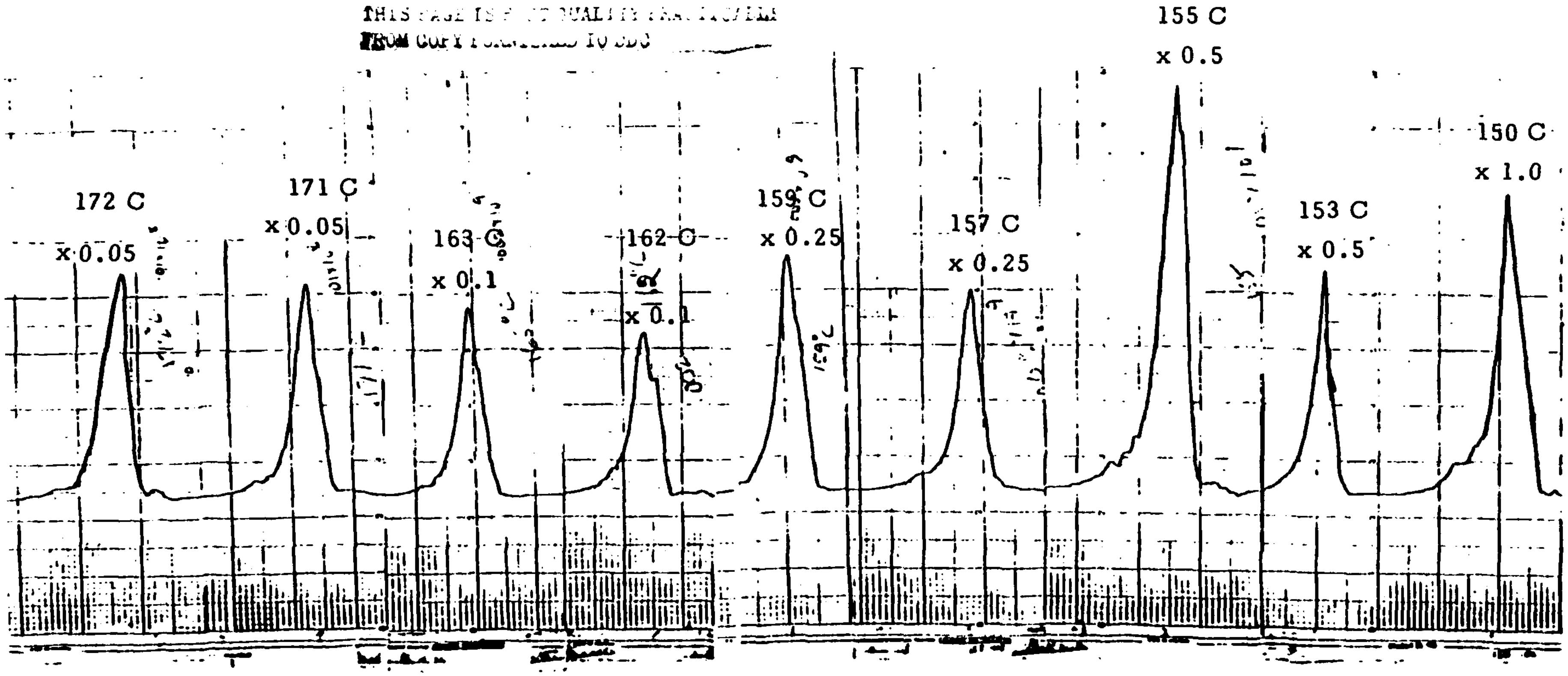


Fig. 7. Decomposition of GAP as a function of temperature.
The amu range is 24 to 32. The central peaks are molecular nitrogen. These graphs are composites of the individual peak heights and are not continuous as a function of temperature.

