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PRELIMINARY REPORT ON THERMAL AND ELECTRICAL CONDUCTIVITIES OF SOME PLUTONIUM-ALUMINUM ALLOYS

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Work done by:
Robert B. Gibney
Thomas A. Sandenaw

Report written by:
Robert B. Gibney

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ABSTRACT

The thermal and electrical conductivities of a series of Pu-Al alloys have been determined in the range 0 - 12 atomic percent Pu. The conductivities are approximately proportional to the volume of free aluminum.

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PRELIMINARY REPORT ON THERMAL AND ELECTRICAL CONDUCTIVITIES OF SOME PLUTONIUM-ALUMINUM ALLOYS

INTRODUCTION

Since a knowledge of the thermal conductivity of plutonium-aluminum alloys, in the low-plutonium end of the system, has become desirable, a simple apparatus has been built for the measurement of thermal conductivity of rods 0.25 inch in diameter and approximately 4 inches long. A lack of homogeneity in the extruded specimens has prompted the measurement of electrical conductivity of short intervals of the rods, so that the nonhomogeneous parts could be definitely located. Chemical analyses have been made of the various portions of each specimen.

METHOD

The electrical conductivity was measured by means of a precision Kelvin bridge. The potential probes were scalpel blades accurately positioned 1.00-cm apart. These could be moved along the rod so that the resistance of a one-cm length could be determined at intervals. The diameter of the rod was determined at the center of each interval.

The thermal conductivity was determined by measuring the thermal gradient of two intervals, 1 inch and 1.5 inches, respectively, in the middle of the 4-inch specimens while one end was kept at 0°C and the other was heated by a direct-current heater to about 25° - 30°C. The electrical power was measured by a Type K-2 potentiometer.

Surrounding the rod was a 1.5-inch diameter stainless steel tube with heaters top and bottom. This was soldered to the same heat sink, a copper block cooled by flowing water from a 0°C bath. Three thermocouples on this shield, with the two heaters, enabled matching of the temperature gradient in the shield to that of the rod, so that no heat was lost by radiation. The top of the stainless steel tube ended in a flange connection to a vacuum system, and all measurements were made at a pressure of about one micron.

The top flange and the copper tube leading to the vacuum system were wound with resistance wire so that they could be kept at the same temperature as the heater cap for the rod; thus all of the energy put into the heater went down the rod.

The specimen made contact with the heater cap and the heat sink by means of tapered ends fitting into tapered holes. The measuring thermocouples were soldered through Kovar-glass seals, soldered into the stainless steel tube. Thermal contact was made by pulling the hot junction bead against the specimen and soldering the leads into the Kovar tubes. Chromel P and alumel wires 0.005 inch in diameter were used.

DISCUSSION OF RESULTS

The nominal 10 atomic percent plutonium rod, which was cast 1/2 inch in diameter and machined to 0.257 inch diameter, was very nonuniform. This inhomogeneity was checked both electrically by probing, and thermally by reversing the rod, end-for-end, in subsequent experiments. Also a radiograph showed these inhomogeneities. Figure 1 shows the radiograph of this specimen with locations of analytical samples. Also is plotted the electrical conductivity of 1.00-cm lengths against the midpoint of each interval. The average thermal conductivity for two sections is indicated.

The nominal 5 atomic percent plutonium rod was extruded. This had a region of high electrical resistance, but very little of this region fell inside the region

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surveyed for thermal conductivity (see Fig. 2). The radiograph of this rod is also given in Fig. 2.

The nominal 1.5 atomic percent plutonium rod, also extruded, was quite uniform in electrical and thermal conductivities (Fig. 3). The extruded pure aluminum rod (99.99 + % Al) was also quite uniform. However, one region was scored badly in extruding, and it was difficult to get good thermal contact to the thermocouple junction at this point.

A plot of thermal conductivity against electrical conductivity gives a straight line, within the limits of error of the experiments, with the same slope as the line

$$K = 5.02\,\sigma T \times 10^{-9} + 0.03 \quad ,$$

where

K = thermal conductivity cal/cm °C sec ,

σ = electrical conductivity (ohm^{-1} cm^{-1}) ,

T = absolute temperature ,

which was used by C. S. Smith to define the relationship between electrical and thermal conductivities for a large number of aluminum alloys (Fig. 4). The data would be fitted somewhat better by a change of the intercept to 0.05, making the equation

$$K = 5.02\,\sigma T \times 10^{-9} + 0.05 \quad .$$

The radiographs also verify the results found for electrical and thermal conductivity. The darkest sections in the radiograph indicate highest plutonium content, and these sections of the rod also show the lowest electrical (and thermal) conductivity.

Figure 5 is a plot of thermal conductivity vs. atomic percent plutonium. The last two points are both from the 10 atomic percent rod. The analytical results from locations Nos. 2 and 3 were used with the two different thermal conductivities found for those same areas.

