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MASTER

PROPERTIES OF PLUTONIUM OXIDE, PART II

THE DOW CHEMICAL COMPANY
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U.S. ATOMIC ENERGY COMMISSION
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PROPERTIES OF PLUTONIUM OXIDE, PART II

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Robert D. White

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Properties of Plutonium Oxide, Part II

Garrel F. Molen and Robert D. White

Abstract. The effect of the maximum exposure temperature and the time of exposure on the properties of plutonium oxide are described. Results showed that temperature, and the interaction of temperature and time, had a significant effect on the properties measured. Time alone did not have a significant effect on the properties measured.

INTRODUCTION

Some properties of plutonium oxide are dependent on the history of the plutonium oxide. Important considerations in the history of the oxide are the compound from which the oxide was formed, the temperature at formation of the oxide, the maximum temperature to which the oxide was exposed, and the length of time of exposure. The plutonium oxide properties, which show a dependence, are the chemical composition, the reactivity, the solubility, the mean crystallite size, the specific surface area, the particle size, and the lattice constant.

Moseley and Wing¹ have studied the effect of temperature-of-formation and the effect of the starting material on some of the properties mentioned. This study elucidates several properties of plutonium oxide and their dependence on the maximum temperature to which the oxide is exposed and the period of exposure.

Experiences with processes, which involve the dissolution of plutonium oxide, indicate that the temperature-of-formation has a direct effect on the rate of dissolution; the rate decreases as the temperature increases. A definite correlation between the specific properties and the rate-of-dissolution would prove to be beneficial because the measurement of these properties would provide a simple, nondestructive indication of the rate at which a given oxide goes into solution.

SUMMARY AND CONCLUSIONS

Low temperature plutonium oxide (electrorefined metal air oxidized at room temperature) was heated at 100,

300, 500, 700 and 900°C for 1-, 4-, and 7-hours at each temperature. The effect of this treatment on the mean crystallite size, the specific surface area, the lattice constant, the particle size distribution and the rate-of-dissolution was measured.

The mean crystallite size of the oxide increased from 105 to 442Å as the temperature increased from 100 to 900°C. The particle size distribution did not significantly change as the temperature increased. The rate-of-dissolution decreased from 89.98% to 67.28% in one hour as the temperature increased from 100 to 900°C.

In general, temperatures greater than 500°C resulted in the most significant effect on the properties of plutonium oxide. The period of exposure at the formation temperature did not have a significant effect on these properties; however, the interaction of time and temperature did result in a significant effect on these properties.

EXPERIMENTAL PROCEDURE

General Procedure

A three-by-five factorial experimental design was used. Such a design provides for testing the dependence of the properties of interest on the temperature at five levels and on the period of time at three levels. This was accomplished by treating low temperature oxide (electrorefined plutonium metal that was oxidized by air at room temperature) at 100, 300, 500, 700 and 900°C for 1, 4 and 7 hours at each temperature. Also incorporated into the design was a brief homogeneity study on the low temperature, untreated oxide.

The apparatus consisted of a type 1300 Thermolyne furnace with a chamber size of 4 by 3¾ by 4½ inches. A stainless steel pan (2½ by 4 by 1 inches) was used as the reaction vessel. This pan had a ½-inch ID tube welded to its floor. The tube acted as a thermowell. A 4 by 3 by 2-inch steel block was placed in the furnace as a heat sink. The thermocouple was connected to a Foxboro recorder.

The mean crystallite size and the lattice constant were determined by x-ray diffraction methods. The determinations of the specific surface area were made using a

¹ J. D. Moseley and R. O. Wing. *Properties of Plutonium Dioxide* (considered Part I). RFP-503. Rocky Flats Division, The Dow Chemical Company, Golden, Colorado. August 24, 1965.

Perkin-Elmer adsorptometer. The particle size distribution was determined by microscopic analysis of the particles dispersed in oil. The dissolution tests were performed by heating 10 grams of oxide in 40 ml of 12.5 M HNO_3 - 0.1 M CaF_2 until boiling, and then refluxing for one hour. The undissolved residue was then filtered off, dried, weighed, and analyzed for plutonium by a fusion-redox titration method. The filtrate volume was measured and analyzed for plutonium by a redox titration method.