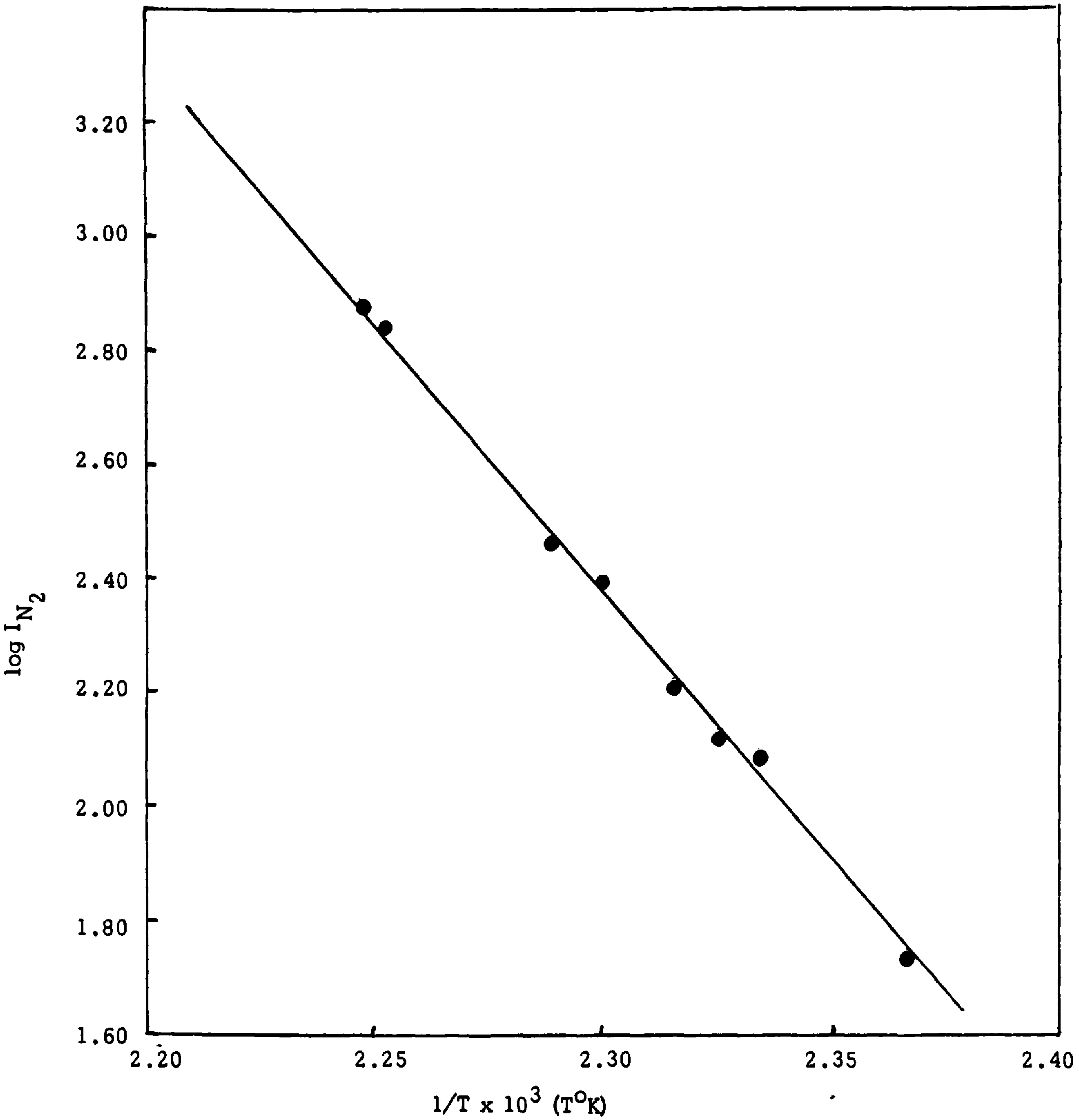


Fig. 8. Log of the relative intensity of N_2 from the thermal decomposition of glycidyl azide polymer (GAP) plotted as a function of the reciprocal of the absolute temperature ($1/T^oK$). Activation energy = 176.6 kJ mol^{-1} (42.2 kcal/mole).

given temperature. The molecular beam of the decomposition products was introduced into the mass spectrometer and relative intensity measurements were made. Prior to heating the AZOX a mass spectrum showed a major peak occurring at 71 amu, which is the AZOX monomer backbone after release of N_2 due to electron impact dissociation within the ionization chamber of the mass spectrometer.