These alloys were prepared for us by F. W. Schonfeld and his group. The radiograph was taken by G. H. Tenney.

CONCLUSIONS

The thermal and electrical conductivities of some plutonium-aluminum alloys, up to 10 atomic percent plutonium, have been determined. Assuming that the compound $PuAl_4$ is a nonconductor, the conductivity is roughly proportional to the amount of residual aluminum. The ratio of thermal conductivity to electrical conductivity is approximately constant over the range of compositions studied.

TABLE I

THERMAL CONDUCTIVITY

Nominal Atomic Percent Pu	Avg. Atomic Percent Measured	K (cal/cm °C sec)
0	0	0.58
1.5	1.39	0.53
5.0	5.42	0.47
10.0	10.98	0.21-0.28

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TABLE II

ELECTRICAL CONDUCTIVITY

Nominal Atomic Percent Pu	Location of Center of Interval (cm)	R x 10^7 (ohm)	σ x 10^{-5} ($ohm^{-1} cm^{-1}$)
0	1.0	91.0	3.58
	2.27	90.0	3.61
	3.54	89.0	3.60
	4.81	90.0	3.57
	6.08	88.6	3.63
	7.35	88.6	3.61
	8.62	88.6	3.60
			3.60 avg.
1.5	1.90	90.3	3.25
	3.17	90.9	3.23
	4.44	92.4	3.22
	5.71	91.1	3.21
	6.98	90.5	3.24
	8.25	90.0	3.25
	9.52	90.0	3.16
			3.22 avg.
5.0	1.77	119.3	2.72
	3.04	117.8	2.74
	4.31	117.0	2.78
	5.58	116.5	2.79
	6.85	118.2	2.74
	8.12	136.0	2.38
	9.49	158.0	2.05
	10.66	150.0	2.12
10	0.63	402.0	0.74
	1.90	269.2	1.11
	3.17	245.0	1.22
	4.44	260	1.15
	5.71	232	1.30
	6.98	176	1.71
	8.25	185	1.63

TABLE III

THERMAL CONDUCTIVITY-ELECTRICAL CONDUCTIVITY

Specimen	σ x 10^{-5} (ohm^{-1} cm^{-1})	K (cal/cm °C sec)
Aluminum	3.60	0.58
1.39 Atomic Pu (Avg.)	3.22	0.53
5.18 Atomic Pu (Avg.)	2.77	0.47
10.26 Atomic Pu	1.48	0.28
11.92 Atomic Pu	1.16	0.21

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TABLE IV

SAMPLE COMPOSITION (MATERIAL DISSOLVED AND ALIQUOT TAKEN FOR ANALYSIS)

Sample Number	Plutonium Weight Percent	Plutonium Atomic Percent	Average Atomic Percent
1	51.6	10.75	10.98
2	54.5	11.92	
3	50.3	10.26	
4	31.9	5.03	5.42
5	33.3	5.34	
6	35.2	5.90	
7	10.8	1.35	1.39
8	11.3	1.42	

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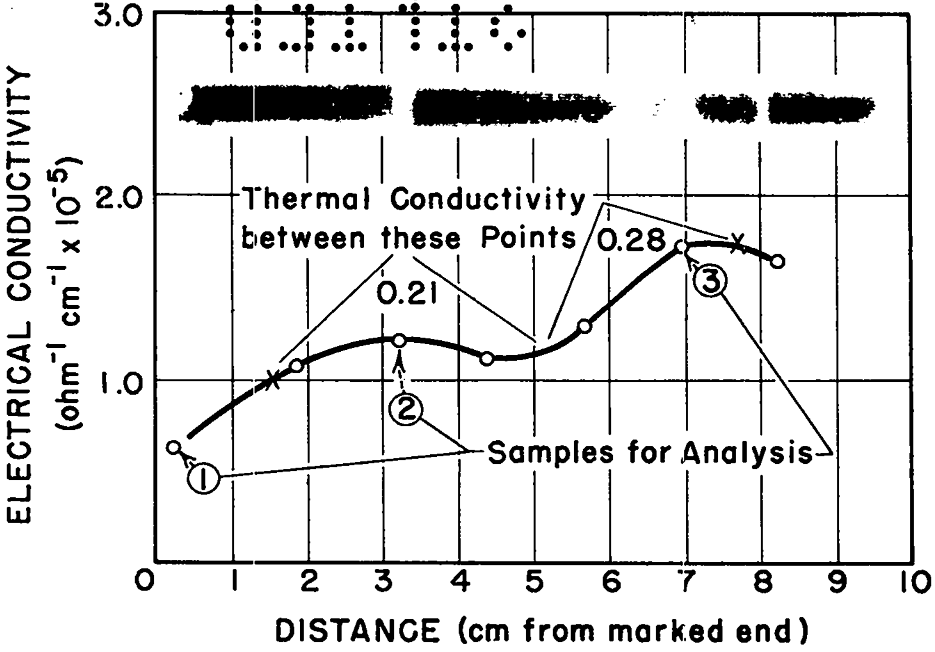

Fig. 1. Radiograph of 10 atomic percent Pu rod and electrical and thermal conductivities as function of location.

