

AD-A056 024

DEPARTMENT OF ENERGY BARTLESVILLE OK BARTLESVILLE EN--ETC F/G 21/2
ENTHALPIES OF COMBUSTION OF EXO-THDC, RJ-4, ISOMERIZED RJ-4, AN--ETC(U)
JUN 78 N K SMITH, W D GOOD

UNCLASSIFIED

AFOSR-TR-78-1069

NL

| OF |
AD
A056024



END
DATE
FILMED
8 -78
DDC

SR-TR- 78 - 1069

LEVEL III (2)

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH

SCIENTIFIC REPORT

AD A056024

AD No. —
DC FILE COPY

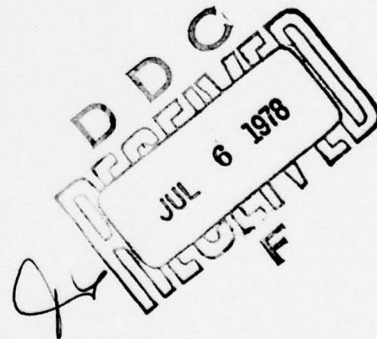
ENTHALPIES OF COMBUSTION OF *exo*-THDC, RJ-4,
ISOMERIZED RJ-4, AND JP-9

by

N. K. Smith and W. D. Good

- (3) Bartlesville Energy Research Center.
① Department of Energy,
② Bartlesville, Oklahoma

410 743



Research sponsored by:

Air Force Office of Scientific Research (NA)
Department of the Air Force
Contract No. AFOSR-ISSA-78-0009

Approved for public release;
distribution unlimited.

June 1978

78 06 27 076

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

1. REPORT DOCUMENTATION PAGE AFOSR-TR-78-1069		READ INSTRUCTIONS BEFORE COMPLETING FORM									
2. GOVT ACCESSION NO.		3. RECIPIENT'S CATALOG NUMBER									
4. TITLE (and Subtitle) ENTHALPIES OF COMBUSTION OF exo-THDC, RJ-4, ISOMERIZED RJ-4, AND JP-9.		5. TYPE OF REPORT & PERIOD COVERED INTERIM Repts									
7. AUTHOR(s) N. K. SMITH W. D. GOOD		6. PERFORMING ORG. REPORT NUMBER									
9. PERFORMING ORGANIZATION NAME AND ADDRESS DEPARTMENT OF ENERGY BARTLESVILLE ENERGY RESEARCH CENTER P. O. BOX 1398, BARTLESVILLE, OK 74003		10. CONTRACT OR GRANT NUMBER(s) AFOSR-ISSA-78-0009									
11. CONTROLLING OFFICE NAME AND ADDRESS AIR FORCE OFFICE OF SCIENTIFIC RESEARCH/NA BLDG 410 BOLLING AIR FORCE BASE, D C 20332		PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 2308B1 61102F									
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) 17p.		12. REPORT DATE JUNE 78									
		13. NUMBER OF PAGES 18									
		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) <table border="0"> <tr> <td>exo-THDC</td> <td>RAMJET FUELS</td> </tr> <tr> <td>RJ-4</td> <td>GROSS HEAT OF COMBUSTION</td> </tr> <tr> <td>RJ-4-I</td> <td>NET HEAT OF COMBUSTION</td> </tr> <tr> <td>JP-9</td> <td></td> </tr> </table>				exo-THDC	RAMJET FUELS	RJ-4	GROSS HEAT OF COMBUSTION	RJ-4-I	NET HEAT OF COMBUSTION	JP-9	
exo-THDC	RAMJET FUELS										
RJ-4	GROSS HEAT OF COMBUSTION										
RJ-4-I	NET HEAT OF COMBUSTION										
JP-9											
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The enthalpies of combustion of four liquid ramjet fuels, exo-THDC, RJ-4, RJ-4-I, and JP-9, were measured by precision oxygen-bomb combustion calorimetry. The following values are reported for the net enthalpy of combustion at 298.15 K (25°C): exo-THDC, $-(10081.5 \pm 2.3) \text{ cal g}^{-1}$; RJ-4, $-(10153.1 \pm 2.3) \text{ cal g}^{-1}$; RJ-4-I, $-(10141.4 \pm 2.2) \text{ cal g}^{-1}$; and JP-9, $-(10089.3 \pm 2.4) \text{ cal g}^{-1}$. 410 743											

