ARGONNE NATIONAL LABORATORY
P. O. Box 299
Lemont, Illinois

SELECTED VALUES OF THE PHYSICAL PROPERTIES
OF VARIOUS MATERIALS

F. J. Tebo

September, 1958

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

Operated by The University of Chicago
under
Contract W-31-109-eng-38

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

SELECTED VALUES OF THE PHYSICAL PROPERTIES OF VARIOUS MATERIALS

by
F. J. Tebo

Selected physical properties of various solids, liquids and gases of interest in nuclear reactor heat transfer and fluid flow analysis are presented. In most cases, values for thermal conductivity, specific heat, density, viscosity and Prandtl numbers are given as functions of temperature. A table of room temperatures values of some properties have been compiled on materials for which data as a function of temperature were not found.

A short list of references to additional physical property data on many materials is provided at the end of the compilation.

The values presented here were compiled after a brief survey of the classified and unclassified literature, and no guarantee is given that this is the best existing information. Much of the data came from sources most frequently used for reference, such as the Reactor Handbook and the Liquid Metals Handbook.

TABLE OF CONTENTS

<u>Solids</u>	<u>Page Number</u>		
	<u>k*</u>	<u>C_p*</u>	<u>ρ*</u>
Alumel	1	-	-
Alumina	2	-	-
Aluminum	3	4	5
Aluminum Alloy 2S	-	6	-
Aluminum Alloy 24S-T4	7	-	8
Aluminum Alloy 75S-T6	-	-	9
Beryllia	10	11	-
Beryllium	12	13	14
Bismuth	15	16	17
Boron Carbide	18	-	-
Cadmium	19	20	-
Cadmium-Silver Alloy	21	X	X
Concrete, High Density	22	-	-
Copper	23	24	25
Graphite	26 & 27	28	29
Inconel	30	-	31
Inconel "X"	32	-	33
Iron, Armco	34	35	-
Iron, Cast	36	-	-
Iron, Pure	37	-	-
Lead	38	39	-

TABLE OF CONTENTS (Con't)

<u>Solids</u>	<u>Page Number</u>		
	<u>k*</u>	<u>C_p*</u>	<u>ρ*</u>
Magnesium	40	41	42
Magnesium Alloy AN-M-29	43	-	-
Magnesium Oxide	44	-	-
Molybdenum	45	46	-
Monel	47	48	-
"K" Monel	49	-	50
Nichrome V	-	51	-
Nickel	52	53	-
"A" Nickel	54	-	-
Nickel Oxide	55	-	-
Nickel-Zirconium Alloy	56	X	X
Silver	57	58	59
Spinel	60	-	-
Stainless Steel 301	61	-	62
Stainless Steel 303	63	---	-
Stainless Steel 304	64	-	-
Stainless Steel 310	65	-	-
Stainless Steel 316	66	-	67
Stainless Steel 321	68	69	-
Stainless Steel 347	70	71	72
Stainless Steel 430	73	-	-
Stainless Steel 446	74	75	-
Steel, SAE 1010	76	77	78

TABLE OF CONTENTS (Con't)

Solids	Page Number		
	<u>k*</u>	<u>C_p*</u>	<u>p*</u>
Steel, Low Carbon	79	-	-
Steel, Mild	80	-	-
Steel, Tungsten	81	-	-
Tantalum	82	-	-
Thorium	83	84	85
Thorium Dioxide	86	-	-
Titanium	-	87	88
Titanium Dioxide	89	-	-
Tungsten	90	91	-
Uranium	92	93	-
Uranium-Chromium Alloy	94	X	X
Uranium-Zirconium Alloys	95	X	96
U-Zr Alloy (Irradiated)	97 & 98	-	-
Uranium Dioxide	99	100	-
Vanadium	101	102	-
Zinc	103	104	105
Zinc Oxide	106	-	-
Zirconium	107	108	109
Zirconium-Tantalum Alloy	110	X	X
Zirconium-Tin Alloy	111	X	X
Zircon	112	-	-
Zirconium Dioxide	113	-	-

TABLE OF CONTENTS (Con't)

<u>Liquids</u>	<u>Page Number</u>				
	<u>k*</u>	<u>C_p*</u>	<u>ρ*</u>	<u>u*</u>	<u>Pr*</u>
Aluminum	114	115	116	117	X
Bismuth	118	119	120	121	122
Cadmium	123	124	125	126	X
Diphenyl	127	X	128	129	X
Dowtherm	130	131	132	133	X
Gallium	X	134	135	136	X
Lead	137	138	139	140	141
Lead-Bismuth Alloy	142	143	144	145	146
Lithium	147	148	149	150	151
Mercury	152	153	154	155	X
Potassium	156	157	158	159	160
Sodium	161	162	163	164	165
56% Na, 44% K Alloy	166	167	168	169	170
22% Na, 78% K Alloy	171	172	173	174	175
Tin	176	177	178	179	X
Water, Heavy	X	180	181	182	X
Water, Light	183	184	185	186	187
Zinc	188	189	190	191	X

TABLE OF CONTENTS (Con't)

<u>Gases</u>	<u>Page Number</u>				
	<u>k*</u>	<u>C_p*</u>	<u>ρ*</u>	<u>u*</u>	<u>Pr*</u>
Air	192	193	194	195	196
Argon	197	198	199	200	201
Carbon Dioxide	202	203	204	205	206
Carbon Monoxide	207	208	209	210	211
Helium	212	213	214	215	216
Hydrogen	217	218	219	220	221
Nitric Oxide	222	223	224	225	226
Nitrogen	227	228	229	230	231
Oxygen	232	233	234	235	236
Steam	237	238	239	240	241

k - Thermal Conductivity

C_p - Heat Capacity

ρ - Density

u - Dynamic Viscosity

Pr - Prandtl Number

- - Single point values

X - No data presented

TABLE OF CONTENTS (Con't)

