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**AMES
LABORATORY
IOWA STATE
COLLEGE**

HANFORD SLUG PROGRAM SEMI-ANNUAL SUMMARY
RESEARCH REPORT. JULY-DECEMBER, 1955

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U N C L A S S I F I E D

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U N I T E D S T A T E S A T O M I C E N E R G Y C O M M I S S I O N

Semi-Annual

HANFORD SLUG REPORT

July 1 to December 31, 1955

Compiled

by

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1

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TABLE OF CONTENTS

	<u>Page</u>
1. Study of the Alpha, Beta and Gamma Transformations in Uranium.	5
1.1 Temperature-Dependence of the Lattice Parameters of Uranium	5
1.2 Refinement of Lattice Parameters.	6
1.3 Future Work	8
2. Heat Treatment of Uranium.	8
3. Corrosion of Uranium by Liquid Lead and the Rate of Growth of Compound Layers in Solid Lead-Uranium Couples	12
4. Alloy Studies.	14
4.1 Uranium-Zinc System	14
4.2 Zirconium-Zinc System	14
5. Thermal Properties of Metals at High Temperatures.	16
5.1 Thermal Conductivity.	16
5.2 Thermal Diffusivity	17
5.3 Specific Heat	22
6. Engineering Properties of Reactor Materials.	22

HANFORD SEMI-ANNUAL SUMMARY RESEARCH REPORT,

For the period July 1 to December 31, 1955

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Previous research reports in this series are

ISC-287
ISC-314
ISC-346
ISC-389
ISC-426
ISC-452
ISC-486
ISC-507
ISC-532
ISC-576
ISC-609
ISC-641

1. Study of the Alpha, Beta and Gamma Transformations in Uranium.
(P. Chiotti)

This investigation includes a study of the kinetics and mechanism of the alpha, beta and gamma transformations in uranium. The temperature-dependence of the lattice parameters of the three crystalline forms of uranium are being measured. These data will permit an evaluation of the volume changes which take place on transformation. If these data are combined with the values of the lattice parameters at the transformation temperatures, an analytical treatment of these transformations, similar to the mathematical treatment developed by Lieberman, Wechsler and Read,¹ might be possible. An attempt will also be made to determine the kinetics of these transformations and to determine the relative orientations of the phases during the transformation.

1.1 Temperature-Dependence of the Lattice Parameters of Uranium.

The change in lattice parameters as a function of temperature for alpha, beta, and gamma uranium, as determined with a Norelco x-ray diffractometer, has been complicated by carbon contamination. The results previously reported (ISC-641) for gamma uranium (cubic), which were obtained by extrapolation from uranium-zirconium alloys and checked with pure uranium samples, are thought to be reliable, but further checks on pure uranium samples are desirable. The partial or complete masking of the uranium reflections above approximately 700°C by uranium monocarbide reflections has prevented these high temperature checks.

The results previously reported for the alpha and beta phases are in question. The determination of the beta parameters at temperature is complicated not only by surface contamination, but also by the narrow temperature range over which the beta phase is stable, and the difficulty of refining the parameters. The determination of the alpha uranium parameters, although not complicated by sample contamination, is not straightforward because of the difficulty of parameter refinement. The available analytical methods for refinement of parameters for low symmetry phases demand back reflection peaks, i.e., reflections for which the Bragg angle, theta, is greater than 60 degrees. Normally only two or three uranium back reflection peaks are observed using the high temperature diffractometer.

The above described problems demanded special adaptations of the high temperature diffractometer and its vacuum system, as well as an investigation of means for obtaining refined lattice parameters from diffractometer data for low symmetry phases. Partial or complete

¹D. S. Lieberman, M. S. Wechsler and T. A. Read, J. of Appl. Phys. 26, 473 (1955), and J. of Metals 5, 1503 (1953).

masking of uranium reflections above approximately 700°C , due to carbon contamination of the sample surface, has been a serious barrier to the studies underway. Several possible sources of contamination have been considered and steps have been taken to eliminate them.