SCIENTIFIC REPORT

ENTHALPIES OF COMBUSTION OF *exo*-THDC, RJ-4,
ISOMERIZED RJ-4, AND JP-9

Bartlesville Energy Research Center
Department of Energy
Bartlesville, Oklahoma

ACCESSION NO.	
NTIS	White Section ☒
DOC	Buff Section ☐
UNANNOUNCED	☐
JUSTIFICATION	
BY	
DISTRIBUTION/AVAILABILITY CODES	
Dist.	AVAIL. and/or SPECIAL
A	

Project Director: W. D. Good

Report prepared by: N. K. Smith
W. D. Good

Qualified requestors may obtain additional
copies from the Defense Documentation Center,
all others should apply to the National
Technical Information Service.

Approved for public release;
distribution unlimited.

Conditions of Reproduction

Reproduction, translation, publication, use and disposal in whole or in part
by or for the United States Government is permitted.

ENTHALPIES OF COMBUSTION OF *exo*-THDC, RJ-4,
ISOMERIZED RJ-4, AND JP-9^a

by

N. K. Smith and W. D. Good

Bartlesville Energy Research Center
Department of Energy

The enthalpies of combustion of four liquid ramjet fuels, *exo*-THDC, RJ-4, RJ-4-I, and JP-9, were measured by precision oxygen-bomb combustion calorimetry. The following values are reported for the net enthalpy of combustion at 298.15 K (25° C): *exo*-THDC, $-(10081.5 \pm 2.3) \text{ cal g}^{-1}$; RJ-4, $-(10153.1 \pm 2.3) \text{ cal g}^{-1}$; RJ-4-I, $-(10141.4 \pm 2.2) \text{ cal g}^{-1}$; and JP-9, $-(10089.3 \pm 2.4) \text{ cal g}^{-1}$.

1. INTRODUCTION

In cooperation with the Air Force Office of Scientific Research, this laboratory has studied compounds with high enthalpies of combustion per unit mass^(1,2) and per unit volume.^(3,4) This report gives the details of experimental measurements of the enthalpies of combustion of four hydrocarbon liquids being evaluated as ramjet fuels.

^a Work conducted under an Interagency Agreement, AFOSR-ISSA-78-0009, between the Air Force Office of Scientific Research (AFSC) and the Department of Energy.

78 06 27 076

2. EXPERIMENTAL

MATERIALS

All four fuels studied are liquids. Carbon skeletons of three are shown in Figure 1. *exo*-THDC, *exo*-tetrahydrodicyclopentadiene, is a pure compound. RJ-4, *exo*-tetrahydrodi(methylcyclopentadiene), and RJ-4-I, *endo*-tetrahydrodi(methylcyclopentadiene) are mixtures of isomers in which the location of the methyl groups is unknown. JP-9 is a blend of 10.3 weight percent methylcyclohexane, 68.4 weight percent of *exo*-THDC, and 21.2 weight percent of the hydrogenated dimers of norbornadiene whose empirical formula is $C_{14}H_{18}$. Carbon skeletons of typical isomers are shown in Figure 2. The empirical formula for the blend is $C_{10.529}H_{16.202}$.

exo-THDC, RJ-4, and RJ-4-I were provided by G. W. Burdette, Propulsion Development Department, Naval Weapons Center, China Lake, California. The JP-9 sample was obtained from James R. McCoy, Fuels Branch, Fuels and Lubrication Division, Air Force Aero Propulsion Laboratory, Wright-Patterson Air Force Base, Ohio; it is from Sun Oil Co. Batch 24. All materials were used as received.

