THERMODYNAMICS AND PHASE RELATIONSHIPS
FOR PLUTONIUM OXIDES

By

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INTRODUCTION

The oxides of an element are usually some of its most important compounds. This paper is a compilation of information on the oxides of plutonium. A large part of the contents is from experiments done by the authors. Space limitations prevent detailed presentation of experimental procedures and data, and generally only the results are given.

PREPARATION OF PLUTONIUM OXIDES

A monoxide, two sesquioxides, and a dioxide of plutonium have been reported. (1)(2)(3)

PuO. - Although X-ray Debye patterns attributed to PuO have been described (1, 2, 4, 5) (and frequently seen in this laboratory, apparently as a surface film on plutonium metal), pure PuO has not been prepared and chemical evidence for its existence is scanty. It is reported that barium reduction of PuO₂ produced PuO as a constituent in the reaction products (1, p 936). We were able to duplicate this result, but unable to separate the material giving the PuO X-ray pattern from the mixture. Possibly PuO exists as a metastable phase and is occasionally seen in situations where the kinetics are such as to retain it; or possibly the proper conditions for the stable existence of PuO as an equilibrium phase were not achieved in our experiments. It is claimed by some authors (6) that UO may be stabilized by small percentages of carbon or nitrogen. The same may be true for PuO.

Hexagonal Pu₂O₃. - Hexagonal Pu₂O₃ is prepared by reducing PuO₂ with about 20% excess of plutonium metal (turnings or fine chips) in a

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closed tantalum crucible at 1500°C. The mixture is held at 1500°C or higher for about 3 hours. The product is a black, sintered mass; at higher temperatures, large flat crystals are produced. Hexagonal Pu_2O_3 made in this way contains excess plutonium as a metal phase, which may be removed by evaporation at 1800° to 1900° from an open crucible in vacuum. Plutonium hydride powder may also be used for the reduction. The heating is done slowly at first until the hydrogen has been driven off; then the temperature is raised to 1500° to effect the reduction. Hexagonal Pu_2O_3 is somewhat pyrophoric and sometimes ignites when scratched or ground, although the undisturbed oxide is stable in air for days at room temperature. The above process has been used to prepare batches of Pu_2O_3 up to 20 grams.

Cubic Pu_2O_3 . - The cubic form of Pu_2O_3 has been prepared by heating PuO_2 in vacuum at 1650 - 1800°C. (1, p 939). Further discussion of this oxide is given later in this paper in the section on the phase diagram of the plutonium-oxygen system.

PuO_2 . - Plutonium dioxide is almost always obtained as the final product when plutonium compounds, with the exception of phosphates, are decomposed and ignited in air, and it is most often the product obtained when the ignitions are conducted up to 1000° in vacuo or in an inert atmosphere.

Methods preferred in this laboratory for the preparation of PuO_2 in bulk quantities are based on the decomposition of plutonium (IV) peroxide, plutonium (III) oxalate and plutonium (IV) oxalate. The precipitation of $\text{Pu}_2(\text{C}_2\text{O}_4)_3 \cdot 11\text{H}_2\text{O}$ is simple and straightforward (7). Improved procedures have been described elsewhere for the precipitation of plutonium (IV) peroxide (8, 9, 10) and $\text{Pu}(\text{C}_2\text{O}_4)_2 \cdot 6\text{H}_2\text{O}$ (10, 11). These procedures insure the formation of the crystalline precipitates necessary for subsequent decomposition to pure PuO_2 . Without proper precautions, the peroxide and, in particular, the tetravalent oxalate, are apt to precipitate as semi-gelatinous materials which upon subsequent ignition, decompose to a sintered, black, impure oxide of indefinite composition. The decomposition of well-dried, crystalline plutonium oxalates and peroxides is effected smoothly by slowly raising the temperature from 25 to about 700°. Plutonium (IV) peroxide should be heated rather slowly over the range 90 to 200° to avoid spattering from dehydration and decomposition which occur simultaneously. Any sulfate anions in the peroxide structure are volatilized as SO_3 between 600° and 700°. Peroxides precipitated in the absence of sulfate are usually less crystalline and contain other anions which must be volatilized. The oxalates require ignition to at least 900° to remove carbon, and, in all cases, ignition to constant weight at 1000° is recommended if well-crystallized, pure PuO_2 is desired (12). Others (13) have recommended ignition at 1050° to 1200° for stoichiometric PuO_2 .