Homogeneity Study Procedure

The low temperature oxide was screened and all visible impurities, such as brush fiber and unoxidized metal, were removed. The material was comprised of about 20% unoxidized metal. The remaining material passed through a 100 mesh Tyler screen. This screened material was then blended by rolling and tumbling in a $\frac{1}{2}$ -gallon bottle. After blending, a 60-gram sample was taken. From the 60-gram sample, two 1-gram samples were taken for the mean crystallite size, the lattice constant, and the particle size determinations. Two 20-gram samples were taken for the rate-of-dissolution determinations. Two 2-gram samples were taken for the specific surface area determinations. The oxide was reblended after each sample was taken. This sequence was repeated six times.

Time and Temperature Dependence Study Procedure

The furnace, including the reaction pan and steel block, was heated to the desired temperature. A 60-gram sample of the screened, blended, untreated oxide was then loaded into the reaction pan. After the furnace had returned to the desired temperature (a period of about 15 minutes) the time was recorded. The material was stirred twice during a run. After the desired amount of time had elapsed, the pan was removed and allowed to cool. After cooling, the treated material was screened, blended, and sampled as in the homogeneity study.

DISCUSSION OF RESULTS

The source material, containing 0.911 g Pu/g, was a green, powdery oxide with a strong tendency to cake. When it was placed in the furnace at 500°C, or above, sparking occurred when the oxide touched the heated pan. There was also a rapid change in color from the initial green to yellow-brown. At 300°C, no changes were observed. After the material had cooled, the

color changed back to the initial green. No differences between the treated material and untreated material could be visually observed after cooling.

Homogeneity Study of the Properties of Plutonium Oxide

Mean Crystallite Size: The mean values range from 101 to 106 Å with a grand mean of 103 Å. The analytical error is ± 1.4 Å or 1.4% relative. The sampling error is ± 1.3 Å or 1.3% relative. The results, which are presented in Table I, show the source material to be homogeneous in crystallite size.

Specific Surface Area: Table II shows the mean values for the specific surface area. The range is 11.15 to 13.65 m^2/g . The analytical error is $\pm 1.22 \text{ m}^2/\text{g}$ or 9.5% relative. The sampling error is indeterminate. These results show the source material to be homogeneous in specific surface area.

Lattice Constant: The lattice constant (see Table III) ranges from 5.4021 to 5.4032 Å. The analytical and sampling errors are ± 0.0002 Å and ± 0.0004 Å respectively. The sampling error is statistically significant. This indicates nonhomogeneity by lattice-constant measurements.

Particle Size Distribution: The particle size distribution (see Table IV) for particles $<1\mu$ is in the range of 5.0 to 6.8%. For particles $1-5\mu$ the range is 91.5 to 93.8%. For particles $>5\mu$ the range is 1.2 to 1.6%. The range on the size of the largest particle is 7.5 to 11.0 μ . The grand mean for the $<1\mu$ particles is 5.8% with an analytical error of $\pm 0.4\%$ or 6.9% relative and

TABLE I. Homogeneity Study of the Properties of Plutonium Oxide - Mean Crystallite Size (Å).

Table of Means	
Sample No.	Mean Crystallite Size (Å)
H-CS-1	103
H-CS-2	106
H-CS-3	103
H-CS-4	102
H-CS-5	104
H-CS-6	101
Statistical Analysis	
Grand mean	103 Å
Analytical error (σ_A)	± 1.4 Å ($\pm 1.4\%$)
Sampling error (σ_s)	± 1.3 Å ($\pm 1.3\%$)

Each mean was based on two observations.
The grand mean was based on twelve observations.
The number in parenthesis is the relative percent error.

TABLE II. Homogeneity Study of the Properties of Plutonium Oxide - Specific Surface Area (m^2/g).

Table of Means	
Sample No.	Specific Surface Area (m^2/g)
H-SA-1	13.65
H-SA-2	11.15
H-SA-3	12.95
H-SA-4	13.20
H-SA-5	13.00
H-SA-6	12.95
Statistical Analysis	
Grand mean	$12.82 \text{ m}^2/\text{g}$
Analytical error (σ_A)	$\pm 1.22 \text{ m}^2/\text{g}$ ($\pm 9.5\%$)
Sampling error (σ_S)	Indeterminate
Each mean was based on two observations.	
The grand mean was based on twelve observations.	
The number in parenthesis is the relative percent error.	

TABLE III. Homogeneity Study of the Properties of Plutonium Oxide - Lattice Constant ($\text{\AA}$).