Carbon dioxide was recovered from the combustion products of typical calorimetric experiments with all four fuels. Quantitative carbon dioxide recovery is a good indication that combustion was complete, that the sample was dry, and that sample composition was understood. A summary of carbon dioxide recovery is given in Table 1. The value for JP-9 is noticeably lower than the recoveries from the other three fuels.

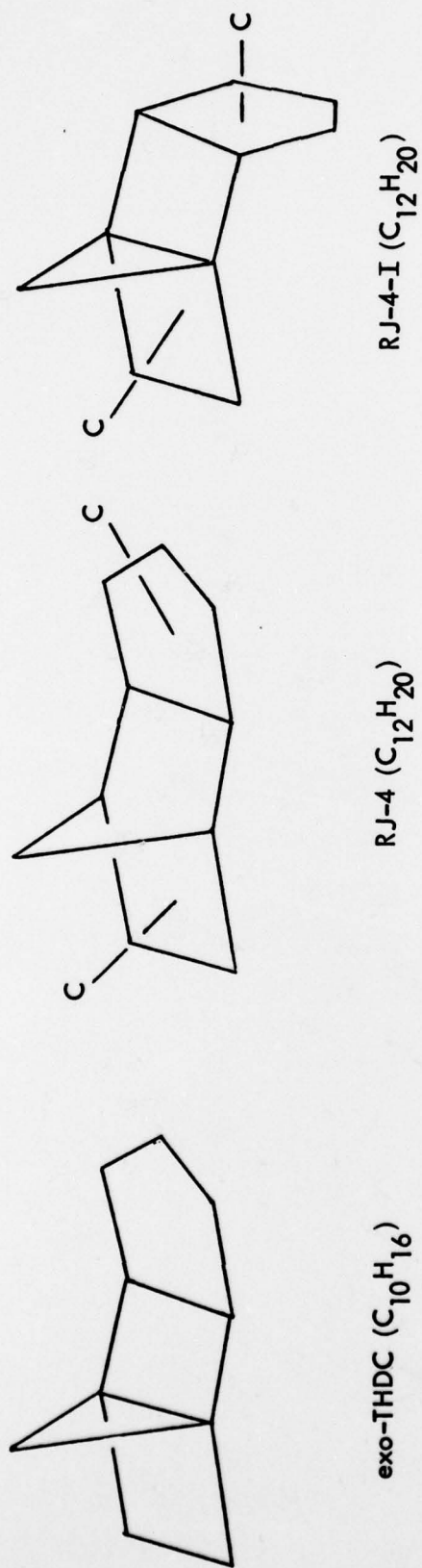


FIGURE 1. Carbon skeletons of hydrocarbon fuels.