Other procedures are more useful for special purposes than for the preparation of bulk quantities of PuO_2 (12, 13, 14, 15).

Higher plutonium oxides. - Katz and Gruen (16) have reported that no higher oxide was produced by attempted oxidation of PuO_2 with NO_2 at 500°C , a technique that has produced higher oxides of some other transuranium elements. Brewer (17) has predicted from thermodynamic considerations that any solid oxide higher than PuO_2 probably will not be stable.

Mixed oxides. - Mulford and Ellinger (18) have described the preparation of mixed oxides of PuO_2 with ThO_2 , CeO_2 and UO_2 . They find that PuO_2 forms a solid solution with each of the three in any proportion.

PROPERTIES OF PLUTONIUM OXIDES

Crystal structures. - The structure derived from the X-ray pattern reported for PuO is cubic, NaCl type, with a unit cell edge of $4.96 \pm 0.01 \text{ \AA}$ and a calculated density of 13.9 g/cc (4).

Hexagonal Pu_2O_3 is isomorphous with the A-type rare earth sesquioxides such as La_2O_3 . The lattice parameters are $a = 3.841 \pm 0.006$ and $c = 5.958 \pm 0.005 \text{ \AA}$. The calculated density is 11.47 g/cc . The structure was solved by one of the authors (F. H. Ellinger) in 1949 and independently by Templeton and Dauben (3).

The cubic Pu_2O_3 phase is isomorphous with Mn_2O_3 -type oxides such as the C-type rare earth sesquioxides. The cell edge is variable with $a = 11.04 \pm 0.02 \text{ \AA}$ being a commonly observed value. The calculated density is 10.2 g/cc . (1, p 1442; 4).

Plutonium dioxide has the fluorite type of crystal structure isomorphous with UO_2 and ThO_2 . The unit cell edge most commonly observed is $5.396 \pm 0.001 \text{ \AA}$. The calculated density is 11.46 g/cc . (1, p 1442; 4).

Other physical properties. - The optical properties of hexagonal Pu_2O_3 and of PuO_2 have been reported by Staritzky and Truitt. (2, chapter 19). Staritzky and Waber made additional measurements of the refractive index of PuO_2 from which estimates of the dielectric constant were made (19). Dawson has measured the magnetic susceptibility of PuO_2 and of solid solutions of PuO_2 in ThO_2 (20). Mardon and Waldron (5) have estimated the linear coefficient of expansion of PuO_2 between room temperature and 500°C by measurement of the change in X-ray lattice parameter with temperature. Their result is $\alpha = 9.0 \pm 1.0 \times 10^{-6}$ per degree C.

Chemical properties. - The refractory nature of highly ignited PuO_2 has long been recognized. A study (12) of "reactive" samples of PuO_2 obtained by decomposition of plutonium (III) and (IV) oxalates at temperatures below 900°C demonstrated that the reactivity could be attributed to the highly distorted, impure PuO_2 lattice produced at low temperatures, and that the reactivity decreased as the impurities were removed and as the

lattice was perfected by ignition at progressively higher temperatures up to 1000°C. A similar explanation is believed to account for the reactivity of plutonium oxide obtained by the decomposition of other plutonium compounds at temperatures below 800-900°C. This summary of reactions applies to PuO₂ obtained by ignition to constant weight at temperatures above 950°C.

Plutonium dioxide can be converted to PuF₃ with a mixture of HF + H₂ at 400-600°C (2) and to PuF₄ with a mixture of HF + O₂ (2) or H₂-free HF at the same temperature.

Plutonium dioxide is difficultly soluble in most solvents. The best solvents are, in order of decreasing effectiveness, 85-100% H₃PO₄ (at 200°), 10 M HNO₃-0.05 M HF, and 5-6 M HI. Refluxing is necessary in all cases and the dissolution is slow. With the phosphoric acid solution, concentrations as high as 250 g plutonium/liter have been obtained. The nitric acid-hydrofluoric acid solution is preferred when it is desired to recover plutonium.

Other solvents, such as hot conc. H₂SO₄, HCl, and HBr have been used (2) but their effectiveness on well-crystallized PuO₂ is questionable. Solution is said to be effected by fusion with potassium pyrosulfate (2) or sodium bisulfate. (13)

Little work has been done on the reaction of PuO₂ with solids. Graphite will convert PuO₂ to a carbide at 1200-1500°C. (2). Reactions with sodium pyrophosphate do not go to completion.