One possible source considered was the rubber "O" rings used as vacuum seals in the camera. To eliminate this possibility "Teflon" "O" rings were used wherever possible and minor changes were made in the water jacket to permit more efficient cooling of the "O" rings.

Another possible source of carbon contamination considered was oil vapor carry-over from the mechanical and oil diffusion pumps. Following a survey of recent developments in high vacuum techniques, various methods involving changes in cold trap design, the use of gettering material and gettering baffles, were tried on the vacuum system. The most satisfactory change has been the introduction of a chromel hot baffle between the oil diffusion pump and the nitrogen cold trap of the system. This change has allowed other metals, such as pure thorium, to be heated to 1400°C without the presence of thorium monocarbide reflections. Before the introduction of this hot baffle, carbide reflections were observed above 800°C on the same sample of thorium. However, biscuit uranium, heated in the diffractometer system with the hot baffle operating, was still observed to be contaminated with the monocarbide after prolonged heating at 750°C .

A suggested explanation of the uranium contamination is the precipitation of carbide at the sample surface after diffusion from the bulk of the metal. However, an explanation believed to be more probable is that the source of the contamination has not been completely eliminated and failure to detect contamination in the case of thorium and the detection of contamination in the case of uranium, under similar conditions, is due to the differences in the solubilities of the carbides in the metals concerned.

An "Evaporion" high vacuum pump, developed by Consolidated Vacuum Corporation, has a pumping action that is due to electronic ion entrapment and the gettering action of evaporated titanium. This pump has no oil pumping fluid, and metal gasket seals are employed. A pump of this type has been ordered for the high temperature x-ray system and is expected to eliminate sources of carbon from the pumping system as well as making possible the attainment of much lower pressures in the camera.

1.2 Refinement of Lattice Parameters.

The Nelson-Reiley graphical extrapolation of diffractometer data for the lattice constants of cubic phases such as alpha and beta thorium and gamma uranium has been shown to be fairly satisfactory.

However, the analytical treatment of the diffractometer data to obtain refined lattice parameters for the tetragonal beta uranium phase and the orthorhombic alpha uranium phase has caused considerable difficulty.

Cohen's analytical treatment of x-ray diffraction errors is applicable to tetragonal and orthorhombic lattices, but as originally developed, the method applies only to reflections for which the Bragg angle, theta, is greater than 60 degrees. Consideration of the diffractometer camera geometry and the fact that massive samples are used indicates that the largest error in the data is the eccentricity error. This error arises from the displacement of the sample from the goniometer axis. Mathematical analysis gives the form

$$\Delta d = K \left(\frac{1}{\sin^2 \theta} - 1 \right)$$

for the eccentricity correction term for the diffractometer. Empirically a plot of Δd versus $\left(\frac{1}{\sin^2 \theta} - 1 \right)$ (using both front and back

reflection data) for cubic samples purposely displaced from the center of the diffractometer, gives a linear extrapolation to zero error. It follows from the relation given above that the appropriate form of the error term in the Cohen method applied to diffractometer data should be

$$\delta = \cos^2 \theta \sin \theta.$$

Refinements using this error term give values for the lattice parameters of alpha uranium in good agreement with values determined by other methods. The room temperature lattice parameters for alpha uranium, as determined by a standard back reflection camera and by the modified high temperature Norelco x-ray diffractometer, are given in Table I. Jacob and Warren's values are also given for comparison.

Table I

Alpha Uranium Room Temperature Lattice Constants

Jacob and Warren Debye-Scherrer Powder Data	Back Reflection Powder Data $\theta > 60^\circ$; $\delta = \theta \sin \theta$	Diffractometer Data, Massive Sample, $\theta > 17^\circ$; $\delta = \cos^2 \theta \sin \theta$
$a_0 = 2.852$	2.854 ₃	2.852 ₆
$b_0 = 5.865$	5.864 ₁	5.868 ₂
$c_0 = 4.945$	4.957 ₅	4.948 ₉

The most recent data on the alpha uranium lattice parameters as a function of temperature are shown graphically in Figures 1, 2 and 3. These data were taken on a sample of massive biscuit uranium with the high temperature diffractometer, and the experimental and analytical refinements described above were employed. More samples will be run to substantiate these results.