<u>Table Number and Title</u>	<u>Page Number</u>
1. Composition of Some Metals	242
2. Single Point Value of Some Properties	243
3. Prandtl Numbers of Gases	246
4. Thermal Conductivities of Gases	247
5. Dynamic Viscosities of Gases	248
6. Viscosities of Argon Under Pressure	249
7. Viscosities of Carbon Dioxide Under Pressure	250
8. Viscosities of Hydrogen Under Pressure	251
9. Viscosities of Nitrogen Under Pressure	252
10. Viscosities of Oxygen Under Pressure	253
11. Viscosities of Steam Under Pressure	254
References	255

ALLUMEL

THERMAL CONDUCTIVITY

95.2 mW
2.2 mW
19.3V
2.2 A

LEGEND

TRANS. ASSIT.
21.1061 1973

AJT

5/12/81

TEMPERATURE °F

0

200

400

600

800

1000

1200

1400

1600

1800

2000

2200

28

26

24

22

20

18

16

14

THERMAL CONDUCTIVITY BTU/HR-FT-°F

ALUMINUM

SPECIFIC HEAT

0.27

0.26

0.25

0.24

0.23

0.22

0.21

0.20

BTU/LB-°F

SPECIFIC HEAT

LEGEND

X-REFRATOR HANDBOOK

O-ANL-WH7-122

MP

SOLID

LIQUID

2/4/35

FJT

TEMPERATURE °F

2200

2000

1800

1600

1400

1200

1000

800

600

400

200

0

ALUMINUM 245-T4

THERMAL CONDUCTIVITY

LEGEND

X-REF TYP-6745-1

2/10/53

FJT

24S-74 ALUMINUM

DENSITY

DENSITY
LB/FT³

DENSITY

TEMPERATURE °F

24S-74

ASTM

LEGEND

X=ASTM B147-1

755-76 ALUMINUM

DENSITY

LEGEND

XAFET-6145-1

2/13/55
FJT

BERYLLIA (BeO)

THERMAL CONDUCTIVITY

X-DENSITY - 3.01 G/CC
 O-DENSITY - 2.87 G/CC

LEGEND

X-NYO-3647
 O-REACTOR HANDBOOK

13/5/55

FJT

THERMAL CONDUCTIVITY BTU/HR-FT-F

TEMPERATURE °F

BERYLLIA (B₂O₃)

SPECIFIC HEAT

SPECIFIC HEAT BTU/LB-°F

LEGEND

REACTOR HANDBOOK

5/20/55

FJT

TEMPERATURE °F

BKSMUTH

THERMAL CONDUCTIVITY

LEGEND

X-METALS REF BOOK

O-REACTOR HANDBOOK

2/17/55

FTT

BISMUTH

SPECIFIC HEAT

LEGEND

NEPA-1C-49-10-1

4/27/55

FJT

BORON CARBIDE

THERMAL CONDUCTIVITY

DENSITIES, A-2.5 G/CC

B-1.9 G/CC

LEGEND

X-BMI-713

O-KAPL-822

2/15/55

FJT

CADMIUM

THERMAL CONDUCTIVITY

LEGEND

X-METALS REF. 600H

2/12/53 FJT

TEMPERATURE °F

CADMIUM

SPECIFIC HEAT

LEGEND

X-NYD-6154

O-ASM METALS HANDBOOK

2/15/55

FJT

CADMIUM-SILVER ALLOYS

THERMAL CONDUCTIVITY

A-51.4 WT % CD
 B-12.9 WT % CD
 C-22.0 WT % CD
 D-31.8 WT % CD
 E-35.7 WT % CD

LEGEND

BM1-77

4/15/50

FJT

HIGH DENSITY CONCRETE USING LIMONITE-IRON

THERMAL CONDUCTIVITY

LEGEND

BMI-71

5/20/55

FJT

THERMAL CONDUCTIVITY BTU/HR-FT²

TEMPERATURE °F

COPPER

THERMAL CONDUCTIVITY

GRAPHITETHERMAL CONDUCTIVITY
(TRANSVERSE)LEGEND

X-NEPA-275

O-REACTOR HANDBOOK

A-BMU-T-35

2/4/55

FJT

CAST IRON

THERMAL CONDUCTIVITY

LEGENDMATERIALS + METHODS
33-107 JUNE 1951

4/27/55

FNT

TEMPERATURE °F

PURE IRON

THERMAL CONDUCTIVITY

LEGEND
 MATERIALS * METHODS
 33-107 JUNE 1951

4/27/55

F.T.T.

0 200 400 600 800 1000 1200 1400 1600 1800 2000

TEMPERATURE °F

MAGNESIUM

THERMAL CONDUCTIVITY

THERMAL CONDUCTIVITY BTU/HR-FT-F

LEGEND

X-METALS REF. BOOK

2/11/65

F.T.T.

TEMPERATURE °F

MAGNESIUM

SPECIFIC HEAT

SPECIFIC HEAT BTU/LB-°F

X — X — X — X — X —

LEGEND

WYO-6141

NS/R/4

FJT

0 25 50 75 100 125 150 175 200 225 250 275

TEMPERATURE °F

MAGNESIUM

DENSITY

120

110

100

90

80

70

60

50

0

DENSITY LBS/FT³LEGEND

REACTOR HANDBOOK

MP

SOLID LIQUID

5/20/55

F.T.T.

TEMPERATURE °F

0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200

MAGNESIUM ALLOY AN-M-29

THERMAL CONDUCTIVITY

THERMAL CONDUCTIVITY
BTU/HR-FT-°F

TEMPERATURE °F

LEGEND

X-1147R-6145-1

2/16/35

FJ7

MAGNESIUM OXIDE (MgO)

THERMAL CONDUCTIVITY

DENSITY - 3.58 G/CC

LEGEND

NYO-3647

5/13/55

F.T.T.