Thermodynamic Properties. - Phipps et al (1, 21) have measured the volatility of PuO₂ by the Knudsen effusion method. They find an equation for the vapor pressure $\log_{10} P_{(\text{mm})} = 11.010 - 27910/T$ for the temperature range between 1500° and 2000°C. Plutonium dioxide probably does not vaporize congruently, however, and it is not known to what process the above numbers pertain.

Brewer (1, 17) has estimated the thermodynamic properties of PuO₂, Pu₂O₃, and PuO. Latimer (22) also has made estimates of thermodynamic quantities for plutonium oxides.

The absolute entropies for plutonium oxides have not yet been determined because the self-heating effect from radioactive decay interferes with accurate measurements at low temperatures. Osborne and Westrum (23) have estimated S₂₉₈° for PuO₂ as 19.7 cal/degree/mole from analogy to the measured absolute entropy of ThO₂. This gives as the entropy of formation $\Delta S_{298}^\circ = -41.4$ cal/degree/mole which agrees with Brewer's (17) estimate of $\Delta S_{298}^\circ = -41$ cal/degree/mole if S₂₉₈° for plutonium metal is taken to be 12.1 cal/degree/mole (22). Coughlin (24) has computed a table of ΔH° and ΔF° (the Gibbs free energy) for PuO₂ as a function of temperature using Brewer's (17) estimated $\Delta H_{298}^\circ = -246 \pm 10$ Kcal/mole and Coughlin's estimates for $\Delta S_{298}^\circ (= -42.0$ cal/degree/mole) and $\Delta C_p (= 1.5$ cal/degree).

From the measured heats of combustion here reported, Coughlin's tables for PuO_2 can be revised as shown in Table I.

Table I
Heat and Free Energy of Formation of PuO_2 (c)

T, °K	$-\Delta H$ (cal./mole)	$-\Delta F^\circ$ (cal./mole)
298.16	252, 900 (± 500)	240, 400 (± 800)
383 (α)	252, 800	236, 800
383 (β)	253, 700	236, 800
400	253, 700	236, 100
500	253, 500	231, 900
593 (γ)	253, 400	228, 000
593 (δ)	254, 100	228, 000
600	254, 100	227, 700
700	253, 900	223, 600
800	253, 800	219, 500
900	253, 600	215, 400
913 (ϵ)	253, 600	214, 900
913 (liq)	254, 100	214, 900
1000	254, 000	211, 400
1100	253, 800	207, 300
1200	253, 700	203, 300
1300	253, 500	199, 200
1400	253, 400	195, 200
1500	253, 200	191, 200

Free Energy Equation $\Delta F^\circ = -253, 480 - 3.45 T \log T + 52.48 T$.

The heats of transition and fusion of the metal are estimated from the respective unpublished work of T. A. Sandenaw and E. M. Cramer of this laboratory.

The $\beta - \gamma$, $\delta - \delta'$ and $\delta' - \epsilon$ heats of transition are believed to be quite small and have been neglected.

Roberts (25) has estimated ΔH_{298}° for Pu_2O_3 to be -393 ± 10 Kcal/mole.

PHASE DIAGRAM

A tentative composition-temperature diagram for the condensed phases in the plutonium-oxygen system as deduced from the experimental evidence which follows is presented in Fig. 1.

Quenching experiments. - Many samples containing PuO_2 and plutonium metal in various ratios were heat-treated in tantalum capsules and quenched from different temperatures. Phase fields in Fig. 1 were determined in this way. Although exact quantitative results were not obtained, several specific points are worthy of note.

First, no PuO phase was found by either metallographic or X-ray examinations. In the composition range where PuO would be expected to exist, mixtures of Pu and hexagonal Pu₂O₃ were always found.

Second, hexagonal Pu₂O₃ was found to be essentially stoichiometric except when coexisting with a higher oxide phase at temperatures above 2000°. Under these conditions a slight departure from stoichiometry toward the oxygen-rich side appeared to exist, giving rise to a small distortion in the crystal lattice as evidenced mainly by changes in position and intensity of some of the lines in the powder pattern.