The monomer vapor was heated and the 24 to 32 amu range was monitored with the mass spectrometer. As can be seen in Fig. 9, the major species was N_2, as it was in the BAMO and GAP studies. However, at temperatures above 160 C two small but prominent peaks appeared at amu 27 and 29, apparently HCN and HCO. This indicates that although the release of N_2 from the azido group is the primary decomposition mechanism, the three-carbon backbone loses stability when the azide bonds are broken. The major difference between this molecule and the BAMO and GAP moeities is that the azide groups are attached to the backbone whereas in the other two they are attached to methyl groups outside the three-carbon structure. These results agree with the findings of Dr. M. B. Frankel and colleagues.[1]

A plot of the log of N_2 intensity against the reciprocal of the absolute temperature (Fig. 10) yielded an activation energy of 167.8 kJ mol^{-1} (40.1 kcal/mole). This apparently is indicative of azide monomers, as shown in a recent publication by Isayev, et al.[2] They reported E_a values of 39 kcal/mole for several aliphatic azides including β-triazoethanol, 1,3,diazide propanol, 1,3,diazide propylene ester of acetic acid, and 1,3,diazide propylene acid.

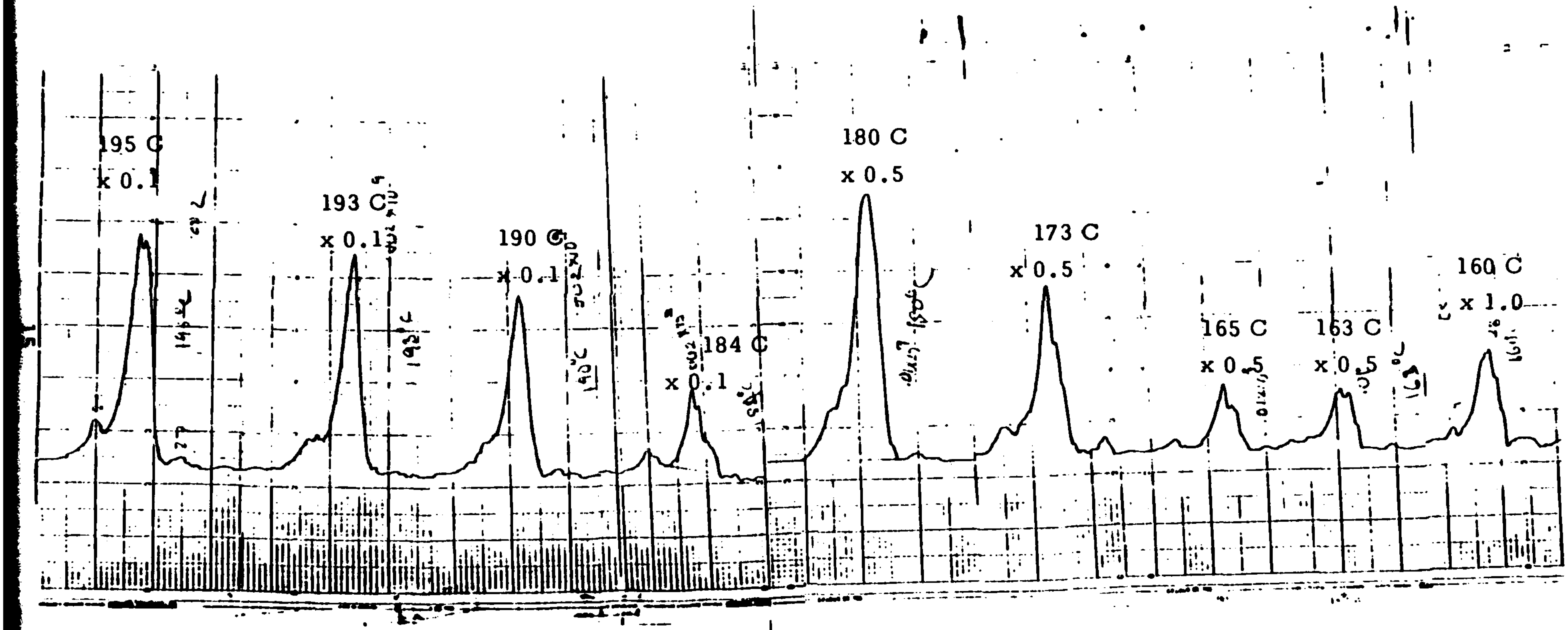


Fig. 9. Decomposition of AZOX monomer as a function of temperature.
The amu range is 24 to 32. The central peaks are molecular nitrogen, with smaller peaks on each side of HCN at 27 amu and HCO at 29 amu. These graphs are composites of the individual peak heights and are not continuous as a function of temperature.

