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SOME OBSERVATIONS ON THE
ELECTRON METALLOGRAPHY OF URANIUM

RELEASED FOR ANNOUNCEMENT
IN NUCLEAR SCIENCE ABSTRACTS

August 1, 1966

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Federal Scientific and Technical Information, National Bureau of
Standards, U. S. Department of Commerce, Springfield, Virginia

MCW-1501

UC-25, Metals, Ceramics, and Materials
(TID-4500, 48th Edition)

COST PRICE

TOPICAL REPORT

H.C. \$3.00; MM 75

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H. C. Kloepper, Jr.

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Mallinckrodt Chemical Works
Uranium Division
Weldon Spring, Missouri

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ABSTRACT

In this report, metallographic techniques are described that are necessary in the preparation of thin-foil specimens of uranium metal that are suitable for study at high magnification with the transmission electron microscope. Also discussed are the relationships between structure revealed in electron microscopy and x-ray diffraction data generated from the same area by the electron beam. Appropriate interpretation of such data permits the identification of the orientation of the matrix lattice and the determination of the crystallographic sites at which dislocations accumulate and precipitates originate. The procedures also reveal the shape and orientation of precipitate particles within the matrix. Application of these techniques to three beta-quenched, alpha-annealed U-Si alloys disclosed that precipitation of U_3Si did not occur within reasonable annealing times at 500°C or less but that precipitation readily took place at dislocation sites when annealed at 600°C, the number and size of particles increasing with annealing time. The U_3Si particles were needle-shaped with a preferred orientation to the uranium matrix. Other studies of structures of a U-Si alloy after tensile testing indicated that the deformation at room temperature was by twinning whereas at 500°C the metallic flow was mainly by slip.

SOME OBSERVATIONS OF THE ELECTRON METALLOGRAPHY OF URANIUM

by

H. C. Kloepper, Jr.*

INTRODUCTION

The long range object of this work was to investigate the effect of solid-solution alloys, of two-phase alloy systems, and of strain rate on the stress necessary to initiate and continue dislocation movement in uranium structures, since this has been postulated to be intimately connected with tendencies for irradiation growth. Since the formation, habit, and stability at elevated temperatures of second-phase particles have been believed to be important in influencing dislocation movement and therefore a factor contributing to the stability of a fuel element under irradiation, a study of such characteristics of uranium alloys was scheduled with the electron microscope. Uranium-silicon alloys were chosen for the first study since they had shown the most promise in resisting grain-boundary tearing during irradiation.

The short range prerequisite for this work was to acquire a familiarization with the techniques of sample preparation, microscope calibration and manipulation, and with the crystallography and crystallographic manipulations necessary to undertake the long-range objectives briefly outlined above. This paper will primarily be concerned with experimental techniques although several examples of preliminary findings relating to the longer-range objectives will be reported.

TECHNIQUES IN ELECTRON MICROSCOPY

Sample Preparation

The description of specimen preparation for this work will deal with the preparation of thin sections from bulk samples derived from heat-treated fuel core sections from portions of tensile test specimens. The reason for this lies in the hope of correlating the electron microscope observations with bulk properties.

Slices 10-20 mils thick should be cut from bulk specimens using a 1/32-inch-thick 60 grit silicon carbide wheel. The sample should be generously flooded with water and cutting should be performed slowly to minimize any heating from the abrasive action. The thickness of the rough specimen should be measured

*Now associated with Mallinckrodt Chemical Works, St. Louis, Missouri.

so that the grinding and polishing sequences may be adjusted to yield a final foil specimen from the center of the original sample. The slice should then be sealed to a 1 1/4-inch-diameter stainless steel mount with Fisher High Temperature Seating Cement and the thickness of the combined specimen and mount measured.

