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May 21, 1952

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ABSTRACT

Thermal-conductivity measurements were made on three powder compacts of uranium and, for comparison, on one sample of cast-and-wrought metal. The conductivities of all specimens ranged from 0.23_4 to 0.24_9 watt $cm^{-1}C^{-1}$ at 40°C and from 0.25_0 to 0.26_2 watt $cm^{-1}C^{-1}$ at 100°C. The slight differences in conductivity probably can be attributed to differences in density.

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INTRODUCTION

Thermal-conductivity measurements were made on three uranium powder compacts and one specimen of conventionally cast and rolled uranium metal. The powder-metallurgy specimens were prepared by Sylvania Electric Products Corporation, and the conductivity measurements were carried out at the request of Sylvania to determine possible differences between conventional and powder-metallurgy materials.

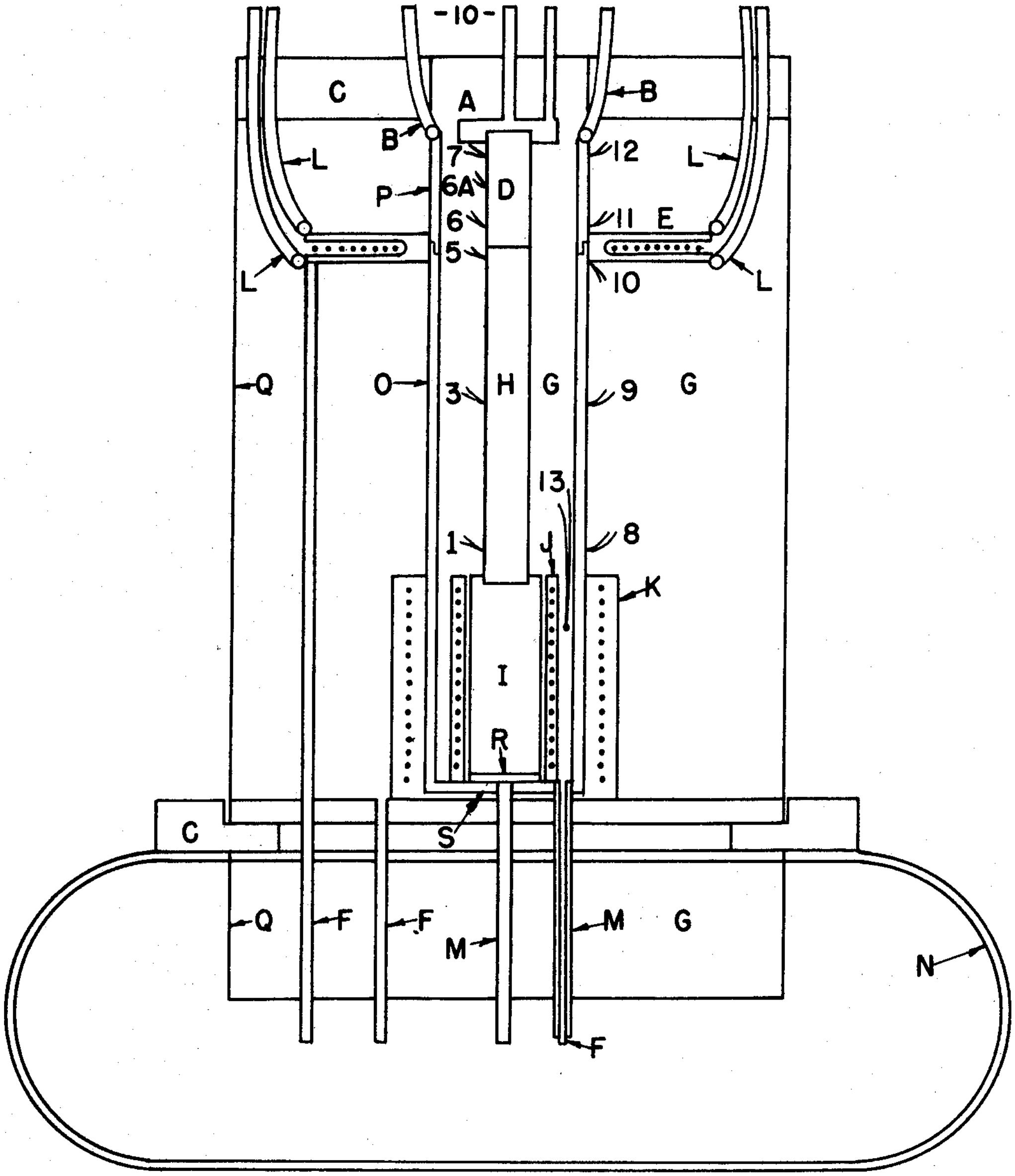
APPARATUS AND METHOD

The method used is a modified form of that described by Van Dusen and Shelton(1). It consists of introducing heat, at a constant rate, into a standard heat-flow meter, one end of which is in series with the specimen. Heat is removed at a constant rate from the other end of the specimen by circulating water at a constant flow rate and temperature. Temperature gradients measured along standard and specimen permit calculating the quantity of heat flowing and the thermal conductivity of the specimen.

Figure 1 is a schematic diagram of the apparatus. An Armco iron standard heat-flow meter, H, 2 cm in diameter and 15 cm long, was tin soldered at its lower end to a heater, I, and at its upper end to the specimen, D. The specimen, 2 cm in diameter and 5 cm long, was tin soldered at its upper end to a water-cooled cap, A. The relative positions and lengths of the specimen and the Armco standard were interchanged for this work, as compared with their usual positions. This arrangement permitted operation at lower specimen temperatures with less oxidation than with the customary assembly.