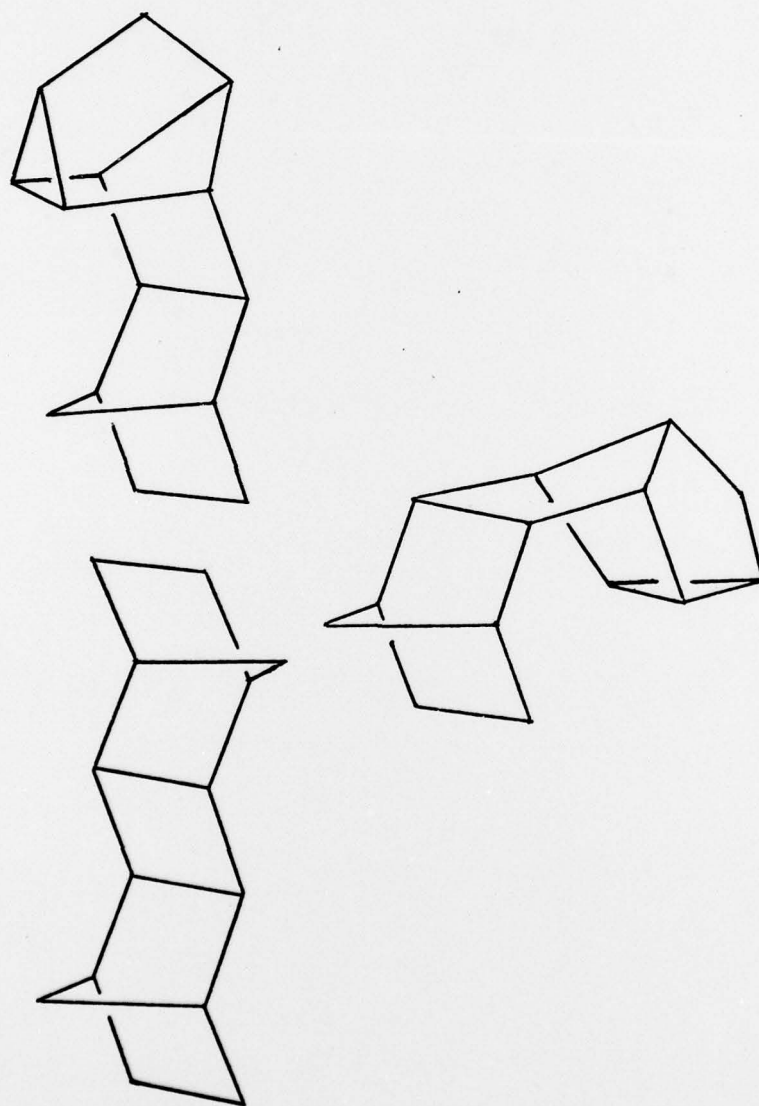


FIGURE 2. Carbon skeletons of typical isomers of hydrogenated dimer of norbornadiene.

TABLE 1. Carbon dioxide recovery

Fuel	Number of experiments	Percent recovery ^a
exo-THDC	6	99.99 ₁
RJ-4	6	99.98 ₃
RJ-4-I	3	99.96 ₂
JP-9	4	99.63 ₀

^a Mean value.

National Bureau of Standards benzoic acid sample 39i was used for calibration. Its certified energy of combustion, $-(26434 \pm 3) \text{ J g}^{-1}$, was converted to standard conditions⁽⁵⁾ giving $-(6313.02 \pm 0.72) \text{ cal g}^{-1}$ for $\Delta E_c^\circ/\text{M}$, the specific energy of the idealized combustion reaction.

Previous combustion experiments on the auxiliary oil, laboratory designation TKL 66, gave a value for $\Delta E_c^\circ/\text{M}$ of $-(11004.41 \pm 0.42) \text{ cal g}^{-1}$.

For the cotton thread fuse, empirical formula $\text{CH}_{1.774}\text{O}_{0.887}$, $\Delta E_c^\circ/\text{M} = -4050 \text{ cal g}^{-1}$.

APPARATUS AND PROCEDURE

Experimental procedures used for the combustion calorimetry of hydrocarbons by this laboratory have been described.^(6, 7) Rotating-bomb calorimeter BMR II⁽⁸⁾ and platinum-lined bomb Pt-3b,⁽⁹⁾ internal volume 0.349_4 dm^3 , were used without bomb rotation. For each experiment, 1 cm^3 of water was added to

the bomb, and the bomb was flushed and charged to 30 atm (3040 kPa) with pure oxygen. Because the oxygen was pure, nitric acid formation was negligible. Each experiment was started at 296.15 K, and the final temperatures were very nearly 298.15 K. Fragile flexible ampoules^(6, 10) of borosilicate glass confined the liquid samples. In filling ampoules with JP-9, the apparatus was charged with enough methylcyclohexane to provide its saturation vapor pressure before introducing the sample in order to minimize the evaporation of that component from the fuel.