Third, PuO₂ did not exhibit a constant cell size. Plutonium dioxide equilibrated with cubic Pu₂O₃ at 1250°, 1650° and 1800° had lattice parameters of 5.40, 5.41, and 5.42 Å, respectively. The lattice parameters of PuO₂ seen in samples after they had been melted ranged from 5.42 to 5.47 Å. The enlarged cell size observed indicates that oxygen-deficient PuO₂ exists, and that the oxygen deficiency becomes greater at higher temperatures.

Fourth, the cubic Pu₂O₃ phase also showed a variation in cell size. In samples consisting of the two phases PuO₂ and cubic Pu₂O₃, equilibrated at 1250°, 1450° and 1800°, a_0 for cubic Pu₂O₃ was 10.98, 10.99, and 11.00 Å, respectively. Cubic Pu₂O₃ coexisting with hexagonal Pu₂O₃ had lattice parameters of 11.01 and 10.98 Å.

Fifth, because cubic Pu₂O₃ was never produced by heat treating and quenching hexagonal Pu₂O₃, cubic Pu₂O₃ is not a polymorph of hexagonal Pu₂O₃; it appears only with an oxygen content slightly greater than PuO_{1.5}. Hexagonal Pu₂O₃ was not produced from cubic Pu₂O₃ by heat treatment except under conditions where partial evaporation of the sample could occur. The composition of cubic Pu₂O₃ is not known accurately. It is believed that this phase lies between PuO_{1.5} and PuO_{1.6}. Zachariasen has deduced, from crystal chemical considerations, that the composition can be between PuO_{1.5} and PuO_{1.75} (1, p 1445). Because cubic Pu₂O₃ is very similar in crystal structure to PuO₂, and because both oxides are known to vary in composition, it is of interest to compare the two structures in detail. The cubic Pu₂O₃ unit cell is a cube with the smallest observed cell edge 10.98 Å. The PuO₂ unit cell is also a cube with the largest observed cell edge 5.47 Å. The unit cell of PuO₂ may be considered as a face-centered-cubic arrangement of plutonium atoms with 8 oxygen atoms clustered together in the center of the cube. Removal of these oxygens from random positions to give oxygen-deficient PuO₂ causes a lattice expansion. If 8 of the PuO₂ unit cells are stacked so as to make a cube with an edge twice as long, and more oxygen atoms removed, a further expansion of the lattice occurs along with a small shift in the positions of some of the plutonium atoms resulting in the cubic Pu₂O₃ structure. Thus, although the crystal lattices are different, the actual spatial arrangement of the plutonium and oxygen atoms is very similar in both. Though it might seem possible to go continuously from the PuO₂ structure to the cubic Pu₂O₃ structure with no abrupt transitions, two-phase mixtures of cubic Pu₂O₃ and PuO₂ were obtained in many different samples in

the PuO_2 to $\text{Pu}_2\text{O}_{3+x}$ composition range quenched from temperatures up to 1850° .

There is a difference in the lattice parameters of the two phases, and intermediate lattice parameters were not observed. (Smallest cubic- Pu_2O_3 cell edge, 10.98 ± 0.01 ; largest double PuO_2 cell edge $10.94 \pm 0.01 \text{ \AA}$). Thus PuO_2 and cubic Pu_2O_3 are distinct phases despite the similarity of structure, and an abrupt transition from one phase to the other occurs as oxygen content is varied.

Oxygen-rich PuO_2 . - The stoichiometric composition of PuO_2 which has been ignited at 1000 – 1200°C in air has been confirmed for analytical purposes. The decomposition of plutonium(IV) peroxide and plutonium (III) and (IV) oxalates to PuO_2 , followed by careful ignition to constant weight at 1000°C , has been used in this laboratory as a gravimetric procedure. Good agreement with potentiometric analyses of solutions of the starting materials has been obtained. However, other data suggesting that PuO_2 can exist with an oxygen to plutonium ratio greater than 2 were obtained in the course of experiments where lower oxides were ignited in pure oxygen.

Cubic Pu_2O_3 was ignited in flowing oxygen ($p = 59 \text{ cm}$) at 950° for 2 hours in a platinum boat to give PuO_2 with a unit cell edge of $5.3820 \pm 0.0004 \text{ \AA}$. Another sample, originally containing both hexagonal and cubic Pu_2O_3 , heated in a platinum boat in oxygen at 1000°C for 34 hours gave inhomogeneous PuO_2 having a range of unit cell sizes from 5.39 to $5.37 \text{ \AA}$. In contrast, hexagonal Pu_2O_3 ignited in platinum in O_2 at 1100° for 25 hours gave PuO_2 with $a_0 = 5.3955 \pm 0.0003 \text{ \AA}$.