TEMPERATURE °F

0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200

THERMAL CONDUCTIVITY BTU/HR-FT-K

0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30

MOIYBDENIUM

THERMAL CONDUCTIVITY

MONE L

THERMAL CONDUCTIVITY

THERMAL CONDUCTIVITY BTU/HR-FT-F

LEGEND

REACTOR HANDBOOK

F.T.T

5/11/53

TEMPERATURE °F

0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200

NICKEL

SPECIFIC HEAT

0.17

0.16

0.15

0.14

0.13

0.12

0.11

0.10

BTU/LB-F

SPECIFIC HEAT

LEGEND

X-ASM METALS HANDBOOK

2/17/55

FJT

TEMPERATURE °F

0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200

"A" NICKEL

THERMAL CONDUCTIVITY

THERMAL CONDUCTIVITY BTU/HR-FT²-°FLEGEND

REACTOR HANDBOOK

FJ T

5/11/55

TEMPERATURE °F

NICKEL OXIDE (w.o.)

THERMAL CONDUCTIVITY

DENSITY-6.8 G/CC

LEGEND

NYO-3647

13/5/55

FJT

THERMAL CONDUCTIVITY BTU/HR-FT²

TEMPERATURE °F

NICKEL-ZIRCONIUM ALLOY (0.27 Zr)

THERMAL CONDUCTIVITY

48

46

44

38

36

34

32

30

THERMAL CONDUCTIVITY BTU/HR-FT-°F

LEGEND

KAPL-439

4/28/55

F T T

0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200

TEMPERATURE °F

SILVER

SPECIFIC HEAT

SPECIFIC HEAT BTU/LB-F

LEGEND

ASM METALS HANDBOOK

5/23/51

F57

TEMPERATURE °F

STAINLESS STEEL TYPE 304

THERMAL CONDUCTIVITY

LEGEND

X-ASM METALS HANDBOOK

2716/55

F37

TEMPERATURE °F

STAINLESS STEEL TYPE 310

THERMAL CONDUCTIVITY

THERMAL CONDUCTIVITY BTU/HR-FT-F

LEGEND

X-J APPL ENR 1952 P-177

2/16/55

F.J.J.

TEMPERATURE °F

STAINLESS STEEL 321

THERMAL CONDUCTIVITY

THERMAL CONDUCTIVITY BTU/HR-FT-°F

LEGENDMATERIALS & METHODS
33107 JUNE 1951

4/27/55

FJT

TEMPERATURE °F

0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200

STAINLESS STEEL 321

SPECIFIC HEAT

LEGEND

NEPA-1493

4/28/55

FJT

TEMPERATURE °F

STAINLESS STEEL 347

THERMAL CONDUCTIVITY

THERMAL CONDUCTIVITY BTU/HR-FT-F

LEGEND

AFTIP-61455-1

3/31/55

F57

TEMPERATURE °F

STAINLESS STEEL TYPE 347

SPECIFIC HEAT

STAINLESS STEEL 430

THERMAL CONDUCTIVITY

LEGEND

X - MATERIALS + METHODS
33.107 JUNE 1951
O - REACTOR HANDBOOK

4/27/55

FTT

TEMPERATURE °F

STAINLESS STEEL TYPE 304

SPECIFIC HEAT

LOW CARBON STEEL

THERMAL CONDUCTIVITY

LEGENDMATERIALS & METHODS
33.107 JUNE 1951

4/27/55

F.T.T.

TEMPERATURE °F

0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200

THERMAL CONDUCTIVITY BTU/HR-FT²

40

35

30

25

20

15

10

5

0

TUNGSTEN STEEL

(1.042 W)

THERMAL CONDUCTIVITY

THERMAL CONDUCTIVITY BTU/HR-FT-F

LEGEND

TRANS 45587
211061 1923

3/12/55

FJT

TEMPERATURE °F

THORIUM

THERMAL CONDUCTIVITY

LEGEND

X-NSC-196
 Δ-NSC-208
 O-REACTOR HANDBOOK
 □-NAA-5P-287
 U-BMI-76

2/4/55

FUT

THORIUM

SPECIFIC HEAT

LEGEND

REACTOR HANDBOOK

5/29/55

F57

TEMPERATURE °F

0032

0031

0030

0029

0028

0027

0026

0025

0

BTU/LB-F

SPECIFIC HEAT

0

200

400

600

800

1000

1200

1400

1600

1800

2000

2200

—X—X—

THORIUM DIOXIDE (ThO₂)

THERMAL CONDUCTIVITY

DENSITY - 9.69 G/CC

LEGEND

NYO-3647

5/13/55

F.T.T.

THERMAL CONDUCTIVITY BTU/HR-FT-°F

TEMPERATURE °F

0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200

TITANIUM

SPECIFIC HEAT

SPECIFIC HEAT
BTU/LB-°FLEGEND

NEPA-722

5/24/55

FJT

TEMPERATURE °F

0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200

URANIUM

SPECIFIC HEAT

SPECIFIC HEAT BTU/LB-F

TEMPERATURE °F

U-Cr ALLOY (5% Cr W/O CHROMIUM)

THERMAL CONDUCTIVITY

LEGEND

BMI-900

6/7/55

FIT

THERMAL CONDUCTIVITY

~~C-X- PERSONAL MEMO~~
~~TO D.D. LEESER~~
~~FROM BMI~~

●-BPM-954

2/3/53
F77

1.6% Zr, 98.4% U Alloy

THERMAL CONDUCTIVITY AS A FUNCTION
OF BURNUP AT 392 °F

% BURNUP DEFINED AS % OF TOTAL U^{235}
AND U^{238} ATOMS PRESENT FISSIONED

% REDUCTION IN THERMAL
CONDUCTIVITY FROM ORIGINAL
SAMPLE DUE TO IRRADIATION
FOR:

0.21% BURNUP - 8.0% REDUCTION
0.75% BURNUP - 9.5% REDUCTION

FROM (BMM-986)

2/23/55
FJT

PERCENT BURNUP

2% Zn 98% U ALLOY

CALCULATED VALUES OF THERMAL
CONDUCTIVITY FOR

O-(0.75% BURNUP)

X-(0.21% BURNUP)

---(10% BURNUP,
EXTRAP. BY ANAL.)

