

UNCLASSIFIED

AD NUMBER
AD807299
NEW LIMITATION CHANGE
TO Approved for public release, distribution unlimited
FROM Distribution authorized to U.S. Gov't. agencies and their contractors; Critical Technology; NOV 1966. Other requests shall be referred to Air Force Materials Lab., Wright-Patterson AFB, OH 45433.
AUTHORITY
AFML ltr, 7 Dec 1972

THIS PAGE IS UNCLASSIFIED

AFML-TR-66-367

807299

THERMAL CONDUCTIVITY OF TANTALUM, TUNGSTEN,

RHENIUM, Ta-10W, T₁₁₁, T₂₂₂, W-25Re

IN THE TEMPERATURE RANGE 1500-2800°K

C. K. Jun and M. Hoch
University of Cincinnati

TECHNICAL REPORT AFML-TR-66-367

NOVEMBER 1966

This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of the Air Force Materials Laboratory (MAYT), Wright-Patterson Air Force Base, Ohio 45433

Air Force Materials Laboratory
Research and Technology Division
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio

NOTICES

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

Copies of this report should not be returned to the Research and Technology Division unless return is required by security considerations, contractual obligations, or notice on a specific document.

THERMAL CONDUCTIVITY OF TANTALUM, TUNGSTEN,
RHENIUM, Ta-10W, T₁₁₁, T₂₂₂, W-25Re
IN THE TEMPERATURE RANGE 1500-2800°K

C. K. Jun and M. Hoch

This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of the Air Force Materials Laboratory (MAYT), Wright-Patterson Air Force Base, Ohio 45433.

FOREWORD

This report was prepared by the Materials Science Program, University of Cincinnati, under USAF Contract AF 33(615)-1759. The contract was initiated under Project No. 7367, "Research on Characterization and Properties of Materials," Task No. 736704, "Extreme High Temperature Research Studies, Techniques, and Measurements." The work was administered under the direction of the Air Force Materials Laboratory, Research and Technology Division, Mr. Hyman Marcus, Project Engineer.

Funds for this project are supplied to the Air Force Materials Laboratory by the Office of Aerospace Research.

This report covers work conducted from April 1, 1965, through September 30, 1966. The manuscript was released by the authors in November 1966 as an RTD Technical Report.

This technical report has been reviewed and is approved.



HYMAN MARCUS, Actg. Chief
Thermo & Chemical Physics Branch
Materials Physics Division
AF Materials Laboratory

ABSTRACT

The thermal conductivity K of tantalum, tungsten, rhenium, Ta-10W, T_{111} , T_{222} , and W-25Re alloys was measured in the temperature range 1500-2800°K. The data are consistent and in agreement with theoretical considerations.

For Ta,

$$K = (.718 \pm .006) - (.435 \pm .208) \times 10^{-4} T \text{ watt/cm}^{\circ}\text{K} \quad 1500 < T < 2700^{\circ}\text{K}.$$

For Ta-10W,

$$K = (.720 \pm .004) - (.655 \pm .082) \times 10^{-4} T \text{ watt/cm}^{\circ}\text{K} \quad 1500 < T < 2700^{\circ}\text{K}.$$

For T_{111} ,

$$K = (.749 \pm .005) - (.675 \pm .141) \times 10^{-4} T \text{ watt/cm}^{\circ}\text{K} \quad 1500 < T < 2800^{\circ}\text{K}.$$

For T_{222} ,

$$K = (.770 \pm .003) - (.910 \pm .103) \times 10^{-4} T \text{ watt/cm}^{\circ}\text{K} \quad 1500 < T < 2000^{\circ}\text{K}.$$

For Re,

$$K = (.601 \pm .005) - (.712 \pm .154) \times 10^{-4} T \text{ watt/cm}^{\circ}\text{K} \quad 1500 < T < 2400^{\circ}\text{K}.$$

For W-25Re,

$$K = (.701 \pm .007) - (.304 \pm .270) \times 10^{-4} T \text{ watt/cm}^{\circ}\text{K} \quad 1500 < T < 2600^{\circ}\text{K}.$$

TABLE OF CONTENTS

	Page
INTRODUCTION	1
EXPERIMENTAL METHOD	1
EQUIPMENT AND EXPERIMENTAL PROCEDURE	2
MATERIALS	2
EXPERIMENTAL RESULTS	2
DISCUSSION OF THE RESULTS	3
REFERENCES	17

NOMENCLATURE

K = thermal conductivity in watt/sec °K

ϵ = total emittance

σ = Stefan-Boltzmann radiation constant

T_o = temperature in °K, at center of flat circular surface

a = radius of the specimen in cm

L = half height of the specimen (center to end) in cm

ΔT = temperature difference ($T_a - T_o$) between center and edge on the flat circular surface of the specimen

K_o, K_o' = constant, characteristic of the length to diameter ratio of the specimen

C_p = specific heat, cal/g/°K

θ = time in seconds

A = area of the sample

m = mass of the sample in grams

d = density, g/cc

$C^\circ = K_o + 0.1 \frac{\pi}{2} \cdot \frac{a}{L} \cdot K_o'$ a constant

r = independent radial variable

INTRODUCTION

There is a great need for accurate thermophysical data on the high temperature refractory metals and their alloys. Our paper reports measurements on the thermal conductivity of tantalum, tungsten, rhenium, and Ta-10W, T₁₁₁, T₂₂₂, and W-25Re alloys in the temperature range 1500-2800°K.