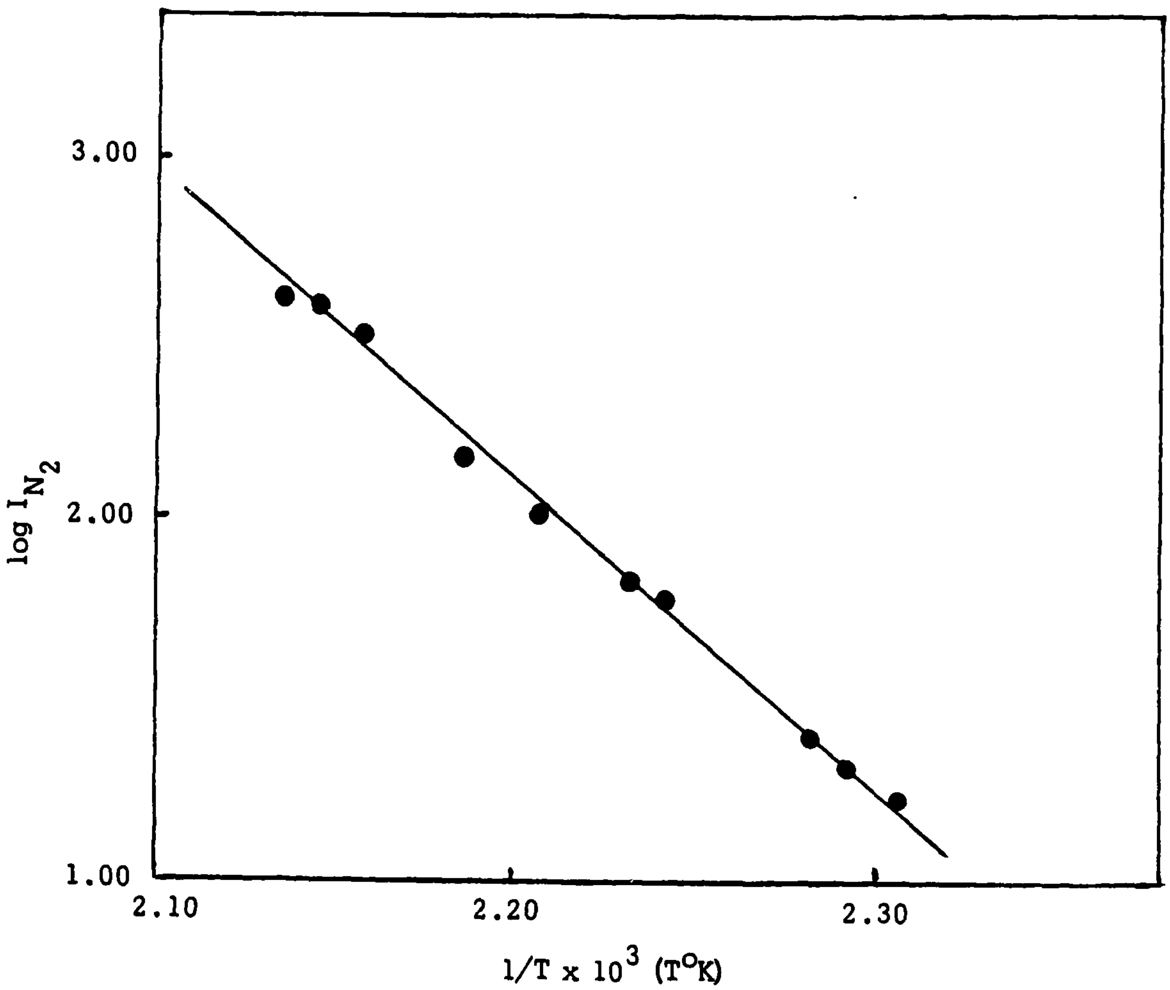


Fig. 10. Log of the relative intensity of N_2 from the thermal decomposition of azido oxetane monomer (AZOX) plotted as a function of the reciprocal of the absolute temperature ($1/T^oK$). Activation energy = 167.8 kJ mol^{-1} (40.1 kcal/mole)

REFERENCES

1. M. B. Frankel, E. R.Wilson, D. O. Woolery, and R. L. Kistner, Symposium on the Chemistry of Synthesis and Characterization of Energetic Monomers and Polymers, 21-22 July 1981, JHU, Laurel, Maryland.
2. B. M. Isayev, S. P. Kanashin, M. S. Kozhukh, and N. P. Tokarev. "Investigation of the Combustion of Certain Organic Azides," Khimicheskaya fizika protessov goreniya i vzryva. Kinetika khimicheskikh reaktsiy. Cernogovka, 1980, 97-101. (Series Note: Vsesoyuznyy simpozium po goreniyu i vzryvu, 6-th, Alma-Ata, 23-26 Sept. 1980. Materialy.)

DISTRIBUTION LIST

No. Copies

Dr. L.V. Schmidt 1
Assistant Secretary of the Navy
(R,E, and S) Room 5E 731
Pentagon
Washington, D.C. 20350

Dr. A.L. Slafkosky 1
Scientific Advisor
Commandant of the Marine Corps
Code RD-1
Washington, D.C. 20380

Dr. Richard S. Miller 10
Office of Naval Research
Code 413
Arlington, VA 22217

Mr. David Siegel 1
Office of Naval Research
Code 260
Arlington, VA 22217