CALCULATIONS BASED ON
RESULTS OBTAINED FROM
IRRADIATION OF 1.6 WT% ZN-
98.4 WT% U.
(SEE BML-986)

THERMAL CONDUCTIVITY BTU/HR-FT²-°F

TEMPERATURE °F

2/23/55

557

0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200

LiO₂

THERMAL CONDUCTIVITY

AT DENSITIES OF

A = 10.9 Gm/cc

B = 8 Gm/cc

LEGEND

NYO-3647

3/31/55

F. J. F.

TEMPERATURE °F

THERMAL CONDUCTIVITY BTU/HR-FT-F

0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200

VANADIUM

THERMAL CONDUCTIVITY

THERMAL CONDUCTIVITY BTU/HR-FT-°F

LEGEND

X-REACTOR HANDBOOK

2/17/55
FJT

TEMPERATURE °F

0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200

ZINC DENSITY

LEGEND

ASM METALS HANDBOOK

5/24/54

F 577

DENSITY LBS/FT³

M.P.
SOLID LIQUID

TEMPERATURE °F

0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200

ZIRCONIUM

THERMAL CONDUCTIVITY

THERMAL CONDUCTIVITY BTU/HR-FT-F

LEGEND

X-KAPL-82R
O-BYI-849
D-BMI-65

2/5/55

F.T.

TEMPERATURE °F

1.0

TANTALUM-ZIRCONIUM ALLOYS

THERMAL CONDUCTIVITY

0-0.16 % Ta
 X-0.01 % Ta

LEGEND

BMI-65

6/7/55

FJT

THERMAL CONDUCTIVITY BTU/HR-FT²

TEMPERATURE °F

TIN-ZIRCONIUM ALLOY (52 TIN)

THERMAL CONDUCTIVITY

LEGEND

BMI-GS

6/7/53

FJT

TEMPERATURE °F

14

12

10

8

6

4

2

0

THERMAL CONDUCTIVITY BTU/HR-FT-F

0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200

TEMPERATURE °F

ZIRCON (ZrSiO₄)

THERMAL CONDUCTIVITY

DENSITY - 4.56 G/CC

THERMAL CONDUCTIVITY BTU/HR-FT-F

LEGEND

NYO-3647

5/13/55

FJT

TEMPERATURE °F

ZIRCONIUM DIOXIDE (ZrO₂)

THERMAL CONDUCTIVITY

DENSITY - 6.1 G/CC

LEGEND

NYO-3647

5/13/53

FJT

TEMPERATURE °F

0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200

THERMAL CONDUCTIVITY BTU/HR-FT-F
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0

ALUMINUM

SPECIFIC HEAT

x

LEGEND

x-LIQUID METALS HANDBOOK

2/12/55

F.T.T.

SOLID LIQUID

TEMPERATURE °F

0.28

0.27

0.26

0.25

0.24

0.23

0.22

0.21

0.20

0

200

400

600

800

1000

1200

1400

1600

1800

2000

2200

BISMUTH

VISCOSITY

VISCOSITY LB/FT-HR

BISMUTH

PRANDTL NUMBER

LEGEND

X-LIQUID METALS HANDBOOK

5/27/55

F.T.T.

MP

SOLID LIQUID

TEMPERATURE °F

CADMIUM

THERMAL CONDUCTIVITY

THERMAL CONDUCTIVITY BTU/HR-FT-F

LEGEND

LIQUID METALS HANDBOOK

5/20/55

FJT

MP

SOLID LIQUID

TEMPERATURE °F

0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200

CADMIUM

SPECIFIC HEAT

BTU/LB-°F

HEAT

SPECIFIC

LEGEND

LIQUID METALS HANDBOOK

MP

SOLID LIQUID

STRESS

F/T

TEMPERATURE °F

2000 1800 1600 1400 1200 1000 800 600 400 200 0

0.00

0.02

0.04

0.06

0.08

0.10

0.12

0.14

CADMIUM

VISCOSITY

LEGEND

LIQUID METALS HANDBOOK

MP

SOLID LIQUID

3/20/55

FIT

TEMPERATURE °F

2200

2000

1800

1600

1400

1200

1000

800

600

400

200

0

LEAD

VISCOSITY

LEGEND

LIQUID METALS HANDBOOK

2/22/55

FPT

TEMPERATURE °F

79.5 WT % Pb, 55.5 WT % Bi

THERMAL CONDUCTIVITY

LEGEND

LIQUID METALS H.B.

8/22/55

F.V.T.

SOLID LIQUID

TEMPERATURE °F

2260

2000

1800

1600

1400

1200

1000

800

600

400

200

0

44.5 WT % Pb, 55.5 WT % Bi (ALLOY)

PRANDTL NUMBER

LEGEND

LIQUID METALS HANDBOOK

6/7/55
FJT

TEMPERATURE °F

LITHIUM

THERMAL CONDUCTIVITY

THERMAL CONDUCTIVITY BTU/HR-FT-°F

LEGEND

TRANS ASME 77.97 35°

2/28/55
J. H.
F. J. T.