1.3 Future Work.

A new "Evaporion" pump will be installed on the high temperature diffractometer system. The study of the change of lattice parameters as a function of temperature for the alpha, beta, and gamma uranium phases will be completed. The kinetics of the uranium transformations will be studied by employing rapid x-ray diffractometer scanning at the temperatures of the transformations and by resistivity measurements.

2. Heat Treatment of Uranium (O. N. Carlson)

During the period covered by this report, a comprehensive investigation of the heat treatment of uranium has been initiated. The effect of heat treatment upon the physical properties of uranium metal is being studied. Variations in rates of heating and cooling, the temperature attained and time at temperature during treatment, the impurities in the metal, the size and shape of the specimen, and the prior fabrication history of the uranium are factors which may affect the final condition of the heat treated specimen. This investigation has as its objective a determination of the effect of these factors upon such properties as grain size, hardness, degree and type of preferred orientation, dimensional stability and mechanical properties.

In studying the effect of metal quality and prior fabrication history, for example, heat treating experiments will be carried out on high purity electrolytic uranium in the form of swaged rods and on commercial uranium in the form of alpha rolled, gamma extruded and as-cast rods.

An apparatus has been designed and is being constructed which will permit wide variations in both heating and cooling rates as well as in sample size and shape. Where possible, the specimen will be heated by passing current directly through the specimen. The equipment is designed to permit direct resistance heating with rods up to 1 inch in diameter. If larger rods are desired, a higher current source will be required, or a graphite heating element may be inserted between the electrodes to heat the rods.

With this apparatus a vapor quench may be used in which a helium jet, which has been cooled in liquid nitrogen, is impinged on the heated sample. This should give a very rapid rate of cooling with

9

Figure 1 - Temperature-Dependence of a_0 for Alpha Uranium

Figure 2 - Temperature-Dependence of b_0 for Alpha Uranium

Figure 3 - Temperature-Dependence of c_0 for Alpha Uranium

resulting suppression of the uranium transformation temperatures. In addition to this more drastic quenching method, the more conventional technique, whereby the sample is dropped into water or molten salt, may also be employed in the new apparatus. It has been necessary, therefore, to construct electrodes which clamp tightly about the bar but which may be released by means of a solenoid valve at the desired instant.

The furnace and quenching chamber can be evacuated to pressures lower than 10^{-6} micron.

A few preliminary experiments have been performed on an alpha rolled rod which was $1\frac{1}{2}$ inch in diameter and 4 inches in length. The purpose of these experiments was to determine quantitatively the rates of heating and cooling and the temperature gradients existing in a uranium rod of this size during an induction heat treatment and a water quench. Two chromelalumel thermocouples were placed in the specimen, one at the center of the rod and one on the periphery. These were connected in a differential circuit to the X_1 scale of a Speedomax X-X recorder and the thermocouple in the center was connected to the X_2 scale. The rod was heated by self induction, using a mercury arc converter at a heating rate of approximately 250° per minute, into the gamma region at a power input of about 20 kW. An appreciable temperature difference between the outer edge and the center was observed, but the exact analysis of this differential has not been completed.

During quenching the specimen was plunged into water with the thermocouples still attached to the sample. The temperature of the uranium rod dropped from above 750°C to below 100°C in 10 to 15 seconds. Both transformation temperatures were slightly depressed and a temperature gradient of greater than 150° was observed between the outer edge and the center, with the center, of course, being the hotter region. More sensitive temperature recording equipment and better insulation of the thermocouple junctions from the quenching medium are now being developed.