It was difficult to get tin to adhere to the uranium. The method finally used was to plate the specimen ends with about 0.001 inch of silver, followed by about 0.003 inch of nickel plated on the silver, and then, another layer of silver about 0.0002 inch thick plated on the nickel. Appropriate chemical and anodic pickles were employed to get clean surfaces. A tin-solder joint made with this plated surface was not completely satisfactory because the plating sometimes separated from the uranium.

Specimen and standard are surrounded by a guard cylinder, O and P, while the entire assembly is in an enclosing can, Q. Dried Sil-O-Cel



A- Cooling Plate
B- Cooling Tube
C- Transite
D- Specimen
E- Ring Heater
F- Heater Leads
G- Thermal Insulation
H- Standard
I- Inconel Heater Block
J- Main Heater

K- Guard Heater
L- Air Cooling Coils
M- Inconel Tubes
N- Supports
O- Inconel Guard Tube
P- Nickel Guard Tube
Q Steel Container
R- Alundum Disk
S- Inconel Bottom
Numbers - Thermocouples

FIGURE I. DIAGRAMMATIC SKETCH OF APPARATUS USED FOR THERMAL-CONDUCTIVITY MEASUREMENTS

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insulation fills the spaces and serves to reduce radial heat flow. Purified argon introduced through the can bottom at M was used to protect the uranium from oxidation.

Heat is supplied to the Armco iron standard and specimen by a resistance heater, J. Similar resistance heaters, K and L, supply heat to the guard cylinder. All heaters are powered from a voltage-regulated source to insure a steady heat input.

Temperature was measured at 3 places on the Armco standard, 3 places on the specimen, and 5 places on the guard cylinder. Thermocouples made from 36-gage Chromel-Alumel calibrated wire are wedged into small holes drilled in the specimen and standard. In operation, heat is supplied to the specimen-standard assembly to bring the specimen to the desired mean temperature. Heat also is supplied to the guard cylinder to bring its temperature as nearly as possible to that of the specimen and standard at corresponding levels. Supplementary cooling coils, L and B, in Figure 1 are provided on the guard cylinder, permitting the use of air or water to aid in matching temperatures. After an equilibrium is established and a good temperature balance exists between the specimen and standard with the guard, thermocouple readings are recorded using a Type K Leeds and Northrup potentiometer.