EXPERIMENTAL METHOD

Thermal Conductivity

The temperature distribution on the flat surface of a cylindrical disc heated in vacuum by induction has been used by Hoch, Nitti, Gottschlich, and Blackburn(1)* to determine the thermal conductivity of solid materials. The following equation applies:

$$K = \frac{\epsilon \cdot \sigma \cdot T_o^4 \cdot a \cdot L}{4 \cdot \Delta T \cdot L \cdot K_o + 2\pi \cdot K_o \cdot a \cdot \Delta T} = \frac{\epsilon \sigma T_o^4}{4 \left(\frac{dT}{dr} \right)^2 \cdot a^2} \cdot \frac{a}{C^\circ} \quad (1)$$

This method has been applied earlier to various materials [Vardi and Hoch(2), Hoch and Vardi(3), Jun and Hoch(4), and Hoch and Jun(5)].

Determination of Total Emittance

When a specimen is heated to high temperature and then let cool in vacuum, the specimen loses heat from the surface to the surroundings only by radiation. From the power balance, Hoch, et al.(6,7,8) derived the relationship:

$$\frac{C_p}{\epsilon} \cdot \frac{d(1/T^3)}{d\theta} = \frac{3\sigma A}{m} \quad (2)$$

Equation 2 yields C_p/ϵ .

The last equation requires the knowledge of the specific heat to obtain the total emittance. The following specific heat equations, derived in an earlier paper(9), were used.

For Ta, Ta-10W, T_{111} , and T_{222} ,

$$C_p = 3.17 \times 10^{-2} + 5.073 \times 10^{-6} T \text{ cal/g}^\circ\text{K}.$$

For W and W-25Re,

$$C_p = 3.022 \times 10^{-2} + 5.368 \times 10^{-6} T + 2.43 \times 10^{-10} T^2 \text{ cal/g}^\circ\text{K}.$$

For rhenium,

$$C_p = 3.023 \times 10^{-2} + 5.81 \times 10^{-6} T \text{ cal/g}^\circ\text{K}.$$

EQUIPMENT AND EXPERIMENTAL PROCEDURE

The equipment and experimental procedure have been described earlier(2,6).

MATERIALS

The tantalum and tungsten were obtained from the Fansteel Metallurgical Corporation, North Chicago, Illinois. The Ta-10W, T_{111} , and T_{222} samples were supplied by the Thermophysics Branch, AFML, RTD. The rhenium, W-25Re samples were supplied by General Electric Company, NMPO, Cincinnati, Ohio.

Compositional analysis on the various samples is given in Table 1, which also gives the grain size of the samples used. The sample dimensions and the ratio of specific heat to total emittance is given in Table 2.

EXPERIMENTAL RESULTS

The experimental results on the various samples are given in Tables 3-9. In Figure 1, all the data obtained on tantalum are represented. The best straight line obtained by least squares analysis gives

$$K = (.718 \pm .006) - (.435 \pm .208) \times 10^{-4} T \text{ watt/cm}^\circ\text{K}.$$

It has to be pointed out that all five samples of tantalum were machined in our shop from the same 1" diameter tantalum rod. The samples were used differently, heated to high temperature, and several of them used in the study to show that $C_p/e(5,6,7)$ is constant and finally in the thermal conductivity measurements shown here. As one can observe in Table 2, an extremely

large grain growth has occurred during these runs. The data presented in Figure 1 were obtained by two experimenters; samples 1, 4, and 5 by one, and samples 2 and 3 by the other. Keeping all this in mind, one can see that the data are fairly consistent.

In Figure 2 we have plotted the thermal conductivity of the tantalum base alloys. They all have a thermal conductivity a little less than tantalum and their slopes are parallel to each other. The only larger than expected fluctuation is observed in the Ta-10W in which sample No. 1 was first run, afterwards heated to 2700°K and the other points, marked sample No. 2 taken. This seems to indicate that sample No. 1 was not in equilibrium. The data can be represented as

$$\text{Ta-10W } K = (.720 \pm .004) - (.655 \pm .082) \times 10^{-4} T \text{ watt/cm}^{\circ}\text{K.}$$

$$T_{111} \quad K = (.749 \pm .005) - (.675 \pm .141) \times 10^{-4} T \text{ watt/cm}^{\circ}\text{K.}$$

$$T_{222} \quad K = (.770 \pm .003) - (.910 \pm .103) \times 10^{-4} T \text{ watt/cm}^{\circ}\text{K.}$$

In Figure 3 we show the data on pure rhenium, tungsten, and W-25Re alloy. The tungsten samples 1, 2, and 3 were all machined from the same tungsten piece. Sample No. 1 was repolished and machined to obtain sample No. 2, after which it was again repolished to obtain sample No. 3. In the W-25Re material, sample No. 2 is a powdered metallurgy sample and sample No. 1 is an arc-cast sample; the difference between the two shows up mainly in the density.