It is unlikely that the small lattice parameter is caused by solid solution of nitrogen in the PuO_2 lattice, because samples ignited in pure oxygen show the decreased lattice, and ignition in air, either flowing or stagnant, usually resulted in PuO_2 of normal lattice size.

Apparently, if cubic Pu_2O_3 is the starting material, excess oxygen can be introduced into the lattice at about 1000° in pure oxygen so that an oxygen-rich PuO_2 is produced. Other oxides having the fluorite type of crystal structure are known to shrink in cell size as excess oxygen is added.

Melting experiments. - A number of samples of plutonium oxides of various compositions in the range from hexagonal Pu_2O_3 to PuO_2 were melted in tantalum. One-sixteenth inch diameter holes were drilled in a tantalum block, the powdered oxides tamped in, the block heated by induction in vacuum, and the temperature observed at which each hole changed its appearance because of melting of the powder. The temperature of the block was read from a deep hole assumed to give black body conditions. All the melting points were between 2170° and 2290°C . The average melting temperature was 2240° ; the average deviation was 33° with an extreme deviation of 70° for one sample. The relative constancy means that a horizontal exists in the

phase diagram. X-ray Debye patterns were run on the samples after melting. Plutonium dioxide was present in every sample and generally cubic and hexagonal Pu_2O_3 were also present. The PuO_2 phase always had a larger unit cell size than normal. The melting point ($2170\text{--}2260^\circ$) obtained by melting a lump of pure hexagonal Pu_2O_3 on a tantalum block lies on the proposed horizontal, and two-phase melting of the lump was noted. This indicates that hexagonal Pu_2O_3 melts incongruently, and this is supported by the fact that PuO_2 with cell edge $5.45 \text{ \AA}$ was present after melting. If hexagonal Pu_2O_3 melted congruently, no change in the X-ray pattern due to melting should be observed.

Numerous attempts to determine a melting point for pure PuO_2 were made, both in vacuum and in an argon atmosphere. Values scattering around 2240° were always obtained, and the X-ray patterns always showed two phases after melting. Because of incongruent vaporization at temperatures near the melting point (21), oxygen is lost from the PuO_2 , so that the melting point observed was that for the two-phase PuO_2 -cubic Pu_2O_3 mixture. The true melting point of stoichiometric PuO_2 thus will have to be measured under an equilibrium oxygen pressure so as to prevent decomposition and keep the PuO_2 at the correct composition.

Solubility of oxygen in plutonium. - Plutonium, on melting in vacuum in an MgO crucible, reacts with the MgO, volatile Mg being continuously removed. If there is no stirring, a dense layer of hexagonal Pu_2O_3 is formed at the interface between the MgO and plutonium, and the plutonium is, in effect, contained in a Pu_2O_3 crucible.

Samples were melted in MgO crucibles in a resistance furnace and held at 1100°C in a vacuum at 10^{-6} mm Hg until a thick layer of Pu_2O_3 was formed, then held at an equilibration temperature in the same crucible, and quenched by lowering the furnace from around the vacuum envelope. Metallographic examination of vertical sections of the ingots showed a fine needle-like precipitate of hexagonal Pu_2O_3 with no sign of gravity segregation. Duplicate samples for oxygen analysis were made by sectioning vertically so as to average any possible segregation. The metallography showed that there was good contact between the metal and the Pu_2O_3 layer. No intermediate phases such as PuO could be seen. The fusion method for oxygen analysis which was used has been described by Smiley. (26)

The solubility of oxygen in Pu equilibrated with Pu_2O_3 , at temperatures from 1000° to 1150° for 5 to 17 hours was 25 ± 10 ppm by wt. The oxygen content of a sample equilibrated at 580° for 40 hours, was the same.

The estimated accuracy of the analytical procedure is ± 10 ppm. The small size of the analytical samples (ca. 100 mg) made the results quite sensitive to any surface oxide and cleaning of the samples was found to be critical. The method adopted was to file the surface of the specimen, wash with CCl_4 and analyze immediately, before any tarnish could form. This procedure gave results which were more reproducible, and considerably lower oxygen content was found than when chemical or electrolytic cleaning methods were used.