SPECIMENS

Three powder-compact specimens were furnished by Sylvania. Two were prepared by hot pressing uranium hydride, UH_3, and one was prepared by hot pressing metal powder. For comparison purposes, a sample of pile-grade, alpha-rolled metal was measured. Table 1 gives other information concerning the specimens.

CALCULATIONS

Temperatures for determining the temperature gradients were taken only after steady heat flow was established and radial temperature gradients were minimized. Under these conditions, the rates of heat flow in standard and specimen are identical and may be equated,

$$q = \frac{K_s A_s (\Delta T)_s}{X_s} = \frac{K_I A_I (\Delta T)_I}{X_I}$$

The desired thermal conductivity then may be expressed in terms of the known conductivity of the standard and the readily measured temperature gradients,

$$K_s = \frac{X_s K_I A_I (\Delta T)_I}{A_s X_I (\Delta T)_s}$$

where,

q = rate of heat flow, watts
K_s = thermal conductivity of specimen, watts $cm^{-1}C^{-1}$
K_I = thermal conductivity of standard, watts $cm^{-1}C^{-1}$
A_s = cross-sectional area of specimen, cm^2
A_I = cross-sectional area of standard, cm^2
X_s = distance between thermocouple beads on specimen, cm
X_I = distance between thermocouple beads on standard, cm
$(\Delta T)_s$ = temperature drop across X_s, degree C
$(\Delta T)_I$ = temperature drop across X_I, degree C

RESULTS

Figure 2 is a plot of specimen thermal conductivity vs. mean specimen temperature. Two equilibria were obtained for each specimen and a straight line drawn through the points.

Table 1 lists thermal-conductivity values at 40 C and 100 C, as taken from Figure 2. Thermal conductivities of the compacts appear to increase with density, as would be expected. The differences, however, are small and are probably just barely significant as comparative values.

Thermal-conductivity values for uranium given in the literature differ widely. A Canadian(2) report shows thermal-conductivity values for uranium at about 100 C from 0.246 to 0.273 watt $cm^{-1}C^{-1}$, with an average value of 0.260 watt $cm^{-1}C^{-1}$. A British(3) report shows conductivities from 0.176 to 0.201 watt $cm^{-1}C^{-1}$ for uranium with densities from 14.8 to 18.5 g/cm^3. An extrapolated thermal conductivity for a density of 19.0 g/cm^3 is 0.222 watt $cm^{-1}C^{-1}$ at 60 C.

A mean density value for alpha-extruded uranium with a reduction ratio of 8.1 is 18.942 ± .001 g/cm^3 at 25 C, according to an MIT report(4).

TABLE 1. URANIUM THERMAL CONDUCTIVITY

Specimen Number	Original Specimen Stock Material Dimension		Specimen Density (From Volume and Weight), g/cm^3	Thermal Conductivity, watt cm^{-1} C^{-1}	
	Diameter, inches	Length, inches		at 40 C	at 100 C
688(1)	1.449	1.98	18.84(5)	0.23$_4$	0.25$_0$
690(2)	1.445	2.06	18.90(5)	0.24$_7$	0.25$_9$
695(3)	1.445	2.008	18.86(5)	0.23$_6$	0.25$_5$
BMI(4)	Rough Forging		18.86(6)	0.24$_9$	0.26$_2$

(1) Compact prepared by decomposition of UH_3 under hot pressing. Grain size 1/4- to 1/2-mm-diameter. Coarse grain resulted from overheating.

(2) Same as Specimen 688, except fine grained. Grain size not checked but thought to be 10- to 20-micron diameter.

(3) Hot-pressed U powder compact.

(4) U metal treated, prior to machining specimen, as follows:
- (a) Rolled from 1-5/8-inch to 7/8-inch-diameter at 500 C.
- (b) Heat treated for 1/2 hour at 725 C (in furnace during heating cycle).
- (c) Water quench from 725 C.
- (d) Alpha anneal, 1 hour at 525 C (furnace cooled).

(5) Densities as calculated by Sylvania from volume and weight of pieces before specimen cylinders were machined.