$$\text{For rhenium } K = (.600 \pm .005) - (.712 \pm .154) \times 10^{-4} T \text{ watt/cm}^{\circ}\text{K.}$$

$$\text{W-25Re } K = (.701 \pm .007) - (.304 \pm .270) \times 10^{-4} T \text{ watt/cm}^{\circ}\text{K.}$$

DISCUSSION OF THE RESULTS

The variation of the thermal conductivity temperature can be evaluated theoretically using the equation given by Mott and Jones(10),

$$\frac{R}{T} = A(1 + 2\alpha_L \gamma T)$$

where R is the resistance, α_L is the linear thermal expansion coefficient, and γ is the Grüneisen constant. A is a constant. If all the conduction is electronic, then the electrical resistivity and thermal conductivity are related by the Wiedeman-Franz-Lorenz relation, $K \cdot R/T = L_0$. These relationships give

$$K = \frac{L_0}{A} \cdot \frac{1}{1 + 2\alpha_L \gamma T} \approx \frac{L_0}{A} (1 - 2\alpha_L \gamma T).$$

Using the values 1.75 for γ , and $1 \times 10^{-5}/^{\circ}\text{K}$ for the linear thermal expansion coefficient, we find that between 1500-2500 $^{\circ}\text{K}$ the thermal conductivity should decrease by 3.5%.

The thermal conductivity of the tantalum alloys is somewhat lower than that of pure tantalum, as required by theory. The decrease in K between 1500 and 2500 $^{\circ}\text{K}$ is 6% for Ta, 9% for Ta-10W and T_{111} , and 12% for T_{222} , which is in agreement with theory.

The thermal conductivity of tungsten drops extremely rapidly between 1500-2100 $^{\circ}\text{K}$ and only drops very little between 2100-2600 $^{\circ}\text{K}$. Why the rapid drop in tungsten thermal conductivity between 1500-2100 $^{\circ}\text{K}$ (which has also been observed by other investigators) cannot be explained at this moment. The thermal conductivity of rhenium drops 12% in agreement with theory. The crystal structure of rhenium is hexagonal, and therefore, should have two distinct values for the thermal conductivity. The axial ratio of rhenium is close to ideal and therefore we have assumed that the two thermal conductivities would not be too different from each other. The material used in this investigation was cut from a sheet which was probably rolled. Therefore, the measurements give an average thermal conductivity. The W-25Re alloy has a thermal conductivity much lower than that of tungsten, as expected, its decrease between 1500-2500 $^{\circ}\text{K}$ is 4%. Thus the addition of 25 wt. % Re modifies the W material in so far as thermal conductivity behavior is concerned.

Further investigation may be necessary to explain the behavior of the thermal conductivity of tungsten and especially to find out the minimum alloying which is required to eliminate the rapid decrease in thermal conductivity.

TABLE 1. CHEMICAL COMPOSITION OF
THE SAMPLES USED

(Everything in ppm, except where noted.)

Impurity	Tantalum			Ta-10W	T ₁₁₁	T ₂₂₂
	1	2 3	4 5			
C	19	137, 30*	.5	25	22	95
H	17	2.7	0.9	ND**	5	12
N	17	16	18	ND	23	ND
O	17	655, 114, 12*	36	20	34	6
W				9.0%	7.8%	8.5%
Hf					2.0%	2.5%
	W	Re		W-25Re		
				No. 1	No. 2	
C	7	47		23	25	
H	<.5				2	
N	<5			<5	ND	
O	<5	11, 16		14	22	
Re				25.04%	24.5%	
Fe				0.001%		

* Data indicates segregation

** Not detected

TABLE 2. DIMENSIONS, GRAIN SIZE AND RATIO OF SPECIFIC HEAT
TO TOTAL EMITTANCE FOR THE SAMPLES USED

Material	Sample	Dia. cm	Height cm	Mass gm	Density gm/cm ³	Avg. Grain Dia. mm	Cp/ ϵ cal/gm ^o K
Ta	1	2.4892	.3927	31.8141	16.65	.26	.210 $\pm$.010
	2	2.2232	.2125	13.7184	16.63		.195 $\pm$.006
	3	2.2232	.2018	13.0145	16.62	1.04	.193 $\pm$.006
	4	1.9075	.2316	11.0043	16.63	1.23	.210 $\pm$.010
	5	1.9062	.2273	10.7614	16.60	1.86	.219 $\pm$.008
Ta-10W	1	2.1265	.3254	19.5351	16.91		.210 $\pm$.008
	2	2.1251	.3145	18.8511	16.91		.209 $\pm$.006
T ₁₁₁	1	2.5476	.2504	22.6110	16.73		.199 $\pm$.005
	2	2.5476	.2504	22.6110	16.73		.209 $\pm$.013
T ₂₂₂	1	2.2524	.3320	27.8949	16.81		.197 $\pm$.004
	2	2.2524	.3320	27.8949	16.81		.210 $\pm$.004
Re	1	1.0711	.1582	2.9890	20.97	.020	.175 $\pm$.012
W-Re	1	1.9196	.0766	4.3870	19.73	.216	.252 $\pm$.004
	2	1.9208	.2103	11.6877	19.19	.041	.198 $\pm$.003
W	1	2.5339	.2999	28.5044	18.89		.142 $\pm$.004
	2	2.4785	.2714	24.9065	19.03		.153 $\pm$.002
	3	2.0801	.2700	17.6461	19.23	.035	.182 $\pm$.005