UNITS OF MEASUREMENT AND AUXILIARY QUANTITIES

The results are based on the 1961 atomic weights⁽¹¹⁾ and the 1963 definition of the thermochemical calorie ($\text{cal} = 4.184 \text{ J}$).⁽¹²⁾ The reference temperature is 298.15 K (25° C). For reducing weights in air to masses, converting the energy of the actual bomb process to that of the isothermal process, and reducing to standard states,⁽⁵⁾ the values in Table 2 were used for density ρ , specific heat capacity c_p , and $(\partial E/\partial P)_T$. The values of density were obtained from the mass of material contained by ampoules of known volume. Values of c_p for exo-THDC and RJ-4 were from differential scanning calorimetry. Values of c_p for RJ-4-I and JP-9 are estimates as are all values of $(\partial E/\partial P)_T$.

CALIBRATION

One set of calibration experiments with benzoic acid was run concurrently with the series of experiments with exo-THDC and RJ-4. The calibration result was $E(\text{calor}) = 4008.11 \pm 0.20) \text{ cal}_{\text{th}} \text{ K}^{-1}$ (mean and standard deviation of the mean). A second set of calibration experiments was run concurrently with

TABLE 2. Physical properties at 298.15 K^a
 (cal_{th} = 4.184 J; atm = 101.325 kPa)

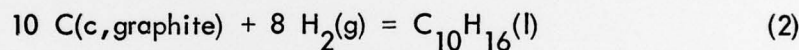
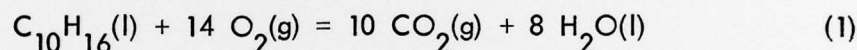
Fuel	ρ g cm ⁻³	$(\partial E/\partial P)_T$ cal _{th} atm ⁻¹ g ⁻¹	c_p cal _{th} K ⁻¹ g ⁻¹
exo-THDC	0.939	(-0.003)	(0.42)
RJ-4	0.920	(-0.003)	(0.44)
RJ-4-I	0.917	(-0.003)	(0.30)
JP-9	0.946	(-0.003)	(0.30)

^a Values in parentheses are estimates.

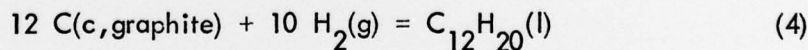
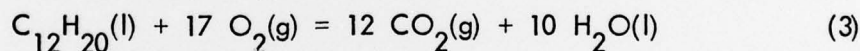
the series of experiments with RJ-4-I and JP-9. The calibration result was $\mathcal{E}(\text{calor}) = (4007.02 \pm 0.26) \text{ cal}_{\text{th}} \text{ K}^{-1}$ (mean and standard deviation of the mean).

3. CALORIMETRIC RESULTS

Results of typical experiments with the four fuels are summarized in Table 3. Values of $\Delta E_c^\circ/\text{M}$, the specific energy of the idealized combustion reaction, for all experiments are given in Table 4; all values refer to the reaction of unit mass of sample. The idealized combustion and formation reactions for exo-THDC are represented by equations 1 and 2, respectively. The idealized



combustion and formation reactions for RJ-4 and RJ-4-I are represented by equations 3 and 4, respectively.



The reader should be reminded that RJ-4 and RJ-4-I are mixtures of isomers. The idealized combustion reaction for JP-9 is represented by equation 5.

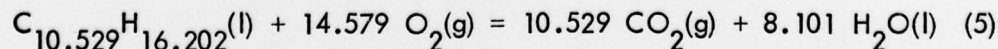


TABLE 3. Summary of typical calorimetric experiments at 298.15 K^a(cal_{th} = 4.184 J)