Dr. R.J. Marcus 1
Office of Naval Research
Western Office
1030 East Green Street
Pasadena, CA 91106

Dr. Larry Peebles 1
Office of Naval Research
East Central Regional Office
666 Summer Street, Bldg. 114-D
Boston, MA 02210

Dr. Phillip A. Miller 1
Office of Naval Research
San Francisco Area Office
One Hallidie Plaza, Suite 601
San Francisco, CA 94102

Mr. Otto K. Heiney 1
AFATL - DLDL
Elgin AFB, FL 32542

Mr. R. Geisler 1
ATTN: MKP/MS24
AFRPL
Edwards AFB, CA 93523

No. Copies

Dr. F. Roberto 1
Code AFRPL MKPA
Edwards AFB, CA 93523

Dr. L.H. Caveny 1
Air Force Office of Scientific Research
Directorate of Aerospace Sciences
Bolling Air Force Base
Washington, D.C. 20332

Mr. Donald L. Ball 1
Air Force Office of Scientific Research
Directorate of Chemical Sciences
Bolling Air Force Base
Washington, D.C. 20332

Dr. John S. Wilkes, Jr. 1
FJSRL/NC
USAF Academy, CO 80840

Dr. R.L. Lou 1
Aerojet Strategic Propulsion Co.
P.O. Box 15699C
Sacramento, CA 95813

Dr. V.J. Keenan 1
Anal-Syn Lab Inc.
P.O. Box 547
Paoli, PA 19301

Dr. Philip Howe 1
Army Ballistic Research Labs
ARRADCOM
Code DRDAR-BLT
Aberdeen Proving Ground, MD 21005

Mr. L.A. Watermeier 1
Army Ballistic Research Labs
ARRADCOM
Code DRDAR-BLI
Aberdeen Proving Ground, MD 21005