TABLE 3. THERMAL CONDUCTIVITY OF TANTALUM

Sample	Temp °K	ΔT °K	K/e cal/sec cm°K	K watt/cm°K
1	1578	21	.780	.617
	1746	34	.722	.584
	1841	42	.722	.590
	1942	52	.723	.597
	2007	59	.726	.606
2	1700	41.2	.799	.691
	1759	48.7	.775	.678
	1869	51.2	.784	.693
	1985	81.2	.752	.675
	2225	138.2	.697	.643
	2334	173.8	.672	.627
	2398	203.4	.640	.603
3	1660	38.6	.817	.703
	1828	59.9	.773	.680
	2043	109.3	.662	.598
	2269	149.8	.734	.680
	2391	224.2	.604	.567
	2490	264.3	.603	.574
4	1563	21	.765	.603
	1585	21	.809	.640
	1712	28	.826	.665
	1714	28	.829	.668
	1811	38	.762	.621
	1817	37	.793	.646
	1907	44	.809	.667
	2020	61	.734	.613
	2142	68	.833	.707
5	1665	26.5	.785	.601
	1816	36.5	.806	.630
	1923	47.5	.779	.616
	2043	63.5	.742	.597
	2162.5	78.5	.754	.615
	2260	95.5	.739	.610
	2468	142	.707	.597
	2542	159	.710	.605
	2671	193	.713	.616

TABLE 4. THERMAL CONDUCTIVITY OF Ta-10W

Sample	Temp°K	$\Delta T^\circ K$	K/ ϵ cal/sec cm°K	K watt/cm°K
1	1514	18	.696	.546
	1648	24	.732	.585
	1753	33	.682	.552
	1807	40	.635	.518
	1857	45	.630	.516
	1938	56	.600	.496
	1973	57	.634	.526
	2072	63	.697	.586
	2130	76	.645	.547
2	1731	29	.753	.610
	1868	40.7	.727	.599
	1990.5	54.9	.695	.581
	2075	65.4	.689	.582
	2238	90.7	.672	.580
	2496	147	.642	.571
	2619	190	.602	.542
	2742	233	.589	.538

TABLE 5. THERMAL CONDUCTIVITY OF T_{111}

Sample	Temp°K	$\Delta T^\circ K$	K/ϵ cal/sec cm°K	K watt/cm°K
1	1652	43.8	.745	.628
	1816	65.4	.729	.627
	1912	82.7	.709	.617
	1990.5	98.1	.702	.617
	2103.5	128.4	.669	.596
	2324.5	195.1	.656	.600
	2430	237.2	.644	.596
	2520	277.6	.637	.596
	2604	333.9	.604	.570
	2671	366.4	.609	.579
	2756	430	.588	.565
2	1524	26	.852	.675
	1585	33	.785	.627
	1685	39	.848	.686
	1800	57	.756	.620
	1808	58	.756	.622
	1915	71	.777	.647
	1962	86	.707	.592
	2022	104	.660	.557
	2082	112	.689	.586

TABLE 6. THERMAL CONDUCTIVITY OF T₂₂₂

Sample	Temp°K	$\Delta T^\circ K$	K/ϵ cal/sec cm°K	K watt/cm°K
1	1660	34	.725	.618
	1798	48	.707	.613
	1990.5	74	.688	.611
	2110.5	100	.644	.580
	2231	126	.639	.584
	2291.5	152.5	.587	.540
	2390	178.4	.594	.553
	2486.5	217.9	.570	.536
	2598.5	259	.571	.545
2	1509	20	.835	.650
	1662	32	.766	.609
	1716	36	.775	.621
	1784	45	.725	.585
	1842	51	.727	.591
	1925	61	.725	.596
	1933	63	.713	.587
	2052	82	.696	.581
	2111	92	.695	.584

TABLE 7. THERMAL CONDUCTIVITY OF TUNGSTEN

Sample	Temp°K	$\Delta T^\circ K$	K/ϵ cal/sec cm°K	K watt/cm°K
1	1513	19	1.032	1.183
	1536	20	1.042	1.197
	1578	23	1.009	1.169
	1678	32	.912	1.072
	1748	37	.945	1.122
	1835	47	.903	1.088
	1898	54	.899	1.092
	1930	63	.824	1.008
2	1571.5	21	1.103	1.182
	1640	26	1.056	1.144
	1675	30	.996	1.084
	1719.5	34.5	.962	1.055
	1745.5	37.5	.940	1.036
	1835.5	46	.937	1.048
	1905	55.5	.901	1.017
3	1836	30.5	1.011	.950
	1948	39.5	.989	.946
	2206	70	.918	.911
	2350	93	.890	.902
	2463	119	.839	.866
	2608	146	.860	.905