3. Corrosion of Uranium by Liquid Lead and the Rate of Growth of Compound Layers in Solid Lead-Uranium Couples (P. Chiotti)

The purpose of the investigation was to determine the rate at which uranium is corroded by molten lead under static conditions and to determine the rate of interpenetration of these two components in the solid state. Since lead has been considered as a possible component in composite protective coatings for uranium, it is desirable to know the behavior of lead in contact with uranium.

Two compounds are formed in the lead-uranium system, UPb_3 and UPb_2 ,² the latter being pyrophoric. Neither of the two compounds shows much resistance to corrosion in boiling water.

²J. T. Maskrey and B. R. T. Frost, The System Uranium-Lead, Atomic Energy Research Establishment Report, No. A.E.R.E. M/R 1027 (1952).

To obtain adequate wetting of the uranium by the lead, the uranium samples were degreased, and etched in HNO_3 , then dipped in a molten KCl-LiCl eutectic + ZnCl_2 salt flux for a short period of time. The samples were then suspended in the molten lead at different temperatures for various periods of time. This procedure did not produce diffusion bands that could be measured. The lead-uranium compounds, formed by reaction with the lead, scaled off into the bath and no diffusion bands were observed.

Uranium samples ($2'' \times 1/4'' \times 1/8''$), with two sides milled parallel to ± 0.0002 inches, were prepared, and the width of each sample was accurately measured by a microscope equipped with a micrometer stage and filar eye piece. Measurements were made prior to dipping and again after the sample had been suspended in the lead. The decrease in thickness due to the corrosion of the uranium by the lead was thus determined. The rates at three temperatures were investigated. The lead bath was not agitated during the time the samples were suspended in the lead. Table II lists the results obtained at each temperature. The data obtained show a decrease in corrosion rate with an increase in time. The reason for this behavior is uncertain. One might suspect the formation of a concentration gradient of uranium in the lead at the uranium-lead interface. However, the solubility of uranium in lead at the temperatures investigated is believed to be slight.

Samples for determining the growth of reaction bands in the solid state were prepared as described above. Each sample was dipped in molten lead for 1 minute at $450-475^\circ\text{C}$ to insure complete wetting by the lead. They were then submerged in molten lead contained in a small graphite crucible and immediately quenched in water. The graphite crucible was removed, leaving the uranium sample encased in solid lead. A section was then cut off and the remaining piece was sealed in pyrex under an atmosphere of helium. Twenty samples were prepared in this way and heated at 200 , 250 , and 300°C . Samples were removed after 350 hours, 600 hours, and 1100 hours. They were sectioned, polished, etched and examined under a microscope at magnifications up to $500\times$. In all of the samples that were examined, no well defined diffusion band was observed. The lead was still well bonded to the uranium. It may be concluded from these observations that the rate of growth of compound layers at the uranium-lead interface is very slow at temperatures up to 300°C .

Some preliminary observations with this couple had indicated the formation of a reactive friable material at the uranium-lead interface as previously reported in ISC-641. No evidence of this was observed in the above experiments. The primary difference in procedure was that greater precautions were taken in the more recent work to exclude air from the samples during the heat treatment. No further work is contemplated on this problem.

Table II

Corrosion of Uranium by Liquid Lead

Temperature °C	Time in Bath (min)	Loss of Uranium on one side (cm)	Av.. Corrosion Rate cm/sec x 10 ⁷
350	60	1.38 x 10 ⁻³	3.84
"	150	1.82 "	2.04
"	260	2.76 "	1.77
"	300	4.97 "	2.76
"	390	3.96 "	1.70
"	660	6.67 "	1.68
"	660	7.36 "	1.86
"	1140	13.80 "	2.04
450	30	1.61 "	8.95
"	60	2.53 "	7.03
"	90	3.30 "	6.12
"	270	5.80 "	3.38
"	270	6.78 "	4.18
"	1230	13.34 "	1.81
600	37	1.27 x 10 ⁻²	57.2
"	100	2.05 "	34.2
"	120	2.43 "	33.8
"	120	2.47 "	34.3
"	150	3.17 "	35.2
"	240	5.87 "	40.8
"	360	6.34 "	29.4
"	420	10.39 "	39.6

4. Alloy Studies (P. Chiotti)

4.1 Uranium-Zinc System.

Work on this system has been completed and the results are summarized in Report ISC-656.