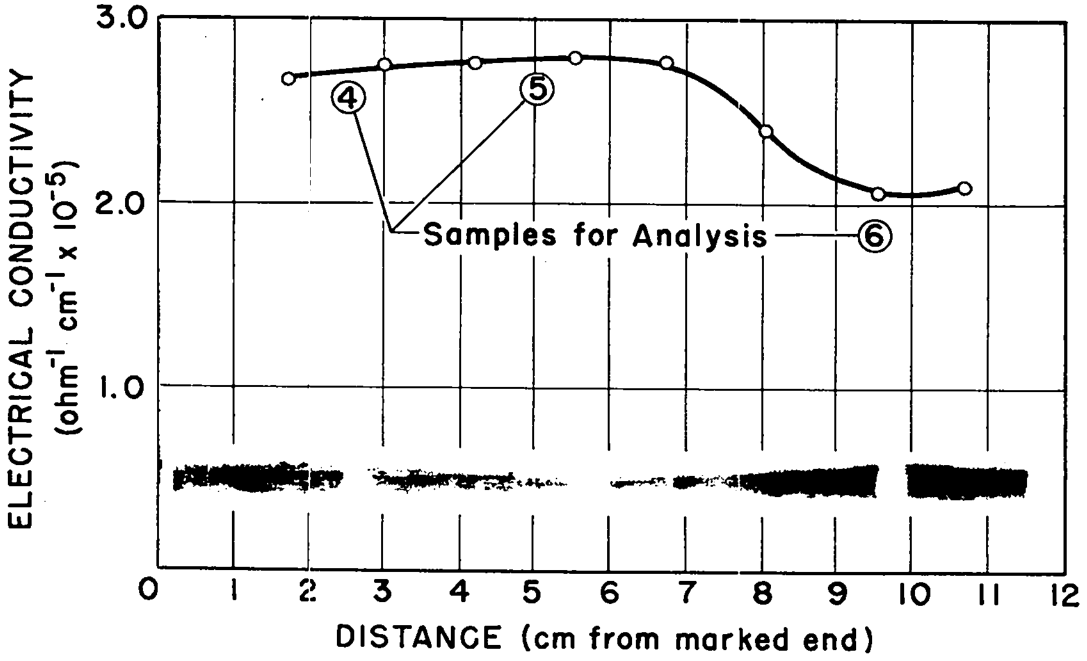

Fig. 2. Radiograph of 5 atomic percent of Pu rod and electrical conductivity as function of location.

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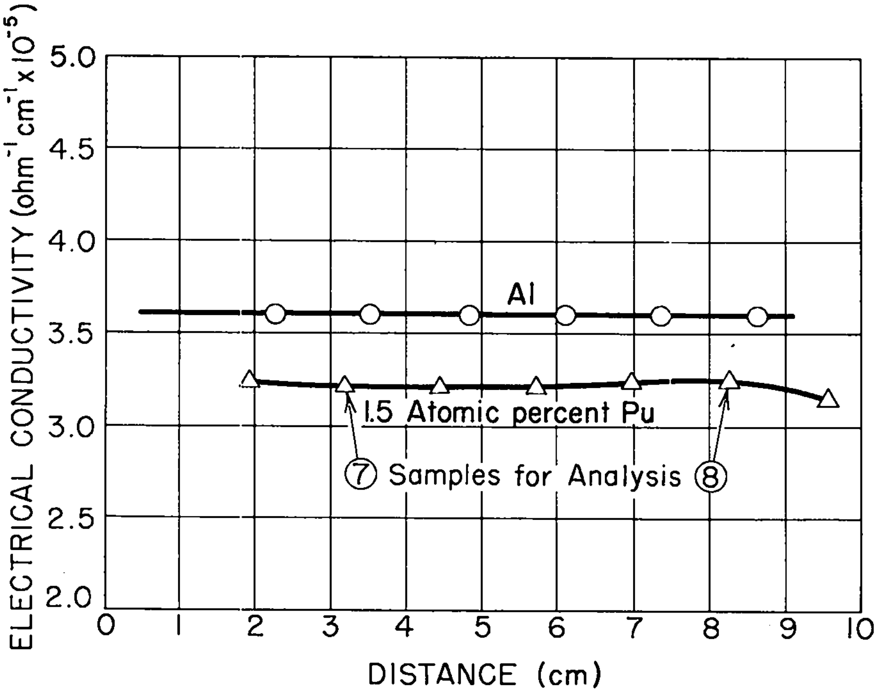

Fig. 3. Electrical conductivity as a function of location on the rod for pure Al and 1.5 atomic percent Pu.