Dr. W.W. Wharton 1
Attn: DRSMI-RKL
Commander
U.S. Army Missile Command
Redstone Arsenal, AL 35898

DISTRIBUTION LIST

	No. Copies
Mr. R. Brown Naval Air Systems Command Code 330 Washington, D.C. 20361	1
Dr. H. Rosenwasser Naval Air Systems Command AIR-310C Washington, D.C. 20360	1
Mr. B. Sobers Naval Air Systems Command Code 03P25 Washington, D.C. 20360	1
Dr. L.R. Rothstein Assistant Director Naval Explosives Dev. Engineering Dept. Naval Weapons Station Yorktown, VA 23691	1
Dr. Lionel Dickinson Naval Explosive Ordnance Disposal Tech. Center Code D Indian Head, MD 20640	1
Mr. C.L. Adams Naval Ordnance Station Code PM4 Indian Head, MD 20640	1
Mr. S. Mitchell Naval Ordnance Station Code 5253 Indian Head, MD 20640	1
Dr. William Tolles Dean of Research Naval Postgraduate School Monterey, CA 93940	1
Naval Research Lab. Code 6100 Washington, D.C. 20375	1

	No. Copies
Dr. J. Schnur Naval Research Lab. Code 6510 Washington, D.C. 20375	1
Mr. R. Beauregard Naval Sea Systems Command SEA 64E Washington, D.C. 20362	1
Mr. G. Edwards Naval Sea Systems Command Code 62R3 Washington, D.C. 20362	1
Mr. John Boyle Materials Branch Naval Ship Engineering Center Philadelphia, PA 19112	1
Dr. H.G. Adolph Naval Surface Weapons Center Code R11 White Oak Silver Spring, MD 20910	1
Dr. T.D. Austin Naval Surface Weapons Center Code R16 Indian Head, MD 20640	1
Dr. T. Hall Code R-11 Naval Surface Weapons Center White Oak Laboratory Silver Spring, MD 20910	1
Mr. G.L. Mackenzie Naval Surface Weapons Center Code R101 Indian Head, MD 20640	1
Dr. K.F. Mueller Naval Surface Weapons Center Code R11 White Oak Silver Spring, MD 20910	1

DYN 6/81

DISTRIBUTION LIST

	No. Copies
Dr. R.G. Rhoades Commander Army Missile Command DRSMI-R Redstone Arsenal, AL 35898	1
Dr. W.D. Stephens Atlantic Research Corp. Pine Ridge Plant 7511 Wellington Rd. Gainesville, VA 22065	1
Dr. A.W. Barrows Ballistic Research Laboratory USA ARRADCOM DRDAR-BLP Aberdeen Proving Ground, MD 21005	1
Dr. C.M. Frey Chemical Systems Division P.O. Box 358 Sunnyvale, CA 94086	1
Professor F. Rodriguez Cornell University School of Chemical Engineering Olin Hall, Ithaca, N.Y. 14853	1
Defense Technical Information Center DTIC-DDA-2 Cameron Station Alexandria, VA 22314	12
Dr. Rocco C. Musso Hercules Aerospace Division Hercules Incorporated Alleghany Ballistic Lab P.O. Box 210 Washington, D.C. 21502	1
Dr. Ronald L. Simmons Hercules Inc. Eglin AFATL/DLDL Eglin AFB, FL 32542	1

	No. Copies
Dr. E.H. Debutts Hercules Inc. Baccus Works P.O. Box 98 Magna, UT 84044	1
Dr. James H. Thacher Hercules Inc. Magna Baccus Works P.O. Box 98 Magna, UT 84044	1
Mr. Theordore M. Gilliland Johns Hopkins University APL Chemical Propulsion Info. Agency Johns Hopkins Road Laurel, MD 20810	1
Dr. R. McGuire Lawrence Livermore Laboratory University of California Code L-324 Livermore, CA 94550	1
Dr. Jack Linsk Lockheed Missiles & Space Co. P.O. Box 504 Code Org. 83-10, Bldg. 154 Sunnyvale, CA 94088	1
Dr. B.G. Craig Los Alamos National Lab P.O. Box 1663 NSP/DOD, MS-245 Los Alamos, NM 87545	1
Dr. R.L. Rabie WX-2, MS-952 Los Alamos National Lab. P.O. Box 1663 Los Alamos NM 37545	1
Dr. R. Rogers, WX-2 Los Alamos Scientific Lab. P.O. Box 1663 Los Alamos, NM 37545	1