4.2 Zirconium-Zinc System.

Work on the Zr-Zn phase diagram was continued during this report period. Thermal, x-ray, and diffusion band analyses from previous work had indicated that the system contained four compounds.

Approximate zinc to zirconium ratios of ZrZn_{15} , ZrZn_6 , ZrZn_2 and ZrZn have been assigned to the four compounds. It was believed that the two highest zinc compounds decompose peritectically at 550° and 750°C , respectively, and a decomposition temperature somewhat above 1050°C has been proposed for the ZrZn phase. Recent work has produced no evidence to indicate these temperatures are not substantially correct. However, a proposed peritectic decomposition for the ZrZn_2 phase at 850°C does not appear substantiated. Vapor pressure measurements, which will be discussed subsequently, and older thermal analysis results indicate the compound may decompose about 900°C or higher.

4.2.1 Vapor Pressure Measurements.

It was decided to employ the rather volatile properties of zinc to advantage by taking vapor pressure measurements to help establish the phase boundaries. A dew point method for determining vapor pressures as described in previous reports was used. By observing the temperature of the alloy and the temperature at which zinc begins condensing on a cooled area above the alloy, the vapor pressure of the zinc over the alloy can be determined from the known vapor pressure of pure zinc.

Plots of $\log$ Vapor pressure vs. $1/T$ were made for various alloy compositions. The boiling points of the alloys could then be determined. Phase changes or peritectic decompositions were made evident by discontinuities in the slopes of the plots. Table III gives a summary of boiling points and slope change temperatures. Especially noteworthy was the large drop in vapor pressure for alloys containing over 41% Zr. This would indicate (at least under the closed conditions in which the measurements were made) that the ZrZn_2 phase does not decompose peritectically until considerably above 900°C and might possibly melt congruently at one atmosphere pressure.

4.2.2 Diffusion Band Investigations.

Attempts were made to substantiate or refute the proposed compositions of the one phase regions and obtain possible information regarding any solid solubility regions by studying the diffusion bands formed between pure zinc and pure zirconium. Methods involving radioactive tracers did not yield any positive results, although information on the requirements and limitations of such investigations was gained. A radioactive zirconium isotope, ^{90}Zr , was used in the investigations. Both film and counting techniques were used in an attempt to obtain the zirconium concentrations of the bands. In both cases the results indicated that the radiation from adjoining regions was obscuring the differences in radioactivity of the individual bands. Use of a suitable slit system in conjunction with a Geiger counter appeared to hold some promise, but no conclusive results were obtained.

Table III

Vapor Pressure of Zirconium-Zinc Alloys

Alloy Composition (%Zr)	Temp. at which Zinc Pressure Equals One Atm. (°C)	Temp. of Observed Change in Slope of Log P vs. T Curves
1.08	910°C	none
4.0	914	none
8.74	915	750
9.0	915	?
12.0	916	760?
15.0	921	780 760
23.73	921	890
24.7	921	749 736
41.0	921	898
44.0	1004	none
46.0	1000	none

5. Thermal Properties of Metals at High Temperatures (G. C. Danielson)

The purpose of the research project on the thermal properties of metals is to develop techniques and equipment for measuring the thermal conductivity (K), thermal diffusivity (k), and specific heat (c) of metals in the temperature range 20-1000°C, and to make these measurements on metals of interest to the Atomic Energy Commission.

5.1 Thermal Conductivity

In view of the difficulties at high temperatures which were mentioned in the previous Hanford Report, ISC-641, no direct thermal conductivity measurements were made during this report period. Present indications are that a somewhat different approach must be made before reliable thermal conductivity measurements can be made at temperatures in excess of 500°C.