Table of Means	
Sample No.	Lattice Constant ($\text{\AA}$)
H-LP-1	5.4032
H-LP-2	5.4024
H-LP-3	5.4024
H-LP-4	5.4028
H-LP-5	5.4021
H-LP-6	5.4026
Statistical Analysis	
Grand mean	$5.4026 \text{\AA}$
Analytical error (σ_A)	$\pm 0.0002 \text{\AA}$ ($\pm 0.0037\%$)
* Sampling error (σ_S)	$\pm 0.0004 \text{\AA}$ ($\pm 0.0074\%$)
Each mean was based on two observations.	
The grand mean was based on twelve observations.	
The number in parenthesis is the relative percent error.	
* Statistically significant.	

a sampling error of $\pm 0.6\%$ or 10.4% relative. The sampling error is statistically significant. The grand mean for the $1-5\mu$ particles is 92.8% . The analytical error is $\pm 0.4\%$ or 0.4% relative. The sampling error is $\pm 0.8\%$ or 0.9% relative which is statistically significant. For the $>5\mu$ particles the grand mean is 1.4% with an analytical error of $\pm 0.2\%$ or 14% relative and a sampling error of $\pm 0.1\%$ or 7% relative. The largest particle grand mean is 9.3μ . Its analytical error is $\pm 1.8\mu$ or 19% relative. The sampling error is $\pm 0.9\mu$ or 10% relative. Some of these results indicate homogeneity and some indicate nonhomogeneity.

Dissolution: The dissolution range is 80.84 to 90.54% in one hour. The grand mean is 87.98% . The analytical error is $\pm 2.41\%$. The sampling error is $\pm 3.33\%$

TABLE IV. Homogeneity Study of the Properties of Plutonium Oxide - Particle Size Distribution (%).

Table of Means		
Sample No.	Particle Size (μ)	Distribution (%)
H-PS-1	< 1	5.1
H-PS-2	< 1	6.8
H-PS-3	< 1	5.6
H-PS-4	< 1	6.0
H-PS-5	< 1	5.0
H-PS-6	< 1	6.2
H-PS-1	1-5	93.5
H-PS-2	1-5	91.5
H-PS-3	1-5	93.2
H-PS-4	1-5	92.4
H-PS-5	1-5	93.8
H-PS-6	1-5	92.4
H-PS-1	> 5	1.4
H-PS-2	> 5	1.6
H-PS-3	> 5	1.2
H-PS-4	> 5	1.6
H-PS-5	> 5	1.2
H-PS-6	> 5	1.4
		Size (μ)
H-PS-1	largest	9.0
H-PS-2	largest	10.5
H-PS-3	largest	7.5
H-PS-4	largest	7.5
H-PS-5	largest	10.5
H-PS-6	largest	11.0
Statistical Analysis		
Grand mean ($< 1\mu$ particles)		5.8%
Analytical error ($< 1\mu$ particles) (σ_A)		$\pm 0.4\%$ ($\pm 6.9\%$)
* Sampling error ($< 1\mu$ particles) (σ_S)		$\pm 0.6\%$ ($\pm 10.4\%$)
Grand mean (1-5 μ particles)		92.8%
Analytical error (1-5 μ particles) (σ_A)		$\pm 0.4\%$ ($\pm 0.43\%$)
* Sampling error (1-5 μ particles) (σ_S)		$\pm 0.8\%$ ($\pm 0.86\%$)
Grand mean ($> 5\mu$ particles)		1.4%
Analytical error ($> 5\mu$ particles) (σ_A)		$\pm 0.2\%$ ($\pm 14.4\%$)
Sampling error ($> 5\mu$ particles) (σ_S)		$\pm 0.1\%$ ($\pm 7.2\%$)
Grand mean (largest particle)		9.3 μ
Analytical error (largest particle) (σ_A)		$\pm 1.8\mu$ ($\pm 19.4\%$)
Sampling error (largest particle) (σ_S)		$\pm 0.9\mu$ ($\pm 9.7\%$)
Each mean was based on two observations.		
Each grand mean was based on twelve observations.		
The number in parenthesis is the relative percent error.		
* Statistically significant.		

which is statistically significant. The data are presented in Table V. These results indicate nonhomogeneity.

The results of these tests on the blended, untreated source material, in general, show no inhomogeneity in crystallite size, specific surface area, and particle size distribution.

TABLE V. Homogeneity Study of the Properties of Plutonium Oxide - Dissolution (% dissolved in one hour).

Solid-to-Liquid Ratio: 250 g/l

Table of Means

Sample No.	% Dissolved in One Hour
H-SO-1	80.84
H-SO-2	87.75
H-SO-3	90.43
H-SO-4	87.79
H-SO-5	90.54
H-SO-6	90.47

Statistical Analysis

Grand mean	87.98%
Analytical error (σ_A)	$\pm 2.41\%$ ($\pm 2.74\%$)
* Sampling error (σ_S)	$\pm 3.33\%$ ($\pm 3.78\%$)

Each mean was based on two observations.