DISTRIBUTION LIST

	No. Copies
Dr. J.F. Kincaid Strategic Systems Project Office Department of the Navy Room 901 Washington, D.C. 20376	1
Strategic Systems Project Office Propulsion Unit Code SP2731 Department of the Navy Washington, D.C. 20376	1
Mr. E.L. Throckmorton Strategic Systems Project Office Department of the Navy Room 1048 Washington, D.C. 20376	1
Dr. D.A. Flanigan Thiokol Huntsville Division Huntsville, Alabama 35807	1
Mr. G.F. Mangum Thiokol Corporation Huntsville Division Huntsville, Alabama 35807	1
Mr. E.S. Sutton Thiokol Corporation Elkton Division P.O. Box 241 Elkton, MD 21921	1
Dr. G. Thompson Thiokol Wasatch Division MS 240 P.O. Box 524 Brigham City, UT 84302	1
Dr. T.F. Davidson Technical Director Thiokol Corporation Government Systems Group P.O. Box 9258 Ogden, Utah 84409	1

	No. Copies
Dr. C.W. Vriesen Thiokol Elkton Division P.O. Box 241 Elkton, MD 21921	1
Dr. J.C. Hinshaw Thiokol Wasatch Division P.O. Box 524 Brigham City, Utah 83402	1
U.S. Army Research Office Chemical & Biological Sciences Division P.O. Box 12211 Research Triangle Park NC 27709	1
Dr. R.F. Walker USA ARRADCOM DRDAR-LCE Dover, NJ 07801	1
Dr. T. Sinden Munitions Directorate Propellants and Explosives Defence Equipment Staff British Embassy 3100 Massachusetts Ave. Washington, D.C. 20008	1
LTC B. Loving AFROL/LK Edwards AFB, CA 93523	1
Professor Alan N. Gent Institute of Polymer Science University of Akron Akron, OH 44325	1
Mr. J. M. Frankle Army Ballistic Research Labs ARRADCOM Code DRDAR-BLI Aberdeen Proving Ground, MD 21005	1

DISTRIBUTION LIST

	No. Copies
Mr. J. Murrin Naval Sea Systems Command Code 62R2 Washington, D.C. 20362	1
Dr. D.J. Pastine Naval Surface Weapons Cneter Code R04 White Oak Silver Spring, MD 20910	1
Mr. L. Roslund Naval Surface Weapons Center Code R122 White Oak, Silver Spring MD 20910	1
Mr. M. Stosz Naval Surface Weapons Center Code R121 White Oak Silver Spring, MD 20910	1
Dr. E. Zimmet Naval Surface Weapons Center Code R13 White Oak Silver Spring, MD 20910	1
Dr. D. R. Derr Naval Weapons Center Code 388 China Lake, CA 93555	1
Mr. Lee N. Gilbert Naval Weapons Center Code 3205 China Lake, CA 93555	1
Dr. E. Martin Naval Weapons Center Code 3858 China Lake, CA 93555	1
Mr. R. McCarten Naval Weapons Center Code 3272 China Lake, CA 93555	1

	No. Copies
Dr. A. Nielsen Naval Weapons Center Code 385 China Lake, CA 93555	1
Dr. R. Reed, Jr. Naval Weapons Center Code 388 China Lake, CA 93555	1
Dr. L. Smith Naval Weapons Center Code 3205 China Lake, CA 93555	1
Dr. B. Douda Naval Weapons Support Center Code 5042 Crane, Indiana 47522	1
Dr. A. Faulstich Chief of Naval Technology MAT Code 0716 Washington, D.C. 20360	1
LCDR J. Walker Chief of Naval Material Office of Naval Technology MAT, Code 0712 Washington, D.C. 20360	1
Mr. Joe McCartney Naval Ocean Systems Center San Diego, CA 92152	1
Dr. S. Yamamoto Marine Sciences Division Naval Ocean Systems Center San Diego, CA 91232	1
Dr. G. Bosmajian Applied Chemistry Division Naval Ship Research & Development Center Annapolis, MD 21401	1
Dr. H. Shuey Rohn and Haas Company Huntsville, Alabama 35801	1