TABLE 8. THERMAL CONDUCTIVITY OF RHENIUM

Temp °K	ΔT °K	K/ϵ cal/sec cm °K	K watt/cm °K
1577	12	.512	.483
1667	15.5	.495	.473
1766	19.5	.496	.480
1837.5	23.5	.482	.472
1930	29	.476	.471
2065	40.5	.446	.450
2142.5	47.5	.441	.450
2166	50	.438	.448
2226	53.5	.456	.471
2294	67	.411	.428
2397	84.5	.388	.411

TABLE 9. THERMAL CONDUCTIVITY OF W-25Re

Sample	Temp°K	$\Delta T^\circ K$	K/c cal/sec cm°K	K watt./cm°K
1*	1616.5	52	1.069	.702
	1710	68	1.027	.682
	1887	107	.965	.660
	1928	114	.987	.680
	2034	146	.955	.668
	2074	154.5	.976	.687
2**	1625	27	.767	.640
	1669	29.5	.781	.657
	1720	36	.722	.612
	1802.5	43	.729	.627
	1804.5	42.5	.741	.637
	1917	57.5	.697	.610
	1925.5	56	.729	.638
	2002.5	67.5	.707	.626
	2043.5	76.5	.677	.603
	2088	81	.697	.626
	2097	83	.692	.623
	2128	95	.641	.580
	2283	118	.684	.631
	2415	149	.678	.639
	2553	187	.674	.648