The grand mean was based on twelve observations.

The number in parenthesis is the relative percent error.

* Statistically significant.

TABLE VI. Time and Temperature Dependence Study of the Properties of Plutonium Oxide - Mean Crystallite Size ($\text{\AA}$).

Table of Means

Temperature ($^{\circ}\text{C}$)	Time (hr)			Temperature Means
	1	4	7	
100	106	104	104	105
300	121	122	122	122
500	158	171	174	167
700	251	278	279	269
900	372	475	478	442
Time Means	202	230	231	

Statistical Analysis

* Grand mean	221 $\text{\AA}$
Analytical error (σ_A)	$\pm 7\text{\AA}$ ($\pm 3.2\%$)
Sampling error (σ_S)	Indeterminate
* Standard deviation for interaction means was	$\pm 25\text{\AA}$ ($\pm 11.3\%$)
Standard deviation for time means was	$\pm 12\text{\AA}$ ($\pm 5.4\%$)
* Standard deviation for temperature means was	$\pm 138\text{\AA}$ ($\pm 62.5\%$)

Each interaction mean was based on four observations.

Each time mean was based on twenty observations.

Each temperature mean was based on twelve observations.

The grand mean was based on sixty observations.

The number in parenthesis is the relative percent error.

* Statistically significant.

FIGURE 1. The Effect of Time and Temperature on the Mean Crystallite Size of Plutonium Oxide.

Time and Temperature Dependence Study of the Properties of Plutonium Oxide

Mean Crystallite Size: The data presented in Table VI and Figure 1 illustrate the effect of time and temperature on the mean crystallite size of plutonium oxide. The grand mean is 221Å. This is statistically significant relative to the mean crystallite size of the source material. The analytical error is 3.2% relative and the sampling error is indeterminate. The standard deviation for the interaction means is $\pm 25\text{Å}$ or 11.3% relative, for the time means it is $\pm 12\text{Å}$ or 5.4% relative, and for the temperature means it is $\pm 138\text{Å}$ or 62.5% relative.

The results show that there is a significant effect on the mean crystallite size as a result of the interaction of time and temperature. The effect from time alone is not significant. The effect from temperature alone is significant.

Specific Surface Area: The effect of time and temperature on the specific surface area is illustrated in Table VII and Figure 2. The grand mean is $10.2 \text{ m}^2/\text{g}$. The analytical and sampling errors are $\pm 0.3 \text{ m}^2/\text{g}$. The standard deviation for the interaction means is $\pm 0.4 \text{ m}^2/\text{g}$ which is statistically significant. The standard

TABLE VII. Time and Temperature Dependence Study of the Properties of Plutonium Oxide — Specific Surface Area (m^2/g).

Temperature ($^{\circ}\text{C}$)	Time (hr)			Temperature Means
	1	4	7	
100	13.3	13.1	12.9	13.1
300	13.4	13.6	13.7	13.6
500	11.8	11.9	10.2	11.3
700	8.0	7.3	7.5	7.6
900	6.0	5.0	5.0	5.4
Time Means	10.5	10.2	9.9	

Statistical Analysis

- * Grand mean $10.2 \text{ m}^2/\text{g}$
- Analytical error (σ_A) $\pm 0.34 \text{ m}^2/\text{g}$ ($\pm 3.3\%$)
- * Sampling error (σ_S) $\pm 0.30 \text{ m}^2/\text{g}$ ($\pm 2.9\%$)
- * Standard deviation for interaction means was $\pm 0.38 \text{ m}^2/\text{g}$ ($\pm 3.7\%$)
- Standard deviation for time means was $\pm 0.23 \text{ m}^2/\text{g}$ ($\pm 2.4\%$)
- * Standard deviation for temperature means was $\pm 3.56 \text{ m}^2/\text{g}$ ($\pm 34.9\%$)

Each interaction mean was based on four observations.
 Each time mean was based on twenty observations.
 Each temperature mean was based on twelve observations.
 The grand mean was based on sixty observations.
 The number in parenthesis is the relative percent error.

* Statistically significant.

FIGURE 2. The Effect of Time and Temperature on the Specific Surface Area of Plutonium Oxide.

deviation for the time means is $\pm 0.2 \text{ m}^2/\text{g}$. The standard deviation for the temperature means is $\pm 3.6 \text{ m}^2/\text{g}$ or 35% relative. This is statistically significant.