DYN 6/81

DISTRIBUTION LIST

	No. Copies
Dr. Ingo W. May Army Ballistic Research Labs ARRADCOM Code DRDAR-BLI Aberdeen Proving Ground, MD 21005	1
Professor N.W. Tschoegl California Institute of Tech Dept. of Chemical Engineering Pasadena, CA 91125	1
Professor M.D. Nicol University of California Dept. of Chemistry 405 Hilgard Avenue Los Angeles, CA 90024	1
Professor A. G. Evans University of California Berkeley, CA 94720	1
Professor T. Litovitz Catholic Univ. of America Physics Department 520 Michigan Ave., N.E. Washington, D.C. 20017	1
Professor W. G. Knauss Graduate Aeronautical Lab California Institute of Tech. Pasadena, CA 91125	1
Professor Edward Price Georgia Institute of Tech. School of Aerospace Engin. Atlanta, Georgia 30332	1
Dr. Kenneth O. Hartman Hercules Aerospace Division Hercules Incorporated P.O. Box 210 Cumberland, MD 21502	1
Dr. Thor L. Smith IBM Research Lab D42.282 San Jose, CA 95193	1

	No. Copies
Dr. J. P. Marshall Dept. 52-35, Bldg. 204/2 Lockheed Missile & Space Co. 3251 Hanover Street Palo Alto, CA 94304	1
Ms. Joan L. Janney Los Alamos National Lab Mail Stop 920 Los Alamos, NM 87545	1
Dr. J. M. Walsh Los Alamos Scientific Lab Los Alamos, NM 87545	1
Professor R. W. Armstrong Univ. of Maryland Department of Mechanical Eng. College Park, MD 20742	1
Prof. Richard A. Reinhardt Naval Postgraduate School Physics & Chemistry Dept. Monterey, CA 93940	1
Dr. R. Bernecker Naval Surface Weapons Center Code R13 White Oak, Silver Spring, MD 20910	1
Dr. M. J. Kamlet Naval Surface Weapons Center Code R11 White Oak, Silver Spring, MD 20910	1
Professor J. D. Achenbach Northwestern University Dept. of Civil Engineering Evanston, IL 60201	1
Dr. N. L. Basdekas Office of Naval Research Mechanics Program, Code 432 Arlington, VA 22217	1
Professor Kenneth Kuo Pennsylvania State Univ. Dept. of Mechanical Engineering University Park, PA 16802	1

DISTRIBUTION LIST

	No. Copies		No. Copies
Dr. S. Sheffield Sandia Laboratories Division 2513 P.O. Box 5800 Albuquerque, NM 87185	1		
Dr. M. Farber Space Sciences, Inc. 135 Maple Avenue Monrovia, CA 91016	1		
Dr. Y. M. Gupta SRI International 333 Ravenswood AVenue Menlo Park, CA 94025	1		
Mr. M. Hill SRI International 333 Ravenswood Avenue Menlo Park, CA 94025	1		
Professor Richard A. Schapery Texas A&M Univ. Dept of Civil Engineering College Station, TX 77843	1		
Dr. Stephen Swanson Univ. of Utah Dept. of Mech. & Industrial Engineering MEB 3008 Salt Lake City, UT 84112	1		
Mr. J. D. Byrd Thiokol Corp. Huntsville Huntsville Div. Huntsville, AL 35807	1		
Professor G. D. Duvall Washington State University Dept. of Physics Pullman, WA 99163	1		
Prof. T. Dickinson Washington State University Dept. of Physics Pullman, WA 99163	1		