MERCURY

THERMAL CONDUCTIVITY

LEGEND

X-LIQUID METALS HANDBOOK

2/12/65
FJT

THERMAL CONDUCTIVITY BTU/HEAT-F

TEMPERATURE °F

POTASSIUM

SPECIFIC HEAT

BTU/LB-°F

SPECIFIC HEAT

LEGEND

LIQUID METALS A.B.

2/22/55

FJT

TEMPERATURE °F

0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200

POTASSIUM

VISCOSITY

LEGEND

LIQUID METALS H.B.

2/22/53

155

POTASSIUM

PRANDTL NUMBER

LEGEND

LIQUID METALS HANDBOOK

4/7/55

FJT

TEMPERATURE °F

0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200

0.014

0.012

0.010

0.008

0.006

0.004

0.002

0.000

MP

SOLID LIQUID

PRANDTL NUMBER

SODIUM

PRANDTL NUMBER

LEGEND

LIQUID METALS HANDBOOK

6/7/55

FIT

TEMPERATURE °F

56 WT 2. Na, 44 WT 7.4 ALLOY

PRANDTL NUMBER

LEGEND

LIQUID METALS HANDBOOK

6/27/55

FVT

22 WT % Na, 78 WT % K CALCIUM

PRANDTL NUMBER

LEGEND

LIQUID METALS HANDBOOK

6/7/55

H. J. T.

TEMPERATURE, °F

HEAVY WATER

SPECIFIC HEAT (1 ATM)

LEGEND

REACTOR HANDBOOK

6/21/55

FTT

TEMPERATURE °F

3.5

3.0

2.5

2.0

1.5

1.0

0.5

0.0

BTU/LB-°F

SPECIFIC HEAT

0

20

40

60

80

100

120

140

160

180

200

220

LIGHT WATER

THERMAL CONDUCTIVITY

LEGEND

REACTOR HANDBOOK

4/24/55

FJT

0.7

0.6

0.5

0.4

0.3

0.2

0.1

0.0

THERMAL CONDUCTIVITY
BTU/HR-FT-°F

0 100 200 300 400 500 600 700 800 900 1000 1100

TEMPERATURE °F

LIGHT WATER

230517X

1937

REAG FOR HANDBOOK

5/12/13

人
人
人

TEMPERATURE

ZINC

THERMAL CONDUCTIVITY

LEGEND

LIQUID METALS HANDBOOK

2/22/85

FJT

THERMAL CONDUCTIVITY BTU/HR-FT-F

TEMPERATURE °F

ARGON

SPECIFIC HEAT (AT 1 ATM)

LEGEND

TRANS. ASME 1954 1967

5/16/55
FJT

CARBON DIOXIDE

THERMAL CONDUCTIVITY (AT 1 ATM)

THERMAL CONDUCTIVITY BTU/HR-FT²LEGEND

X-ASME TRANS 1954 P-967
 Δ-REACTOR HANDBOOK
 O-MCGADAMS, HEAT TRANSMISSION

2/25/55

FJT

TEMPERATURE °F

CARBON DIOXIDE

SPECIFIC HEAT (AT 1 ATM)

SPECIFIC HEAT
BTU/LB-°FLEGENDX-TRANS ASME 1954 P-967
Δ-KEENAN & KEYE-GAS TABLES

5/14/55

FJT

TEMPERATURE °F

0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200

CARBON DIOXIDE

DENSITY (AT 1 ATM)

LEGEND

TRANS. ASME 1954 P-967

5/17/55

FJT

TEMPERATURE °F

CARBON MONOXIDE

THERMAL CONDUCTIVITY (AT 1 ATM)

LEGEND

X-ASME TRANS 1954 P-962
 O-MEADAMS, HEAT TRANSMISSION

2/25/58

FJJ

TEMPERATURE °F

CARBON MONOXIDE

SPECIFIC HEAT (AT 1 ATM)

LEGENDX-TRANS ASME 1954 P-967
Δ-KEENAN + KEYE-GAS TABLES

5/16/53

FJT

TEMPERATURE °F

CARBON MONOXIDE

DENSITY (AT 1 ATM)

LEGEND

TRANS. ASME 1954 P-967

5/17/55

FJT

0.14

0.12

0.10

0.08

0.06

0.04

0.02

0.00

DENSITY
LB/FT³DENSITY
LB/FT³

TEMPERATURE °F

0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200

CARBON MONOXIDE

PRANDTL NUMBER

LEGEND

ASME TRANS 1954 P-967

2/25/55

FJT

TEMPERATURE °F

HELIUM

SPECIFIC HEAT (AT 1 ATM)

SPECIFIC HEAT BTU/LB-F

LEGEND

X-TRANS ASME 1959 P-967

A-REACTOR HANDBOOK

5/12/55

F.T.T

TEMPERATURE °F

HELIUM

DENSITY (AT 1 ATM)

LEGENDX-TRANS. ASME 1954 P-967
A-REACTOR HANDBOOK

SN7/55

FST

HELIUM

DYNAMIC VISCOSITY (AT 1 ATM)

2/25/53

FJT

HYDROGEN

THERMAL CONDUCTIVITY (AT 1 ATM)

LEGEND

X-ASME TRANS 1954 P-9.1.7
 A-REACTOR HANDBOOK
 O-MCGADAMS, HEAT TRANSMISSION

2/25/55

FUT

TEMPERATURE °F

2.3

HYDROGEN

SPECIFIC HEAT (AT 1 ATM)

LEGEND

X-TRANS ASME 1954 P.967
 A-KEENAN & KEYE-GAS TABLES

5/16/55

FJT

HYDROGEN

DENSITY (AT 1 ATM)

LEGEND

TRANS. ASME 1954 P-967

5/13/55

F. J. T.

TEMPERATURE °F

0.007

0.006

0.005

0.004

0.003

0.002

0.001

0.000

0

200

400

600

800

1000

1200

1400

1600

1800

2000

2200

DENSITY
LB./FT.³

DENSITY

HYDROGEN

PRANDTL NUMBER

LEGEND

ASME TRANS 1954 P-96.7

2/25/55

FJJ

TEMPERATURE °F

NITRIC OXIDE (NO)

SPECIFIC HEAT (AT 1 ATM)

LEGEND

MCADAMS, W. H., HEAT
TRANSMISSION, P-446

5/16/55
F.T.