The results show that there is no significant time effect but there is a significant temperature effect. The effect from the interaction of time and temperature is significant.

Lattice Constant: Table VIII and Figure 3 illustrate the dependence of the lattice constant on the time and temperature. The standard deviation for the interaction means is $\pm 0.0007 \text{ \AA}$, for the time means is $\pm 0.0008 \text{ \AA}$, and for the temperature means is $\pm 0.0028 \text{ \AA}$. The interaction of the time and temperature is significant. The temperature effect is significant. The time effect is not significant.

Particle Size Distribution: The data illustrating the time and temperature dependence of the particle size distribution are illustrated in Table IX. The grand mean for the $<1\mu$ particles is 5.7%. The grand mean for the $1-5\mu$ particles is 92.3% and the grand mean for the $>5\mu$ particles is 2.0%. For the largest particle the grand mean is 25.3μ . There is a statistically significant interaction mean for the $<1\mu$ particles of $\pm 1.5\%$ or 26.3% relative. The interaction mean for the $1-5\mu$

TABLE VIII. Time and Temperature Dependence Study of the Properties of Plutonium Oxide - Lattice Constant ($\text{\AA}$).

Temperature ($^{\circ}\text{C}$)	Time (hr)			Temperature Means
	1	4	7	
100	5.4018	5.4004	5.3980	5.4012
300	5.3972	5.3948	5.4016	5.4002
500	5.3998	5.3988	5.3948	5.3986
700	5.3948	5.4004	5.4004	5.3956
900	5.3989	5.3950	5.3941	5.3946
Time Means	5.3984	5.3980	5.3978	

Statistical Analysis

* Grand mean	5.3981 $\text{\AA}$
Analytical error (σ_A)	$\pm 0.0003 \text{ \AA}$ ($\pm 0.0056\%$)
Sampling error (σ_S)	Not measured
* Standard deviation for interaction means was	$\pm 0.0007 \text{ \AA}$ ($\pm 0.013\%$)
Standard deviation for time means was	$\pm 0.00008 \text{ \AA}$ ($\pm 0.0015\%$)
* Standard deviation for temperature means was	$\pm 0.0028 \text{ \AA}$ ($\pm 0.052\%$)

Each interaction mean was based on two observations.
Each time mean was based on ten observations.
Each temperature mean was based on six observations.
The grand mean was based on thirty observations.
The number in parenthesis is the relative percent error.

* Statistically significant.

FIGURE 3. The Effect of Time and Temperature on the Lattice Constant of Plutonium Oxide.

TABLE IX. Time and Temperature Dependence Study of the Properties of Plutonium Oxide - Particle Size Distribution (%).

Table of Means				
Particle Size: $<1\mu$				
Temperature ($^{\circ}\text{C}$)	Time (hr)			Temperature Means
	1	4	7	
100	11.3	6.1	5.5	7.4
300	5.8	4.8	4.4	5.6
500	6.4	5.3	5.1	5.2
700	4.3	6.4	4.4	5.4
900	4.7	5.4	5.0	4.7
Time Means	6.7	5.1	5.2	
Particle Size: $1-5\mu$				
100	87.5	92.6	92.6	91.2
300	92.9	93.5	94.0	92.8
500	91.4	92.4	92.4	92.7
700	92.0	92.0	94.2	92.5
900	93.2	92.2	91.6	92.4
Time Means	91.8	92.4	92.6	
Particle Size: $>5\mu$				
100	1.2	1.2	1.9	1.4
300	1.2	1.7	1.6	1.6
500	2.2	1.8	2.4	1.9
700	3.8	1.4	1.4	2.0
900	2.1	2.4	3.4	3.0
Time Means	1.5	2.4	2.2	
Particle Size: largest (μ)				
100	25.0	27.5	20.0	20.0
300	12.5	16.0	12.5	16.3
500	10.5	15.0	40.0	15.8
700	75.0	22.5	11.0	30.0
900	12.5	37.5	42.5	44.5
Time Means	20.2	30.6	25.2	