5.2 Thermal Diffusivity.

The apparatus for measuring thermal diffusivity continues to operate satisfactorily. The thermal diffusivity of Armco iron and additional data on uranium are reported.

The thermal diffusivity of Armco iron from room temperature to 1000°C is shown in Figure 4. These results exhibit what is considered to be typical behaviour at both the Curie point at 780°C and the phase transformation at 910°C. The thermal conductivity (K) of Armco iron calculated from this diffusivity (k) data, the specific heat (c) data of Darkin and Smith³ and a density (d) of 7.867 gm/cm³ using the relation $K = kcd$, is shown in Figure 5 by the circled points and by the solid line. The points⁴ indicated by triangles in Figure 5 are those obtained by Powell⁴ for Armco iron by direct thermal conductivity measurements. The excellent agreement indicates that the techniques used in measuring thermal diffusivity are valid in this temperature range.

One of the significant features of the thermal diffusivity data shown in Figure 4 is the sharp minimum at the Curie point. Since the specific heat exhibits a nearly equal maximum at the Curie point, the thermal conductivity which is calculated from the diffusivity and specific heat data exhibits nothing more than a change in slope, a situation which has been shown to exist at the Curie point for nickel⁵ but which is not so clearly indicated for iron. The thermal conductivity data reported by Powell for Armco iron does not clearly indicate whether the change in slope occurs at the Curie point or at the $\alpha - \gamma$ phase change which occurs at a somewhat higher temperature. However, the electrical conductivity reported for iron,⁶ which should show a similar behavior, seems to indicate that the change in slope does occur at the Curie point. It is also significant that at the phase transition at 910°C, the thermal diffusivity and the specific heat are discontinuous by equal and opposite amounts, resulting in a continuous thermal conductivity through the phase transition as Powell's data indicates. The discrepancy between Powell's conductivity data and the thermal conductivity calculated from diffusivity and specific heat data in the region just below the Curie point is probably due to the fact that the specific heat data used in the calculation is that reported

³L. S. Darkin and R. P. Smith, Ind. Engr. Chem. 43, 1815 (1951).

⁴R. W. Powell, Proc. Roy. Soc. 51, 407 (1939).

⁵M. S. Van Dusen and S. M. Shelton, Bur. Stds. J. Res. 12, 429 (1934).

⁶H. E. Cleaves and J. G. Thompson "The Metal Iron" McGraw-Hill Book Co., N. Y. (1935) p. 188.

Figure 4 - Temperature Dependence of the Thermal Diffusivity of Armco Iron

Figure 5 - Temperature Dependence of the Thermal Conductivity of Armco Iron

for pure iron. Specific heat data for Armco iron is not available. However, for the ferromagnetic metals it is reasonable to expect that the effect of small differences in impurity content would be most prominent in the region just below the Curie point where the specific heat is abnormally large.

Additional measurements of the thermal diffusivity of uranium have been made. The results of these measurements, numbered in the order in which they were obtained, are shown in Figure 6. Before making measurements in either the α -, β -, or γ -phase, the sample was annealed for one hour at whichever of the temperatures 625, 700 or 850°C was appropriate. Small segments of the sample were removed periodically for grain size determinations.

After annealing for 1 hour at 625°C, the results shown in curve 1 (Figure 6) were obtained and the sample was allowed to cool to room temperature. At room temperature a section was removed for grain size determination. The average grain diameter was found to be about 0.03 mm. The sample was then heated and one measurement made in the high α -phase region. This result was in excellent agreement with the previously obtained α -phase data, indicating that the excursion back to room temperature had not appreciably altered the sample. The sample was then β -annealed at 700°C for one hour and the results shown by curve 2 (Figure 6) were obtained. The sample was cooled to room temperature and another section removed for grain size determination. The sample was then α -annealed and the α -phase results shown by curve 3 (circle points, Figure 6) were obtained.