* arc cast

** powdered metallurgy

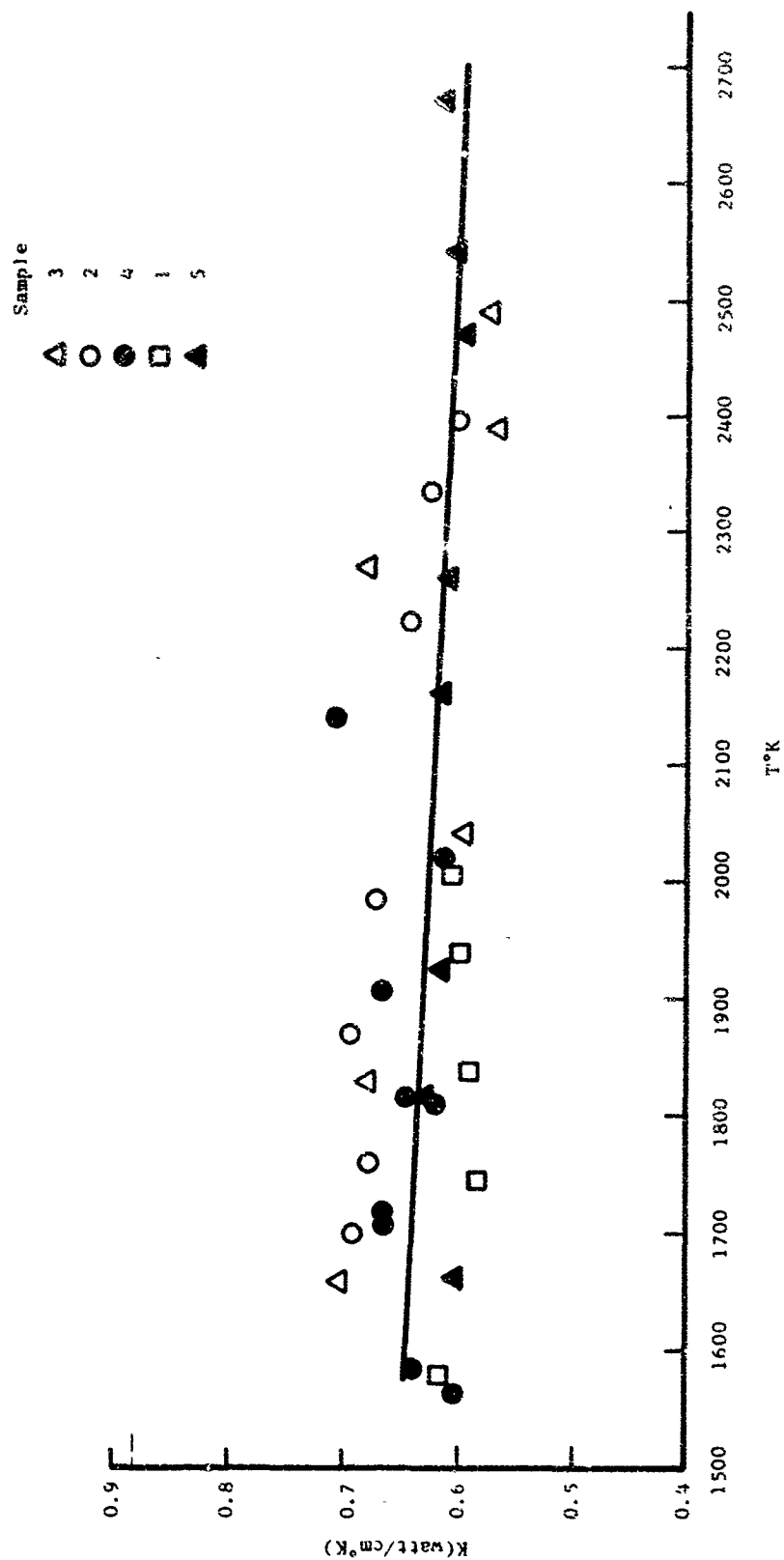


FIGURE 1. THERMAL CONDUCTIVITY OF TANTALUM

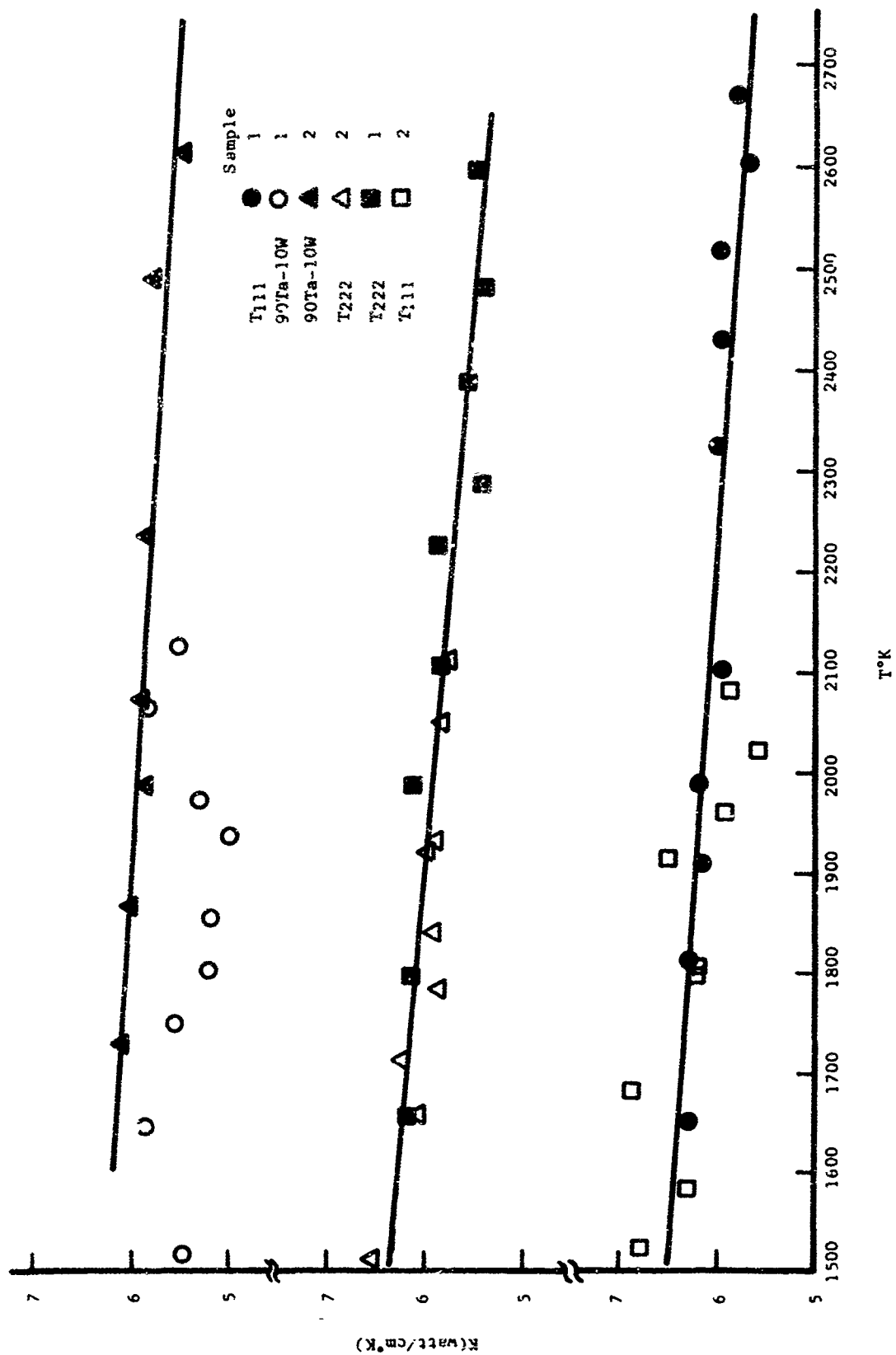


FIGURE 2 THERMAL CONDUCTIVITY OF TANTALUM ALLOYS

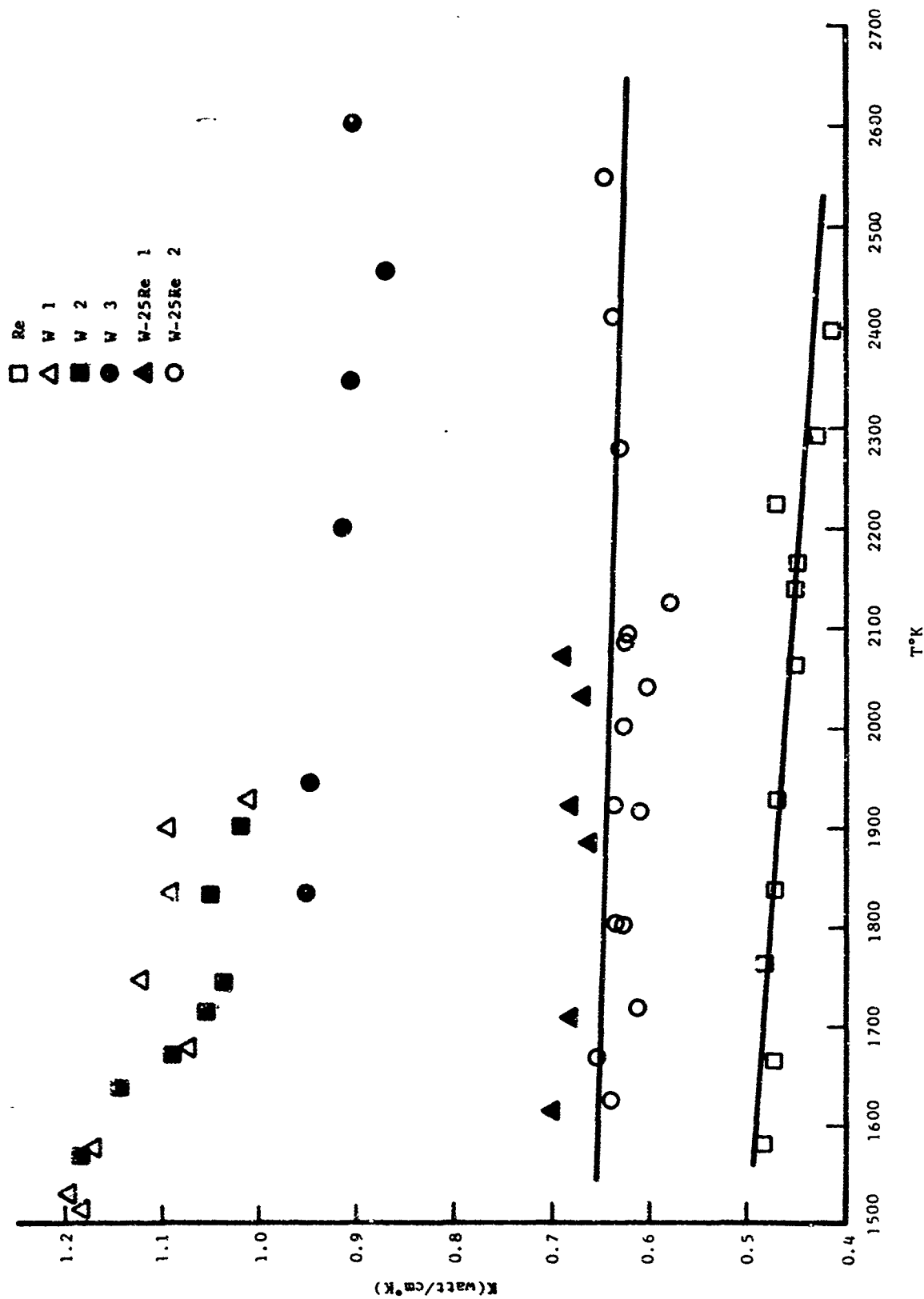


FIGURE 3 THERMAL CONDUCTIVITY OF TUNGSTEN, RHENIUM AND W-25Re

REFERENCES

1. M. Hoch, D. A. Nitti, C. F. Gottschlich, and P. E. Blackburn, "New Method for the Determination of Thermal Conductivities Between 1000 and 3000°C," in Progress in International Research on Thermodynamic and Transport Properties, ASME, Academic Press, New York, 512-518 (1962).
2. J. Vardi and M. Hoch, "Thermal Conductivity of Anisotropic Solids at High Temperatures - The Thermal Conductivity of Molded and Pyrolytic Graphites," J. Am. Cer. Soc. 46, 129-132 (1963).
3. M. Hoch and J. Vardi, "Thermal Conductivity of TiC," J. Am. Cer. Soc. 46, 245 (1963).
4. C. K. Jun and M. Hoch, "Thermal Conductivity of Molybdenum at Elevated Temperatures: Influence of Grain Size," in Advances in Thermophysical Properties at Extreme Temperatures and Pressures, ASME, New York (1965).
5. M. Hoch and C. K. Jun, "The Thermal Conductivity of TiB_2 , ZrB_2 , HfB_2 , and NbB_2 at Elevated Temperatures," NPL Thermal Conductivity Conference, Teddington, England, 1964.
6. M. Hoch and H. V. L. Narasimhamurty, "Relation Between Specific Heat and Emissivity of Tantalum at Elevated Temperatures," ASD-TDR-63-371, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio, 1963.
7. M. Hoch, "Thermal Conductivity and Total Emissivity Measurements in the Temperature Range 1000-3000°C," ML-TDR-64-59, Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio, 1964.
8. H. V. L. Narasimhamurty, A. S. Iyer, and M. Hoch, "Relation Between Specific Heat and Total Emittance in Tantalum, Niobium, Tungsten, and Molybdenum," J. Phys. Chem. 69, 1420-1423 (1965).
9. M. Hoch, "High Temperature Specific Heat of Refractory Metals and Alloys," AFML-TR-66-360, Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio, 1966.
10. N. F. Mott and H. Jones, "The Theory of the Properties of Metals and Alloys," Dover, New York, 958.