A group of such stainless steel mounts may be put into the holder of a Buehler Automet polisher. The specimens should be ground wet on successively finer grit silicon carbide papers starting with 180 grit paper and finishing with 600 grit paper. Grinding times should be adjusted to remove a layer approximately 2 mils less than half of the specimen thickness. The specimen should then be polished on an AB Microcloth covered wheel charged with Linde A and chromic acid and finally on an AB Microcloth covered wheel charged with Linde B and chromic acid. If optical photo-micrographs are to be obtained, the sample may be electropolished and photographed at this point.

After photographing, the specimen and mount should be immersed in benzene to dissolve the cement holding the specimen to the mount. The thickness of the cleaned specimen should then be carefully measured and the polished face of the specimen cemented to the mount and the specimen and mount thickness again measured. The grinding and polishing steps should then be repeated. This time, however, the grinding should be continued until the specimen is 4 mils thick. As a quick visual guide to the specimen thickness remaining, the sample mounts have been provided with a 5-mil depression in the center. Thus when metal begins to be removed from the edges of the mount, it is time to check the specimen thickness carefully and then continue grinding cautiously until the desired thickness value is reached.

The polished specimen should then be removed from the holder, thoroughly cleaned, and finally sectioned into a number of 1/8-inch-diameter disks with a specimen screen punch. The disks may be prepared for electrolytic thinning by securing each in turn in a clamping type stainless steel tweezer. Before thinning can proceed, the edges and one side of the specimen as well as the tip of the tweezer should be coated with lacquer and allowed to dry thoroughly. Polystyrene pellets dissolved in benzene makes a suitable stop-off lacquer.

A sample may then be thinned electrolytically using a modification of the thinning technique of J. O. Stiegler for copper specimens devised at the Oak Ridge National Laboratory. The apparatus may consist of a glass flask similar in construction to a wash bottle. In the exit tube a platinum wire should be sealed and beyond this the tube should be constricted to form a nozzle. The electrolyte should be forced through a 20-mil opening in the nozzle under about 1 to 2 psi of air pressure. The electrolyte stream completes the electric circuit between the platinum cathode and the uranium anode, which should be at 80 volts potential under open circuit conditions. The electrolyte should consist of 75 g. of CrO_3 dissolved in 42 ml. of water and 400 ml. of glacial acetic acid and may be used at temperatures up to room temperature.

The action of the small stream of electrolyte should be such that a dimple will be formed where the stream hits the uranium surface. The sample may be dimpled from one or from both faces of the specimen. If both faces are to be dimpled, only the edges of the specimen need to be lacquered. The dimpling procedure should continue until a small hole in the sample appears. At this point the thinning should immediately be stopped and the sample thoroughly rinsed as quickly as possible.

After cleaning away the stop-off lacquer with benzene, the specimen should be rinsed with acetone and dried. The specimen should then be cleansed of oxide electrolytically, using a solution consisting of 75 ml. of sulfuric acid, 7 ml. of water and 18 ml. of glycerin at 35° to 40° F. An open-circuit potential of 10 volts should be used between the platinum cathode and the specimen. Since transfer time to the microscope after cleaning is especially critical to minimize reoxidation, stop-off lacquer should not be used. Instead, the edge of the sample should be held gingerly between the tweezers connected to the power supply. The sample should be immersed in the electrolyte only far enough for the surface tension to cause the dimple to be covered but not the tweezers. A green film will quickly form on the specimen, indicating that the cleaning action has commenced. The specimen may be immersed for as much as 30 seconds after the green film appears without excessive loss of specimen area. The specimen should be removed from the electrolyte with the current on and quickly plunged into water and agitated to minimize chemical attack. The sample should first be quickly washed with water and then with alcohol, drying thereafter with a blast from a Freon gas duster. The specimen should then be placed immediately in the sample holder and transferred to the microscope. There is no need to place the specimen on a copper grid as the dimpled specimen is capable of supporting itself. If removal of oxide was not complete or if oxidation has occurred in the microscope, the specimen should be cleaned again. Only a limited number of cleanings are possible, however, before excessive loss of thin-foil area occurs.