TEMPERATURE °F

0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10

SPECIFIC HEAT BTU/LB-F

0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200

NITRIC OXIDE (NO)

DENSITY (AT 1 ATM)

LEGEND

TRANS. ASME 1954 P-961

5512/155

F77

NITROGEN

SPECIFIC HEAT (BT / ATM)

SPECIFIC HEAT BTU/LB-F

LEGEND

X-TRANS. ASME 1954 P-967
 Δ-KEENAN + KEYE-GAS TABLES

5/16/55

FIT

TEMPERATURE °F

OXYGEN

THERMAL CONDUCTIVITY (AT 1 ATM)

LEGEND

X-ASME TRANS 1954 P-967

A- REACTOR HANDBOOK

2/25/55

FJT

OXYGEN

PRANDTL NUMBER

LEGEND

ASME TRANS 1954 P-967

2/24/55

F.T.T.

STEAM

THERMAL CONDUCTIVITY (AT 1 ATM)

STEAM

SPECIFIC HEAT (AT 1 ATM)

SPECIFIC HEAT BTU/LB-°F

LEGEND

TRANS ASME 1954 P-967

5/14/51

FUT

TEMPERATURE °F

0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200

STEAM

DENSITY (AT 1 ATM)

LEGENDKEENAN + KEYES,
THERMODYNAMIC PROPERTIES
OF STEAM

5/27/55

F.T.T.

TEMPERATURE °F

0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200

0.02

0.06

0.05

0.04

0.03

0.02

0.01

0.00

1.85/57°

DENSITY X 10³

TABLE I
COMPOSITIONS OF SOME PLOTTED METALS* (PER CENT)

Metal	C	Mn	Si	Ni	Cr	P	S	Cu	Fe	Al	N	Cb
Inconel X	0.03	0.47	0.39	73.19	14.38	---	0.007	0.03	6.99	0.83	---	---
Nickel	0.06	0.22	0.02	99.48	---	---	0.005	0.05	0.14	---	---	---
SS Type 303	0.17	0.61	0.51	8.97	18.42	---	---	---	bal.	---	---	---
SS Type 310	0.10	1.83	0.84	20.68	25.54	0.025	0.005	---	50.98	---	---	---
SS Type 347	0.069	1.80	0.70	11.20	18.00	0.021	0.007	---	bal.	---	---	0.77
SS Type 446	0.13	0.56	0.50	0.10	26.00	0.012	0.007	---	bal.	---	0.14	---
1010 Steel	---	---	---	---	---	---	---	---	bal.	---	---	---

* Journal of Applied Physics 23:177 (Feb. 1952).

Ref: Pages 25, 37, 41, 43, 46, 49, and 52.

Table II

SINGLE POINT VALUES

<u>Solid</u>	<u>k (Btu/hr-ft-°F)</u>	<u>C_p (Btu/lb-°F)</u>	<u>ρ (lbs/ft³)</u>
Alumel	-	0.13	537
Alumina	-	0.23	248
Aluminum Alloy 2S	128	-	169
Aluminum Alloy 24S-T4	-	0.23	-
Aluminum Alloy 75S-T6	70	0.23	-
Beryllia	-	-	188
Boron Carbide	-	0.437	156
Cadmium	-	-	540
Cadmium-Silver Alloy	-	X	X
Concrete, High Density	-	0.166	269
Inconel	-	0.109	-
Inconel "X"	-	0.109	-
Iron, Armco	-	-	487
Iron, Cast	-	0.13	446
Iron, Pure	-	0.11	490
Lead	-	-	708
Magnesium Alloy AN-M-29	-	0.25	111
Magnesium Oxide	-	0.285	224
Molybdenum	-	-	643
Monel	-	-	552
"K" Monel	-	0.127	-

Table II (Con't)
SINGLE POINT VALUES

<u>Solids</u>	<u>k (Btu/hr-ft²-F)</u>	<u>c_p (Btu/lb²-F)</u>	<u>ρ (lbs/ft³)</u>
Nichrome V	7.9	-	515
Nickel	-	-	556
"A" Nickel	-	0.13	554
Nickel Oxide	-	0.159	425
Nickel-Zirconium Alloy	-	X	X
Spinel	-	0.257	221
Stainless Steel 301	-	0.12	-
Stainless Steel 303	-	0.12	493
StainlessSteel 304	-	0.12	493
Stainless Steel 310	-	0.12	493
Stainless Steel 316	-	0.12	-
Stainless Steel 321	-	-	500
Stainless Steel 430	-	0.11	481
Stainless Steel 446	-	-	475
Steel, Mild	-	0.112	487
Steel, Low Carbon	-	0.115	488
Steel, Tungsten	-	0.115	498
Tantalum	-	0.036	1036
Thorium Dioxide	-	0.0548	605
Titanium	8.7	-	-
Titanium Dioxide	-	0.179	266

Table II (Con't)

SINGLE POINT VALUES

<u>Solids</u>	<u>k (Btu/hr-ft²-F)</u>	<u>C_p (Btu/lb-F)</u>	<u>ρ (lbs/ft³)</u>
Tungsten	-	-	1200
Uranium	-	-	1174
Uranium-Chromium Alloy	-	X	X
Uranium-Zirconium Alloys	-	X	-
U-Zr Alloy (Irradiated)	-	0.0319	1161
Uranium Dioxide	-	-	680
Vanadium	-	-	382
Zinc Oxide	-	0.121	353
Zirconium-Tantalum Alloy	-	X	X
Zirconium-Tin Alloy	-	X	X
Zircon	-	0.132	285
Zirconium Dioxide	-	0.16	381