Unclassified

Security Classification

DOCUMENT CONTROL DATA - R&D		
(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)		
1 ORIGINATING ACTIVITY (Corporate author) Materials Science Program University of Cincinnati Cincinnati, Ohio		2a REPORT SECURITY CLASSIFICATION Unclassified
		2b GROUP N.A.
3 REPORT TITLE Thermal Conductivity of Tantalum, Tungsten, Rhenium, Ta-10W, T ₁₁₁ , T ₂₂₂ , W-25Re in the Temperature Range 1500-2800°K		
4 DESCRIPTIVE NOTES (Type of report and inclusive dates) Technical Report, April 1, 1965 to September 30, 1966		
5 AUTHOR(S) (Last name, first name, initial) Jun, C. K., and Hoch, M.		
6 REPORT DATE November 1966	7a TOTAL NO. OF PAGES 17	7b NO. OF REFS 10
8a CONTRACT OR GRANT NO. AF 33(615)-1759	8b ORIGINATOR'S REPORT NUMBER(S) AFML-TR-66-367	
9a PROJECT NO 7367		
9c Task No 736704	9b OTHER REPORT NO(S) (Any other numbers that may be assigned this report) None	
10 AVAILABILITY/LIMITATION NOTICES This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of the Air Force Materials Laboratory (MAYT), Wright-Patterson Air Force Base, Ohio 45433.		
11 SUPPLEMENTARY NOTES	12 SPONSORING MILITARY ACTIVITY Air Force Materials Laboratory (MAYT) Wright-Patterson Air Force Base, Ohio	
13 ABSTRACT The thermal conductivity K of tantalum, tungsten, rhenium, Ta-10W, T ₁₁₁ , T ₂₂₂ , and W-25Re alloys was measured in the temperature range 1500-2800°K. The data are consistent and in agreement with theoretical considerations. For Ta, $K = (.718 \pm .006) - (.435 \pm .208) \times 10^{-4} T \text{ watt/cm}^2\text{K } 1500 < T < 2700^\circ\text{K}.$ For Ta-10W, $K = (.720 \pm .004) - (.655 \pm .082) \times 10^{-4} T \text{ watt/cm}^2\text{K } 1500 < T < 2700^\circ\text{K}.$ For T ₁₁₁ , $K = (.749 \pm .005) - (.675 \pm .141) \times 10^{-4} T \text{ watt/cm}^2\text{K } 1500 < T < 2800^\circ\text{K}.$ For T ₂₂₂ , $K = (.770 \pm .003) - (.910 \pm .103) \times 10^{-4} T \text{ watt/cm}^2\text{K } 1500 < T < 2000^\circ\text{K}.$ For Re, $K = (.601 \pm .005) - (.712 \pm .154) \times 10^{-4} T \text{ watt/cm}^2\text{K } 1500 < T < 2400^\circ\text{K}.$ For W-25Re, $K = (.701 \pm .007) - (.304 \pm .270) \times 10^{-4} T \text{ watt/cm}^2\text{K } 1500 < T < 2600^\circ\text{K}.$		

DD FORM 1 JAN 64 1473

Unclassified

Security Classification

Unclassified

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Thermal conductivity Total emittance Tantalum Tungsten T111, T222, Ta-10W Rhenium W-25Re Refractory metals						

INSTRUCTIONS

1. **ORIGINATING ACTIVITY:** Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization (*corporate author*) issuing the report.

2a. **REPORT SECURITY CLASSIFICATION:** Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. **GROUP:** Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. **REPORT TITLE:** Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. **DESCRIPTIVE NOTES:** If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. **AUTHOR(S):** Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. **REPORT DATE:** Enter the date of the report as day, month, year, or month, year. If more than one date appears on the report, use date of publication.

7a. **TOTAL NUMBER OF PAGES:** The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. **NUMBER OF REFERENCES:** Enter the total number of references cited in the report.

8a. **CONTRACT OR GRANT NUMBER:** If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. **PROJECT NUMBER:** Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. **ORIGINATOR'S REPORT NUMBER(S):** Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. **OTHER REPORT NUMBER(S):** If the report has been assigned any other report numbers (*either by the originator or by the sponsor*), also enter this number(s).

10. **AVAILABILITY/LIMITATION NOTICES:** Enter any limitations on further dissemination of the report, other than those

imposed by security classification, using standard statements such as:

- (1) "Qualified requesters may obtain copies of this report from DDC."
- (2) "Foreign announcement and dissemination of this report by DDC is not authorized."
- (3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through _____."
- (4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through _____."
- (5) "All distribution of this report is controlled. Qualified DDC users shall request through _____."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. **SUPPLEMENTARY NOTES:** Use for additional explanatory notes.

12. **SPONSORING MILITARY ACTIVITY:** Enter the name of the departmental project office or laboratory sponsoring (paying for) the research and development. Include address.

13. **ABSTRACT:** Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as (TS), (S), (C), or (U).

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. **KEY WORDS:** Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.

Unclassified

Security Classification