(6) Density as calculated from specimen weight and volume after run. This value thought to be low because of some specimen dimensional irregularity, with a consequent error in its volume measurement. Correct density probably near 18.94 g/cm^3.

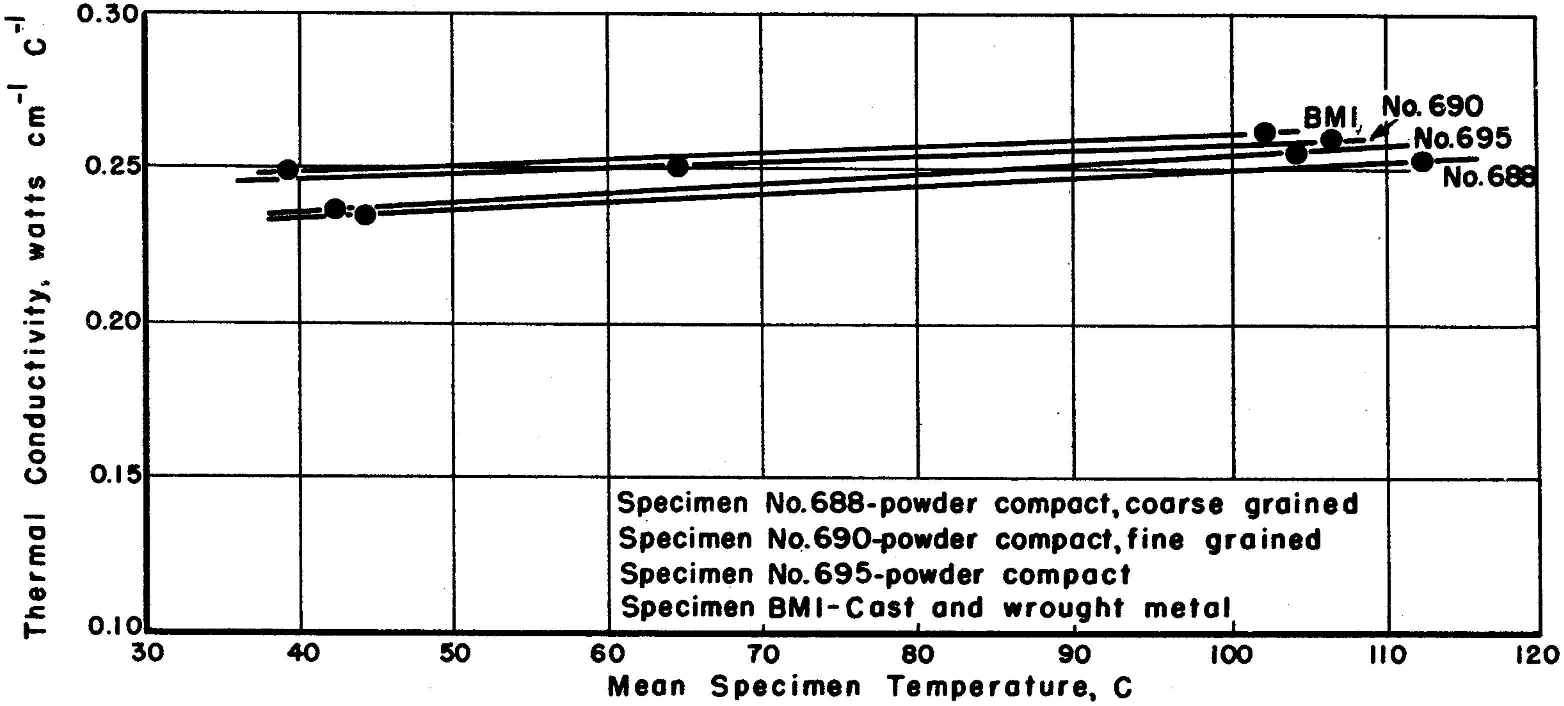

FIGURE 2. THERMAL CONDUCTIVITY OF URANIUM POWDER-METALLURGY COMPACTS

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