Calibration of the Electron Microscope

In order to use effectively transmission electron microscopy as a tool for the study of metallic structure, the microscope must be calibrated for magnification, rotation, and diffraction. Magnification calibration is necessary to determine accurately the size of all features observed in electron micrographs and may be conveniently determined with a replica from a 15000-line-per-inch diffraction grating.

Rotation and diffraction calibrations are especially important as these two permit the correlation of features in the photomicrograph with crystal orientations. Rotation calibration may be easily accomplished using sublimed MoO_3 crystals. These crystals grow as thin, long, flat needles such that the long dimension is the [100] direction, the width is the [001] direction and the thickness is the [010] direction. By photographing a crystal at various magnification and superimposing the selected area diffraction pattern, one can

measure the angle between the [100] direction in the crystal and the [100] direction in the diffraction pattern. This angle will vary with the magnification.

Diffraction calibration can be combined with the magnification calibration if the replica is shadowed with gold, platinum or other heavy metal. Diffraction patterns can be obtained from this replica and the appropriate diffraction constants calculated from the measured lines on the photographic plate.

Crystallographic Data

In order to interpret the data that are available in the micrographs and the corresponding diffraction patterns, recourse must be made to the crystallography of the materials being investigated. It is convenient to have stereographic projections, and tables of d spacings and interplanar angles for the materials involved. Since not all of these were available or in a complete enough form to be useful, calculations have been compiled for a number of crystal properties of uranium and U_3Si .

Tables I and II list the d spacings for alpha-uranium at 25°C using the lattice constants²: $a_0 = 2.8545 \text{ \AA}$, $b_0 = 5.8681 \text{ \AA}$, and $c_0 = 4.9566 \text{ \AA}$. Table I presents the reflections in hkl order while Table II lists them in d spacing order. All hkl's from 001 to 999 were calculated without regard for extinctions. This was done since many forbidden reflections often occur in very thin sections of uranium for a variety of reasons. The calculations were made using the formula for orthorhombic symmetry,

$$\frac{1}{d^2} = \left(\frac{h}{a}\right)^2 + \left(\frac{k}{b}\right)^2 + \left(\frac{l}{c}\right)^2,$$

may be found in Appendix III of The Structure of Metals by Barrett.³

Tables III and IV list the d spacings calculated for the tetragonal cell of U_3Si using the lattice constants $a_0 = 6.0290 \text{ \AA}$ and $c_0 = 8.6963 \text{ \AA}$, which were calculated from the kX units given by Zachariasen.⁴ Again, all hkl's were calculated without regard for possible extinctions. The list has been abbreviated, however, since in the tetragonal lattice h and k may be interchanged while the d spacing remains the same. Table III presents the d spacings for U_3Si in hkl order while Table IV lists them in order of d spacing.

The angle, ϕ , between two crystal plans $(h_1k_1l_1)$ and $(h_2k_2l_2)$ may be determined for orthorhombic, tetragonal and cubic symmetry by using the formula quoted by Barrett³:

$$\cos \phi = \frac{\frac{h_1 h_2}{a^2} + \frac{k_1 k_2}{b^2} + \frac{l_1 l_2}{c^2}}{\sqrt{\left(\frac{h_1^2}{a^2} + \frac{k_1^2}{b^2} + \frac{l_1^2}{c^2}\right) \left(\frac{h_2^2}{a^2} + \frac{k_2^2}{b^2} + \frac{l_2^2}{c^2}\right)}}$$

Table I

Interplanar Spacings, d_{hkl} , in Angstroms for Alpha-Uranium at 25°C
 Arranged in (hkl) Order
 (without regard for extinctions, using $a_0 = 2.8545 \text{ \AA}$,
 $b_0 = 5.8681 \text{ \AA}$, and $c_0 = 4.9566 \text{ \AA}$)