Because of the very small solubility of oxygen in Pu, no attempt was made to determine any effects on transformation temperatures caused by dissolved oxygen.

HEAT OF COMBUSTION OF PLUTONIUM

The method, which involved the determination of the heat evolved from the combustion of a weighed sample of the metal in a bomb calorimeter at a known initial pressure of oxygen, has been described (27). The energy equivalent of the calorimeter was $10,017.8 \pm 4.2$ joules/ $^{\circ}\text{C}$ as determined by the combustion of standard benzoic acid.

The α -plutonium metal was analyzed spectroscopically and found to contain no metallic impurities in amounts greater than 0.01% by weight. The oxygen content was estimated by the argon fusion method to be 0.0035% and the carbon content by a microcombustion method to be 0.0035%. The hydrogen content was found to be 0.0008% by heating a weighed sample of the metal to 1000°C and collecting and analyzing the gas evolved. The sulfur and fluorine contents as determined by standard chemical methods were found to be negligibly small. No analysis was made for nitrogen and it is assumed to be negligibly small.

The metal was burned in the form of chunks on sintered discs of pure PuO_2 supported on a platinum platform. Ignition was by means of a 10 cm length of stabilized delta-plutonium alloy fuse wire 0.010 inches in diameter, fired electrically. The discs were made by stirring 30 grams of the powdered oxide with about 100 ml of CCl_4 containing about 2 grams of Carbowax (Pl-400), evaporating the mixture to dryness, loading the resulting wax-coated particles into a die having the punch faces lined with Saran wrap, pressing under vacuum for 5 minutes at about 10,000 p.s.i., and then firing the resulting disc in air in a muffle furnace at about 1050°C . The fired discs were sufficiently strong to permit handling. Several discs were used per run, as the top disc always cracked allowing the molten PuO_2 to run down through it. X-ray examination of the discs showed only PuO_2 with a lattice constant of $5.3955 \pm 0.0003 \text{ \AA}$, typical of stoichiometric PuO_2 .

The product of the combustion was a dark colored, fused mass which included considerable amounts of disc material. X-ray examination showed only PuO_2 with a lattice constant the same within experimental error as for the PuO_2 disc material.

The completeness of combustion was determined by heating the combustion products in air at 1000°C and noting the change in weight. A slight loss in weight was observed in each case, showing that there was no significant amount of unburned metal. About half the loss in weight occurred below 200° and probably was due to water. The remainder was assumed to be due to the loss of excess oxygen in the fused PuO_2 . The average weight loss corrected for water corresponds to an initial formula for the fused products of $\text{PuO}_{2.003}$.

The results are presented in Table II. The average initial temperature for the runs was 25.3°C. The uncertainty interval is twice the standard deviation of the mean.

The average heat of combustion, when corrected for impurities, and including all estimated uncertainties becomes 4413.4 ± 5.4 joules/gram. The heat of formation of PuO_2 calculated from this result is -1058.0 ± 1.6 kJoules/mole or -252.87 ± 0.38 kcal/mole (atomic weight of plutonium taken as 239.1). This value is in good agreement with the value of -252.4 ± 1.1 kcal/mole reported by Popov and Ivanov (28), who burned their plutonium on either ThO_2 or BeO . Our combustions, carried out on PuO_2 and giving the same value, support their conclusion that the heat of solution of ThO_2 in PuO_2 is small.

Table II

The Heat of Combustion of Plutonium

Mass α -Pu (g)	Mass δ -Pu (g)	Weight PuO_2 (g)	Joules/Degree Total	ΔT , °C	Energy From		Dev. From Mean
					Firing J.	Pu J/gram	
2.9876	0.0622	87.7	10,042.5	1.3435	7.2	4420.7	4.3
2.9294	0.0573	106.4	10,047.0	1.3126	5.5	4412.6	3.8
3.1487	0.0658	121.3	10,050.6	1.4130	6.3	4415.0	1.4
3.2339	0.0618	135.6	10,054.0	1.4489	6.8	4417.1	0.7
2.9899	0.0615	135.9	10,054.1	1.3404	6.7	4419.9	3.5
					Av.:	4416.4	
					2 x Stand. Dev.:	2.8	
Fuse	3.2542	129.2	10,052.5	1.4441	6.7	4458.9	
wire	3.2274	128.9	10,052.4	1.4355	6.9	4469.0	
material					Av.:	4464.0	

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Pu - O PHASE DIAGRAM