Statistical Analysis

Grand mean ($<1\mu$ particles)	5.7%
Analytical error ($<1\mu$ particles) (σ_A)	$\pm 0.7\%$ ($\pm 12.3\%$)
Sampling error ($<1\mu$ particles) (σ_S)	Not measured
Grand mean ($1-5\mu$ particles)	92.3%
Analytical error ($1-5\mu$ particles) (σ_A)	$\pm 0.7\%$ ($\pm 0.76\%$)
Sampling error ($1-5\mu$ particles) (σ_S)	Not measured
* Grand mean ($>5\mu$ particles)	2.0%
Analytical error ($>5\mu$ particles) (σ_A)	$\pm 0.3\%$ ($\pm 15\%$)
Sampling error ($>5\mu$ particles) (σ_S)	Not measured
* Grand mean (largest particle)	25.3%
Analytical error (largest particle) (σ_A)	$\pm 11.0\mu$ ($\pm 43.5\%$)
Sampling error (largest particle) (σ_S)	Not measured
* Standard deviation for interaction means ($<1\mu$ particles) was	$\pm 1.5\%$ ($\pm 26.3\%$)
Standard deviation for time means ($<1\mu$ particles) was	$\pm 0.6\%$ ($\pm 10.5\%$)
Standard deviation for temperature means ($<1\mu$ particles) was	$\pm 0.4\%$ ($\pm 7.0\%$)
* Standard deviation for interaction means ($1-5\mu$ particles) was	$\pm 1.8\%$ ($\pm 1.9\%$)
Standard deviation for time means ($1-5\mu$ particles) was	Indeterminate
Standard deviation for temperature means ($1-5\mu$ particles) was	Indeterminate
* Standard deviation for interaction means ($>5\mu$ particles) was	$\pm 0.4\%$ ($\pm 20\%$)
* Standard deviation for time means ($>5\mu$ particles) was	$\pm 0.4\%$ ($\pm 20\%$)
* Standard deviation for temperature means ($>5\mu$ particles) was	$\pm 0.5\%$ ($\pm 25\%$)
* Standard deviation for interaction means (largest particle) was	$\pm 14.8\mu$ ($\pm 58.5\%$)
Standard deviation for time means (largest particle) was	Indeterminate
Standard deviation for temperature means (largest particle) was	$\pm 7.3\mu$ ($\pm 28.8\%$)

Each interaction mean was based on two observations.
 Each time mean was based on ten observations.
 Each temperature mean was based on six observations.
 Each grand mean was based on thirty observations.
 The number in parenthesis is the relative percent error.

* Statistically significant.

particles is $\pm 1.8\%$ and is also statistically significant. For the $>5\mu$ particles the interaction mean is $\pm 0.4\%$ or 20% relative. It is also statistically significant.

In general, the results show that the time and temperature have a significant effect on the distribution for the $>5\mu$ particles and the largest particle.

Dissolution: The grand mean is 82.63% in one hour. The analytical error is $\pm 2.12\%$ and the sampling error is $\pm 0.76\%$. Neither is statistically significant. The standard deviation of the interaction means is $\pm 5.75\%$ or 6.95% relative. For the temperature means the standard deviation is $\pm 8.91\%$ or 10.8% relative. Both are statistically significant. The results for the time and temperature dependence on the rate-of-dissolution are shown in Table X and Figure 4.

The general trend shows that the rate-of-dissolution decreases as the temperature increases. Time does not have any significant effect upon the rate-of-dissolution.

TABLE X. Time and Temperature Dependence Study of the Properties of Plutonium Oxide - Dissolution (% dissolved in one hour).

Solid-to-Liquid Ratio: 250 g/l				
Table of Means				
Temperature ($^{\circ}\text{C}$)	Time (hr)			Temperature Means
	1	4	7	
100	88.43	94.32	87.18	89.98
300	85.94	85.94	94.84	80.91
500	81.33	88.59	92.78	87.57
700	88.38	73.69	76.20	79.42
900	69.88	66.03	65.93	67.28
Time Means	82.79	81.72	83.39	

Statistical Analysis

* Grand mean	82.63%
Analytical error (σ_A)	$\pm 2.12\%$ ($\pm 2.56\%$)
Sampling error (σ_S)	$\pm 0.76\%$ ($\pm 0.92\%$)
* Standard deviation for interaction means was	$\pm 5.75\%$ ($\pm 6.95\%$)
Standard deviation for time means was	Indeterminate
* Standard deviation for temperature means was	$\pm 8.91\%$ ($\pm 10.8\%$)

Each interaction mean was based on four observations.
 Each time mean was based on twenty observations.
 Each temperature mean was based on twelve observations.
 The grand mean was based on sixty observations.
 The number in parenthesis is the relative percent error.

* Statistically significant.

FIGURE 4. The Effect of Time and Temperature on the Rate-of-Dissolution of Plutonium Oxide.