<u>(hkl)</u>	<u>d_{hkl}</u>	<u>(hkl)</u>	<u>d_{hkl}</u>	<u>(hkl)</u>	<u>d_{hkl}</u>	<u>(hkl)</u>	<u>d_{hkl}</u>
001	4.95660	025	0.93916	050	1.17362	075	0.64011
002	2.47830	026	0.79518	051	1.14204	076	0.58841
003	1.65220	027	0.68832	052	1.06070	077	0.54094
004	1.23915	028	0.60621	053	0.95680	078	0.49826
005	0.99132	029	0.54128	054	0.85210	079	0.46029
006	0.82610	030	1.95603	055	0.75731	080	0.73351
007	0.70809	031	1.81948	056	0.67553	081	0.72561
008	0.61958	032	1.53541	057	0.60628	082	0.70335
009	0.55073	033	1.26219	058	0.54791	083	0.67041
010	5.86810	034	1.04678	059	0.49857	084	0.63121
011	3.78657	035	0.88424	060	0.97802	085	0.58965
012	2.28304	036	0.76101	061	0.95952	086	0.54850
013	1.59036	037	0.66580	062	0.90974	087	0.50944
014	1.21241	038	0.59065	063	0.84162	088	0.47332
015	0.97747	039	0.53012	064	0.76771	089	0.44041
016	0.81803	040	1.46703	065	0.69622	090	0.65201
017	0.70299	041	1.40670	066	0.63110	091	0.64644
018	0.61615	042	1.26243	067	0.57355	092	0.63055
019	0.54832	043	1.09699	068	0.52339	093	0.60649
020	2.93405	044	0.94664	069	0.47988	094	0.57701
021	2.52485	045	0.82137	070	0.83830	095	0.54474
022	1.89329	046	0.71982	071	0.82656	096	0.51180
023	1.43964	047	0.63769	072	0.79410	097	0.47964
024	1.14152	048	0.57076	073	0.74758	098	0.44913
		049	0.51560	074	0.69434	099	0.42073

Table I contd.

$(hk\ell)$	$d_{hk\ell}$	$(hk\ell)$	$d_{hk\ell}$	$(hk\ell)$	$d_{hk\ell}$	$(hk\ell)$	$d_{hk\ell}$
100	2.85450	125	0.89212	150	1.08546	175	0.62460
101	2.47362	126	0.76602	151	1.06033	176	0.57629
102	1.87140	127	0.66915	152	0.99427	177	0.53148
103	1.42995	128	0.59298	153	0.90719	178	0.49084
104	1.13667	129	0.53180	154	0.81650	179	0.45442
105	0.93646	130	1.61355	155	0.73199	180	0.71043
106	0.79354	131	1.53430	156	0.65737	181	0.70324
107	0.68726	132	1.35221	157	0.59306	182	0.68293
108	0.60548	133	1.15437	158	0.53809	183	0.65265
109	0.54076	134	0.98278	159	0.49113	184	0.61632
110	2.56691	135	0.84465	160	0.92522	185	0.57746
111	2.27938	136	0.73533	161	0.90951	186	0.53864
112	1.78293	137	0.64840	162	0.86678	187	0.50152
113	1.38929	138	0.57840	163	0.80726	188	0.46695
114	1.11593	139	0.52121	164	0.74136	189	0.43526
115	0.92475	140	1.30479	165	0.67639	190	0.63564
116	0.78638	141	1.26181	166	0.61621	191	0.63048
117	0.68259	142	1.15455	167	0.56231	192	0.61571
118	0.60228	143	1.02398	168	0.51481	193	0.59325
119	0.53848	144	0.89852	169	0.47324	194	0.56557
120	2.04598	145	0.78935	170	0.80433	195	0.53509
121	1.89120	146	0.69797	171	0.79395	196	0.50377
122	1.57778	147	0.62235	172	0.76505	197	0.47301
123	1.28541	148	0.55968	173	0.72319	198	0.44368
124	1.05991	149	0.50739	174	0.67466	199	0.41623

Table I contd.