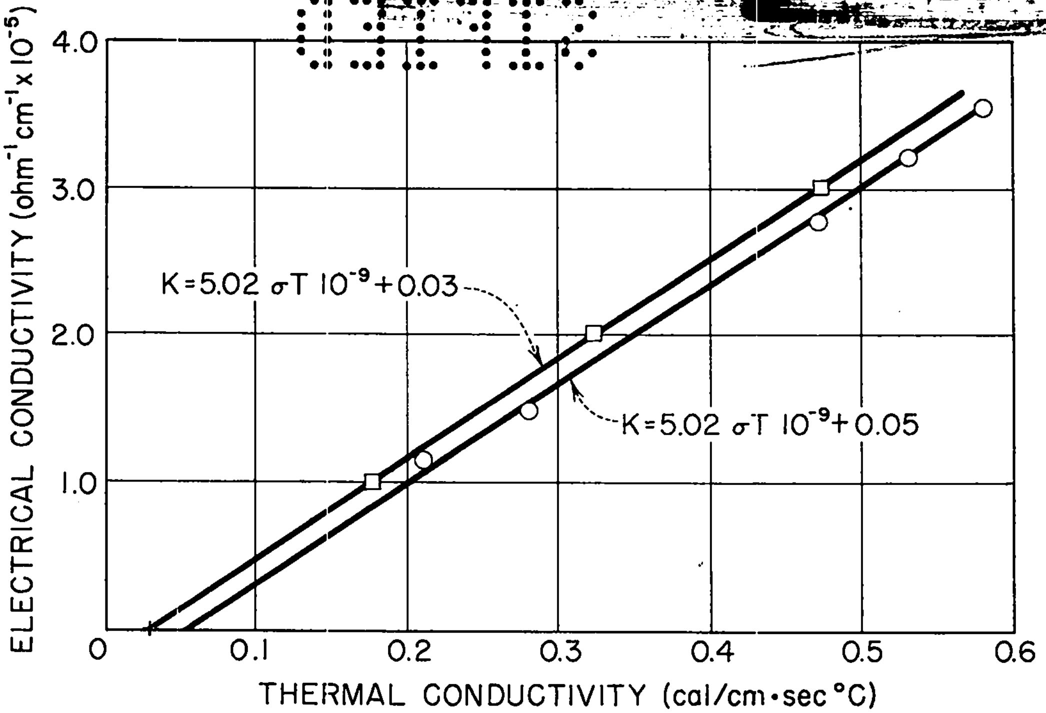

Fig. 4. Electrical conductivity as function of thermal conductivity for Pu-Al alloys.

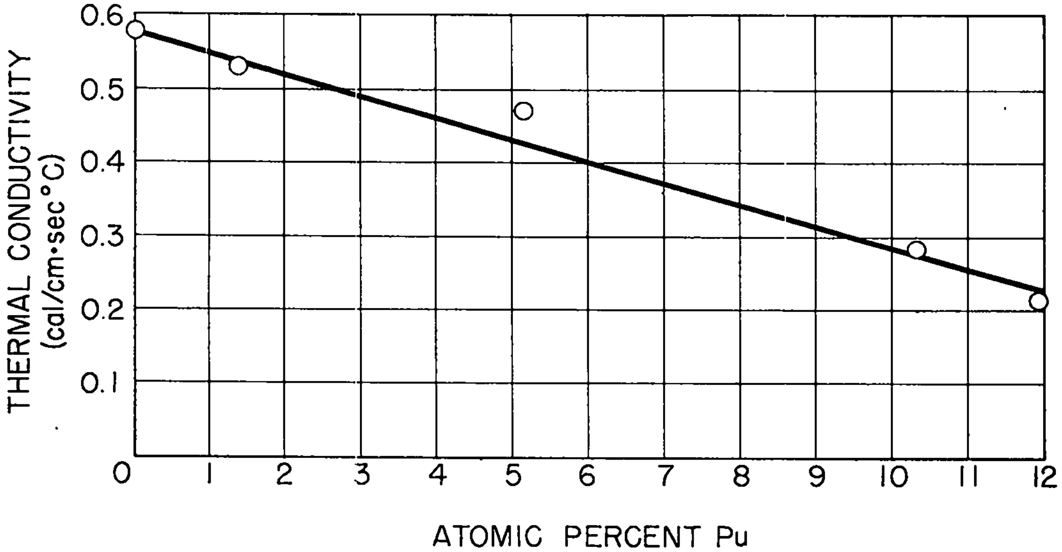

Fig. 5. Thermal conductivity as a function of atomic percent Pu in Pu-Al alloys.