	exo-THDC	RJ-4	RJ-4-I	JP-9
m' (fuel)/g	0.693077	0.671733	0.661629	0.675054
m'' (auxiliary substance)/g	0.056663	0.071059	0.081998	0.073573
m''' (fuse)/g	0.001316	0.001200	0.001250	0.001078
n ⁱ (H ₂ O)/mol	0.05535	0.05535	0.05535	0.05535
$\Delta T_c / K = (T_f - T_i + \Delta T_{corr}) / K$	2.00216	2.00052	2.00235	1.99890
$\mathcal{E}(\text{calor})(-\Delta T_c) / \text{cal}_{th}$	-8024.89	-8018.33	-8023.45	-8009.63
$\mathcal{E}(\text{cont})(-\Delta T_c) / \text{cal}_{th}$ ^b	-10.20	-10.19	-10.00	-10.02
$\Delta E_{ign} / \text{cal}_{th}$	0.18	0.18	0.18	0.18
$\Delta E_{(corr \text{ to std states})} / \text{cal}_{th}$ ^c	3.02	2.90	2.91	3.09
$\{-m''(\Delta E_c^\circ / M)(\text{auxiliary substance})\} / \text{cal}_{th}$	623.54	781.96	902.33	809.63
$\{-m'''(\Delta E_c^\circ / M)(\text{fuse})\} / \text{cal}_{th}$	5.33	4.86	5.06	4.36
$\{m'(\Delta E_c^\circ / M)(\text{fuel})\} / \text{cal}_{th}$	-7403.02	-7238.62	-7122.97	-7202.39
$\{(\Delta E_c^\circ / M)(\text{fuel})\} / \text{cal}_{th} \text{ g}^{-1}$	-10681.37	-10776.04	-10765.81	-10669.36

^a The symbols and abbreviations of this table are those of reference 3 except as noted. ^b $\mathcal{E}(\text{cont})(T_i - 298.15 \text{ K}) - \mathcal{E}(\text{calor})(298.15 \text{ K} - T_i + \Delta T_{corr})$. ^c Items 81 to 85, 87 to 90, 93, and 94 of the comparison form of reference 3.

TABLE 4. Summary of experimental results at 298.15 K
 $(\text{cal}_{\text{th}} = 4.184 \text{ J})$

	$(\Delta E_c^\circ/M)/\text{cal}_{\text{th}} \text{ g}^{-1}$			
	exo-THDC	RJ-4	RJ-4-I	JP-9
	-10685.70	-10776.90	-10764.58	-10672.20
	81.04	74.78	63.98	68.51
	79.84	76.04	65.81	69.36
	83.59	76.14	62.83	66.61
	81.37	77.91	62.17	70.21
	-10680.53	-10772.28	-10762.49	-10668.09
Mean	-10682.01	-10775.68	-10763.64	-10669.16
Standard deviation of the mean	0.90	0.80	0.57	0.78

4. DERIVED RESULTS

Derived values of the standard molar energy of the idealized combustion reaction, ΔE_c° , the standard molar enthalpy of combustion, ΔH_c° , and the standard molar enthalpy of formation, ΔH_f° , (exo-THDC, RJ-4, and RJ-4-I only), of the fuels in the liquid state are given in Table 5. Values of ΔE_c° and ΔH_c° refer to equations 1, 3, and 5; the values of ΔH_f° refer to equations 2 and 4. The uncertainties given in Table 5 are the "uncertainty intervals."⁽¹³⁾ The enthalpies of formation of $\text{CO}_2(\text{g})$ and $\text{H}_2\text{O}(\text{l})$ were taken to be -94.051 and -68.315 $\text{kcal}_{\text{th}} \text{mol}^{-1}$, respectively.⁽¹⁴⁾ Uncertainties assigned to the respective values were 0.011 $\text{kcal}_{\text{th}} \text{mol}^{-1}$ for CO_2 ⁽¹⁵⁾ and 0.010 $\text{kcal}_{\text{th}} \text{mol}^{-1}$ for $\text{H}_2\text{O}(\text{l})$.⁽¹⁶⁾

The values of enthalpy of combustion given in Tables 3, 4, and 5 are the "gross" heats of combustion for which the reaction products are gaseous carbon dioxide and liquid water. For combustion yielding gaseous carbon dioxide and gaseous water, the values of the "net" heat of combustion are: exo-THDC, $-(10081.5 \pm 2.3) \text{ cal g}^{-1}$; RJ-4, $-(10153.1 \pm 2.3) \text{ cal g}^{-1}$; RJ-4-I, $-(10141.4 \pm 2.2) \text{ cal g}^{-1}$; and JP-9, $-(10089.3 \pm 2.4) \text{ cal g}^{-1}$.