$(hk\ell)$	$d_{hk\ell}$	$(hk\ell)$	$d_{hk\ell}$	$(hk\ell)$	$d_{hk\ell}$	$(hk\ell)$	$d_{hk\ell}$
200	1.42725	225	0.78455	250	0.90650	275	0.58406
201	1.37152	226	0.69465	251	0.89171	276	0.54399
202	1.23681	227	0.61999	252	0.85134	277	0.50583
203	1.08006	228	0.55796	253	0.79474	278	0.47042
204	0.93570	229	0.50611	254	0.73163	279	0.43807
205	0.81419	230	1.15295	255	0.66897	280	0.65240
206	0.71497	231	1.12297	256	0.61059	281	0.64682
207	0.63431	232	1.04537	257	0.55802	282	0.63090
208	0.56833	233	0.94550	258	0.51151	283	0.60680
209	0.51381	234	0.84409	259	0.47068	284	0.57728
210	1.38682	235	0.75168	260	0.80677	285	0.54497
211	1.33553	236	0.67152	261	0.79630	286	0.51199
212	1.21022	237	0.60338	262	0.76715	287	0.47980
213	1.06222	238	0.54576	263	0.72496	288	0.44926
214	0.92402	239	0.49695	264	0.67610	289	0.42083
215	0.80647	240	1.02299	265	0.62574	290	0.59306
216	0.70972	241	1.00188	266	0.57719	291	0.58886
217	0.63064	242	0.94560	267	0.53218	292	0.57677
218	0.56569	243	0.86977	268	0.49139	293	0.55819
219	0.51185	244	0.78889	269	0.45486	294	0.53495
220	1.28345	245	0.71190	270	0.72284	295	0.50894
221	1.24248	246	0.64271	271	0.71527	296	0.48177
222	1.13969	247	0.58222	272	0.69392	297	0.45466
223	1.01357	248	0.52996	273	0.66223	298	0.42842
224	0.89146	249	0.48493	274	0.62437	299	0.40356

Table I contd.

$(hk\ell)$	$dhk\ell$	$(hk\ell)$	$dhk\ell$	$(hk\ell)$	$dhk\ell$	$(hk\ell)$	$dhk\ell$
300	0.95150	325	0.66841	350	0.73911	375	0.53111
301	0.93444	326	0.61016	351	0.73103	376	0.50045
302	0.88828	327	0.55770	352	0.70828	377	0.47026
303	0.82454	328	0.51126	353	0.67468	378	0.44140
304	0.75468	329	0.47048	354	0.63477	379	0.41435
305	0.68646	330	0.85564	355	0.59254	380	0.58093
306	0.62380	331	0.84317	356	0.55083	381	0.57698
307	0.56805	332	0.80879	357	0.51131	382	0.56560
308	0.51920	333	0.75979	358	0.47482	383	0.54804
309	0.47665	334	0.70409	359	0.44162	384	0.52600
310	0.93923	335	0.64773	360	0.68199	385	0.50121
311	0.92281	336	0.59431	361	0.67563	386	0.47520
312	0.87828	337	0.54551	362	0.65755	387	0.44912
313	0.81652	338	0.50183	363	0.63040	388	0.42378
314	0.74851	339	0.46310	364	0.59748	389	0.39968
315	0.68181	340	0.79829	365	0.56187	390	0.53785
316	0.62030	341	0.78814	366	0.52593	391	0.53471
317	0.56541	342	0.75985	367	0.49121	392	0.52561
318	0.51718	343	0.71879	368	0.45859	393	0.51143
319	0.47508	344	0.67109	369	0.42847	394	0.49338
320	0.90510	345	0.62176	370	0.62900	395	0.47275
321	0.89037	346	0.57406	371	0.62400	396	0.45074
322	0.85017	347	0.52973	372	0.60967	397	0.42830
323	0.79379	348	0.48945	373	0.58784	398	0.40616
324	0.73089	349	0.45332	374	0.56088	399	0.38479

Table I contd.