It is known that grain growth is rapid in the β -phase and the sample was now found to be very large grained, some of the grains extending entirely across the sample. The observed decrease in diffusivity following the β -anneal is not consistent with the observed increase in grain size, suggesting that some mechanism other than grain growth is responsible. Possibly the true explanation involves the large anisotropy of uranium and its tendency to become oriented in some preferred direction. It is quite possible that during the β -anneal and the subsequent transformation to the α -phase, the crystals in the sample became more oriented in a direction of low diffusivity, resulting in the decrease in diffusivity which was observed. Electrical conductivity measurements will be made to determine whether a similar decrease is observed in the electrical conductivity of uranium which has had the same thermal treatment.

Existing thermal conductivity (K), specific heat (c) and density (d) data together with the relation $K = kcd$ permit a consideration of the behavior that should be expected at the transformation temperature. From these considerations the thermal diffusivity is expected

ISC-709

Figure 6 - Temperature Dependence of the Thermal Diffusivity of Uranium

to decrease slightly just prior to the transformation and then show a discontinuous increase of about 14%. The general features of the β -phase data in curve 2 and the α -phase data in curve 3 are consistent with the behavior to be expected. If the decrease in thermal diffusivity following β -anneal is to be attributed to an increase in the number of grains oriented in the direction of low diffusivity, then this increase in number must have occurred upon annealing in the β -phase, with the number of grains so oriented remaining essentially unchanged during both the β -phase and the α -phase diffusivity measurements.

The same sample was then taken into the β region, the γ region and back to the β region and the data shown by curves 4, 5 and 6 (Figure 6) were obtained. Since these measurements were made on only one sample and since it is quite evident that this sample was not stable from a metallurgical point of view, an interpretation of the behavior in these regions is not possible at this time. Prior to making additional measurements, attempts will be made to increase the stability of the sample.

The sample was then cooled to room temperature and another section removed for grain size determination. The grain size remained essentially the same as that following the initial β -anneal. The α -phase data shown by curve 7 (triangle points, Figure 6) was then obtained. It is significant to note that the α -phase diffusivity is the same as that previously obtained following only β -anneal. This indicates that the excursion into the γ -phase had essentially no effect on either the grain size or the degree of preferred orientation if the decreased diffusivity is interpreted to be the result of this mechanism. Much additional work remains to be done to adequately interpret the high temperature thermal behavior of uranium.

5.3 Specific Heat.

Several major revisions are being made in both the apparatus and the technique of the pulse heating method for measuring specific heats of metals. These revisions were suggested by the previously reported measurements on platinum and nickel and are designed to improve the reliability and accuracy of the measurement. Details of the method and technique will be reported at a later date.

6. Engineering Properties of Reactor Materials (G. Murphy)

The objective of our investigations in this field is to develop a better understanding of the behavior of materials under load in order to predict their performance in engineering applications and to assist in solving some current operating problems in reactors,

This investigation is of interest to the AEC because the engineering properties of materials, as well as their nuclear properties, must be known before these materials can be used in reactors. New materials, new conditions of operation, and extensions of present limits of temperature, pressure, etc., all require a better understanding of the factors by which properties can be controlled.

During the past six months work in this field has included the following projects:

a. Continuation of the evaluation of slug metals with the objective of improving their performance. Static and repeated loading tests at various temperatures have been made on materials that indicate some potential value as slug metals.

b. Basic studies of strain hardening in metals. The strain response to slowly applied repeated and alternating loads, in tension and compression, has been studied for uranium and some alloys. The directional aspects of the strain hardening, and its effects upon such properties as the modulus of elasticity are under investigation. Some preliminary findings are given in Report ISC-700.

c. Basic studies on fatigue. Attention is being given to the effects of high temperature and high stress upon the fatigue properties of metals and of uranium, in particular. Six new high temperature fatigue machines have been designed and were built during this period. These will be of material assistance in extending the range of the investigation.

d. Creep tests of thorium. The creep tests of thorium, started several years ago, are being continued.

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