TABLE 5. Derived molar values for the liquid state at 298.15 K
 $(\text{cal}_{\text{th}} = 4.184 \text{ J})$

Fuel	ΔE_c°	ΔH_c°	ΔH_f°
	$\text{kcal}_{\text{th}} \text{ mol}^{-1}$	$\text{kcal}_{\text{th}} \text{ mol}^{-1}$	$\text{kcal}_{\text{th}} \text{ mol}^{-1}$
exo-THDC	-1455.31 ± 0.33	-1457.68 ± 0.33	-29.35 ± 0.35
RJ-4	-1770.37 ± 0.37	-1773.33 ± 0.37	-38.43 ± 0.40
RJ-4-I	-1768.39 ± 0.36	-1771.36 ± 0.36	-40.41 ± 0.39
JP-9	-1523.52 ± 0.34	-1525.92 ± 0.34	-----

REFERENCES

1. Good, W. D. J. Chem. Thermodynamics, 3, 539 (1971).
2. Good, W. D.; Moore, R. T.; Osborn, A. G.; Douslin, D. R. J. Chem. Thermodynamics, 6, 303 (1974).
3. Good, W. D.; Lee, S. H. J. Chem. Thermodynamics, 8, 643 (1976).
4. Good, W. D. J. Chem. Thermodynamics (in press).
5. Hubbard, W. N.; Scott, D. W.; Waddington, G. In Experimental Thermochemistry, Chap. 5, pp. 75-128, F. D. Rossini, editor. Interscience: New York. 1956.
6. Good, W. D.; Smith, N. K. J. Chem. Eng. Data, 14, 102 (1969).
7. Good, W. D. J. Chem. Eng. Data, 14, 231 (1969).
8. Good, W. D.; Scott, D. W.; Waddington, G. J. Phys. Chem., 60, 1080 (1956).
9. Good, W. D.; Douslin, D. R.; Scott, D. W.; George, A.; Lacina, J. L.; Dawson, J. P.; Waddington, G. J. Phys. Chem., 63, 1133 (1959).
10. Guthrie, G. B.; Scott, D. W.; Hubbard, W. N.; Katz, C.; McCullough, J. P.; Gross, M. E.; Williamson, K. D.; Waddington, G. J. Am. Chem. Soc., 74, 4602 (1952).
11. Cameron, A. E.; Wichers, E. J. Am. Chem. Soc., 84, 4175 (1962).
12. Cohen, E. R.; DuMond, J.W.M. Rev. Mod. Phys., 37, 537 (1965).
13. Rossini, F. D. In Experimental Thermochemistry, Chap. 14, pp. 297-320, F. D. Rossini, editor. Interscience: New York. 1956.
14. Wagman, D. D.; Evans, W. H.; Halow, I.; Parker, V. B.; Bailey, S. M.; Shumm, R. H. Natl. Bur. Std. (U.S.) Tech. Note 270-3. 1968.
15. Rossini, F. D.; Jessup, R. S. J. Res. Natl. Bur. Std., 21, 491 (1938).
16. Rossini, F. D. J. Res. Natl. Bur. Std., 6, 1 (1931).

April 1977

DISTRIBUTION LIST

THERMOPHYSICAL PROPERTIES

Project 2308, Task B1

CONTRACTORS

Aerospace Corporation
The Ivan L Getting Laboratories
Attn: Dr Charles M Randall
P. O. Box 95085
Los Angeles, CA 90045

Energy Research & Development
Administration
Bartlesville Energy Research Center
Attn: Mr William D Good
Bartlesville, OK 74004

CINDAS
Purdue University Research Park
Attn: Dr H H Li
2595 Yeager Road
West Lafayette, IN 47907

Dow Chemical Company
Thermal Laboratory, Bldg 1707
Attn: Dr Malcolm Chase
Midland, MI 48640

National Bureau of Standards
Physical Chemistry Division, IMS
US Department of Commerce
Attn: Dr Stan Abramowitz
Dr Ared Cezairlijan
Mr David Ditmars
Washington, DC 20234