- Graph

X No data presented

TABLE III

PRANDTL NUMBER*

$$\frac{\mu C}{k}$$

Temp. OF	Air	Nitrogen	Oxygen	Helium	Hydrogen	Argon	Carbon Monoxide	Carbon Dioxide	Nitric Oxide	Steam
-280	0.770	0.786	0.815	0.677	0.712	0.692		0.830	0.789	
-100	0.739	0.747	0.745	0.674	0.719	0.676	0.764	0.770	0.745	
80	0.708	0.713	0.729	0.686	0.706	0.670	0.737	0.738	0.729	1.037
260	0.689	0.691	0.696	0.700	0.690	0.664	0.722	0.702		0.995
440	0.680	0.684	0.697	0.715	0.675	0.658	0.718	0.685		0.992
620	0.680	0.686	0.703	0.729	0.664	0.655	0.724	0.687		1.000
800	0.684	0.695			0.661	0.654		0.692		1.015
980	0.689	0.708			0.660	0.653		0.698		
1160	0.696	0.723				0.654		0.705		
1340	0.702	0.740				0.654		0.712		
1520		0.757				0.656		0.721		
1700		0.774				0.657		0.729		
1880						0.659				
2060						0.661				
2240						0.663				

*At one atms pressure

REF: Trans. ASME 76:967, 1954

TABLE IV

THERMAL CONDUCTIVITY*k, B/hr-ft²-(°F/ft)

Temp. Of	Air	Nitrogen	Oxygen	Helium	Hydrogen	Argon	Carbon Monoxide	Carbon Dioxide	Nitric Oxide	Steam (1 atmos.)
-280	0.0053	0.0055	0.0052	0.0422	0.0384	0.0037	0.0050		0.0052	
-100	0.0104	0.0105	0.0105	0.0672	0.0741	0.0072	0.0101	0.0055	0.0103	
80	0.0152	0.0151	0.0150	0.0866	0.1050	0.0102	0.0146	0.0096	0.0150	
260	0.0194	0.0193	0.0200	0.1109	0.1319	0.0129	0.0186	0.0142	0.0195	0.0148
440	0.0233	0.0230	0.0241	0.1171	0.1572	0.0153	0.0223	0.0194		0.0195
620	0.0269	0.0265	0.0279	0.1299	0.1820	0.0174	0.0257	0.0243		0.0243
800	0.0303	0.0296			0.2070			0.0285		0.0292
980	0.0334	0.0324						0.0324		0.0342
1160	0.0363	0.0351						0.0359		
1340	0.0390	0.0374						0.0393		
1520		0.0396						0.0423		
1700		0.0415						0.0451		
1880								0.0477		

*At one atmos pressure

REF: Trans. ASME 76:967, 1954

TABLE V
DYNAMIC VISCOSITY**
 μ , (lb/hr-ft)

Temp. OF	Air	Nitrogen	Oxygen	Helium	Hydrogen	Argon	Carbon Monoxide	Carbon Dioxide	Nitric Oxide	Steam
-280	0.0168	0.0166	0.0188	0.0230	0.0102	0.0201	0.0159		0.0169	
-100	0.0321	0.0313	0.0359	0.0366	0.0165	0.0393	0.0308	0.0244	0.0331	
80	0.0447	0.0432	0.0499	0.0480	0.0217	0.0555	0.0432	0.0362	0.0468	0.0237
260	0.0553	0.0532	0.0618	0.0582	0.0263	0.0693	0.0537	0.0467	0.0584	0.0325
440	0.0646	0.0622	0.0724	0.0676	0.0306	0.0816	0.0631	0.0562	0.0688	0.0412
620	0.0730	0.0705	0.0821	0.0764	0.0346	0.0928	0.0716	0.0645	0.0782	0.0499
800	0.0806	0.0782	0.0911	0.0848	0.0383	0.1032	0.0796	0.0729	0.0870	0.0587
980	0.0877	0.0854	0.0996	0.0927	0.0419	0.1130	0.0870	0.0804	0.0952	0.0674
1160	0.0943	0.0923	0.1076	0.1004	0.0454	0.1223	0.0941	0.0874	0.1030	0.0767
1340	0.1004	0.0990	0.1154	0.1078	0.0487	0.1311	0.1010	0.0941	0.1105	0.0867
1520	0.1063	0.1053	0.1229	0.1149	0.0519	0.1396	0.1075	0.1004	0.1176	0.0961
1700	0.1119	0.1114	0.1301	0.1149		0.1478	0.1139	0.1066	0.1246	0.1047
1880	0.1172	0.1174	0.1370			0.1559	0.1200	0.1125		0.1124
2060	0.1223	0.1231	0.1437			0.1638	0.1259	0.1183		0.1192
2240	0.1273	0.1287	0.1503			0.1712	0.1317	0.1238		0.1252
2420	0.1320		0.1566					0.1293		
2600	0.1366		0.1629					0.1346		
2780	0.1410		0.1690							
2960	0.1453		0.1750							
3140			0.1809							

*At one atmos pressure

REF: Trans. ASME 76:967, 1954

TABLE VI

VISCOSITIES OF GASES UNDER PRESSURE - lb/hr-ftARGON

<u>Temp., F</u>	<u>1 atm</u>	<u>20 atm</u>	<u>40 atm</u>	<u>60 atm</u>	<u>80 atm</u>	<u>100 atm</u>
77	-----	0.0552	0.057	0.059	-----	-----
122	0.058	0.0595	0.061	0.063	0.066	-----
212	0.066	0.0665	0.067	0.069	0.072	0.074
302	0.071	0.0723	0.074	0.075	0.077	0.080
392	0.077	0.0784	0.080	0.081	0.083	0.086
572	0.088	0.0883	0.089	0.091	0.092	0.095