University of Nevada
Mackay School of Mines
Attn: Prof Eugene Miller
Reno, NV 89507

Purdue University
School of Mechanical Engineering
Properties Research Laboratory
Attn: Dr R E Taylor
2595 Yeager Road
West Lafayette, IN 47907

Space Sciences, Inc
Attn: Mr Milton Farber
135 W Maple
Monrovia, CA 91016

Stanford Research Institute
Physical Sciences Division
Attn: Dr D L Hildenbrand
Menlo Park, CA 94025

NON-CONTRACTORS

Aerojet-General Corporation
Attn: Mr James P Coughlin
Dept 4940, Bldg 0525
P. O. Box 1947
Sacramento, CA 95809

Aerospace Corporation
Attn: Dr Nev A Gokcen
P. O. Box 95085
Los Angeles, CA 90045

AFML/LP (Dr Merrill L Minges)
Wright-Patterson AFB, OH 45433

AFML/MBG (Dr W C Kessler)
Wright-Patterson AFB, OH 45433

AFRPL/LKCB (Mr Curtis C Selph)
Edwards AFB, CA 93523

AFRPL/DYSP (Dr J D Stewart)
Edwards AFB, CA 93523

NON-CONTRACTORS

AFWL/ALD(Dr Leroy Wilson)
Kirtland AFB, New Mexico 87117

AFWL/ALC (Major David S Olson)
Kirtland AFB, New Mexico 87117

U. S. Army Research Office
Attn: Dr David R Squire
P. O. Box 12211
Research Triangle Park, NC 27709

AFAPL/RJT (Dr F D Stull)
Wright-Patterson AFB, OH 45433

Atlantic Research Corporation
Attn: Dr Charles Henderson
5390 Cherokee Avenue
Alexandria, VA 22314

University of California
Department of Chemistry
Attn: Dr Leo Brewer
Berkeley, CA 94700

Chemical Propulsion Information Agency
APL/JHU (2 copies)
Johns Hopkins Road
Laurel, MD 20810

Cornell University
Department of Chemistry
Attn: Dr S H Bauer
Ithica, New York 14850

ERDA
Pittsburgh Energy Research Center
Attn: Dr Francis E Spencer, Jr
4800 Forbes Avenue
Pittsburgh, PA 15213

Hercules Incorporated
P. O. Box 98
Attn: Dr Billings Brown
P. O. Box 98
Magna, UT 84044

Jet Propulsion Laboratory
Attn: Mr Theodore W Price
4800 Oak Grove Drive
Pasadena, CA 91103

Johns Hopkins University
Applied Physics Laboratory
Attn: Dr Robert Fristrom
Johns Hopkins Road
Laurel, MD 20810

Naval Ordnance Station
Attn: Mr Al Camp
Indian Head, MD 20640

NASA
Lewis Laboratories (Mail Stop 6-1)
Attn: Mr Sanford Gordon
Cleveland, OH 44135

NASA
Scientific and Technical Information
Facility
5001 Calvert Road
College Park, MD 20740

NAS-NRC
Attn: Dr H Van Olphen
2101 Constitution Avenue, NW
Washington, DC 20418

National Bureau of Standards
ADM A-538
Attn: Dr David Lide
Washington, DC 20234

National Bureau of Standards
Institute for Materials Research
Attn: Mr Donald D Wagman
Washington, DC 20234

NSSC
Department of the Navy
Code NSEA-0331
Attn: Mr John W Murrin
Washington, DC 20360

NON-CONTRACTORS

Office of Naval Research
Attn: Mr Rudolph Marcus
1030 E Green Street
Pasadena, CA 91101

Office of Naval Research
Power Program, Code 473
Attn: Dr Richard Miller
800 North Quincy St
Arlington, VA 22217

Rice University
Department of Chemistry
Attn: Dr John Margrave
Houston, TX 77001

United Technologies Corporation
Chemical Systems Division
Attn: Dr R O MacLaren
Sunnyvale, CA 94086