Ref: Trans. ASME 76:967 (1954)

TABLE VII

VISCOSITIES OF GASES UNDER PRESSURE - lb/hr-ftCARBON DIOXIDE

<u>Temp., F</u>	<u>1 atm</u>	<u>20 atm</u>	<u>40 atm</u>	<u>60 atm</u>	<u>80 atm</u>	<u>100 atm</u>
122	0.039	0.0406	0.044	0.050	0.059	
212	0.044	0.0452	0.048	0.052	0.062	
302	0.050	0.0506	0.052	0.057	0.063	
392	0.054	0.0559	0.058	0.061	0.065	
482	0.059	0.0605	0.062	0.064	0.068	
572	0.064	0.0649	0.066	0.068	0.070	

Ref: Trans. ASME 76:967 (1954)

TABLE VIII

VISCOSITIES OF GASES UNDER PRESSURE - lb/hr-ft

<u>Temp.,</u> <u>F</u>	<u>HYDROGEN</u>					
	<u>1 atm</u>	<u>20 atm</u>	<u>40 atm</u>	<u>60 atm</u>	<u>80 atm</u>	<u>100 atm</u>
-238	0.012	0.012	0.012	0.012	0.012	0.013
-148	0.015	0.015	0.015	0.015	0.015	0.015
32	0.020	0.020	0.020	0.020	0.021	0.021
212	0.025	0.025	0.025	0.025	0.025	0.025
392	0.029	0.029	0.029	0.030	0.030	0.030
572	0.034	0.033	0.034	0.034	0.034	0.034

Ref: Trans. ASME 76:967 (1954)

TABLE IX

VISCOSITIES OF GASES UNDER PRESSURE - lb/hr-ftNITROGEN

<u>Temp., F</u>	<u>1 atm</u>	<u>20 atm</u>	<u>40 atm</u>	<u>60 atm</u>	<u>80 atm</u>	<u>100 atm</u>
68	0.042	0.043	0.044	0.046	0.078	0.050
122	0.046	0.046	0.047	0.048	0.049	0.050
212	0.054	0.051	0.051	0.052	0.053	0.054
392	0.060	0.060	0.061	0.061	0.062	0.062
752	0.076	0.076	0.077	0.077	0.077	0.078
1112	0.090	0.091	0.091	0.091	0.091	0.092
1472	0.104	0.104	0.104	0.104	0.104	0.102
1832	0.116	0.116	0.116	0.116	0.117	0.117
2192	0.127	0.127	0.127	0.129	0.128	0.128

Ref: Trans. ASME 76:967 (1954)

TABLE X

VISCOSITIES OF GASES UNDER PRESSURE - lb/hr-ftOXYGEN

<u>Temp., F</u>	<u>1 atm</u>	<u>20 atm</u>	<u>40 atm</u>	<u>60 atm</u>	<u>80 atm</u>	<u>100 atm</u>
77	0.050	0.052	0.055	0.058	0.060	0.064
122	0.053	0.055	0.057	0.060	0.063	0.066
212	0.059	0.061	0.063	0.065	0.067	0.070
302	0.065	0.066	0.067	0.069	0.071	0.0730
392	0.070	0.071	0.072	0.074	0.075	0.077

Ref: Trans. ASME 76:967 (1954)

TABLE XI

VISCOSITIES OF GASES UNDER PRESSURE - lb/hr-ftSTEAM

<u>Temp.,</u> <u>F</u>	<u>1 atm</u>	<u>20 atm</u>	<u>40 atm</u>	<u>60 atm</u>	<u>80 atm</u>	<u>100 atm</u>
77	0.0024					
122	0.0257					
212	0.0304					
392	0.0389					
572	0.0476	0.0479	0.0483	0.0489	-----	-----
752	0.0563	0.0566	0.0569	0.0572	0.0577	0.0583
932	0.0651	0.0653	0.0655	0.0658	0.0662	0.0665
1112	0.0739	0.0743	0.0745	0.0747	0.0750	0.0753
1293	0.0891	0.0843	0.0844	0.0846	0.0848	0.0851
1472	0.0937	0.0938	0.0940	0.0942	0.944	0.0945
1652	0.1025					
1832	0.1104					
2012	0.1175					
2192	0.1237					

Ref: Trans. ASME 76:967 (1954)

REFERENCES TO ADDITIONAL MATERIAL

1. Powell, R. L., and Blanpied, W. A., Thermal Conductivity of Metals and Alloys at Low Temperatures. NBS Circular 556, National Bureau of Standards (1954).
2. Pagerey, P. R., The Thermal Conductivity of Organic Liquids. Preprint of paper contributed by Heat Transfer Division of the American Society of Mechanical Engineers for presentation at the Semi-Annual Meeting. Paper No. 54-SA-55, June 20, 1954.
3. Sakiadis, B. C., and Coates, J., A Literature Survey of the Thermal Conductivity of Liquids. Engineering Experimental Station, Bulletin No. 34. College of Engineering, Louisiana State University (1954).
4. Liquid Metals Handbook, edited by R. N. Lyon, Department of the Navy and U.S. Atomic Energy Commission, NAVEXOS P-733, Chapter 2, June 1952.
5. Evans, J. E., Thermal Conductivity of Fourteen Metals and Alloys Up to 1100°F, Report NACA-RM-E50LO7 (1951).
6. The Reactor Handbook, Vol. 3, Materials, 1953.
7. Metals Handbook, Compiled by the American Society for Metals.