<u>(hk_l)</u>	<u>dhk_l</u>	<u>(hk_l)</u>	<u>dhk_l</u>	<u>(hk_l)</u>	<u>dhk_l</u>	<u>(hk_l)</u>	<u>dhk_l</u>
400	0.71363	425	0.56820	450	0.60975	475	0.47650
401	0.70634	426	0.53111	451	0.60519	476	0.45399
402	0.68576	427	0.49542	452	0.59209	477	0.43109
403	0.65513	428	0.46201	453	0.57204	478	0.40853
404	0.61841	429	0.43126	454	0.54710	479	0.38681
405	0.57917	430	0.67040	455	0.51937	480	0.51150
406	0.54003	431	0.66435	456	0.49059	481	0.50879
407	0.50264	432	0.64714	457	0.46205	482	0.50094
408	0.46785	433	0.62121	458	0.43459	483	0.48862
409	0.43600	434	0.58964	459	0.40870	484	0.47280
410	0.70841	435	0.55533	460	0.57648	485	0.45455
411	0.70128	436	0.52056	461	0.57262	486	0.43488
412	0.68113	437	0.48682	462	0.56149	487	0.41463
413	0.65108	438	0.45501	463	0.54430	488	0.39445
414	0.61500	439	0.42555	464	0.52268	489	0.37479
415	0.57637	440	0.64173	465	0.49834	490	0.48135
416	0.53776	441	0.63642	466	0.47275	491	0.47910
417	0.50081	442	0.62124	467	0.44705	492	0.47252
418	0.46637	443	0.59819	468	0.42205	493	0.46214
419	0.43480	444	0.56985	469	0.39822	494	0.44869
420	0.69341	445	0.53870	470	0.54340	495	0.43301
421	0.68672	446	0.50679	471	0.54016	496	0.41590
422	0.66776	447	0.47550	472	0.53079	497	0.39808
423	0.63938	448	0.44573	473	0.51619	498	0.38012
424	0.60511	449	0.41793	474	0.49765	499	0.36243

Table I contd.

<u>(hk_l)</u>	<u>dhk_l</u>	<u>(hk_l)</u>	<u>dhk_l</u>	<u>(hk_l)</u>	<u>dhk_l</u>	<u>(hk_l)</u>	<u>dhk_l</u>
500	0.57090	525	0.48784	550	0.51338	575	0.42606
501	0.56715	526	0.46376	551	0.51065	576	0.40974
502	0.55633	527	0.43943	552	0.50271	577	0.39267
503	0.53959	528	0.41561	553	0.49026	578	0.37539
504	0.51852	529	0.39280	554	0.47429	579	0.35833
505	0.49472	530	0.54803	555	0.45588	580	0.45052
506	0.46966	531	0.54472	556	0.43604	581	0.44868
507	0.44444	532	0.53511	557	0.41563	582	0.44326
508	0.41984	533	0.52017	558	0.39531	583	0.43466
509	0.39637	534	0.50120	559	0.37553	584	0.42341
510	0.56822	535	0.47962	560	0.49305	585	0.41015
511	0.56452	536	0.45668	561	0.49062	586	0.39553
512	0.55385	537	0.43339	562	0.48357	587	0.38011
513	0.53733	538	0.41049	563	0.47246	588	0.36438
514	0.51650	539	0.38847	564	0.45811	589	0.34871
515	0.49298	540	0.53203	565	0.44146	590	0.42952
516	0.46816	541	0.52899	566	0.42337	591	0.42791
517	0.44317	542	0.52018	567	0.40462	592	0.42321
518	0.41877	543	0.50642	568	0.38580	593	0.41570
519	0.39546	544	0.48888	569	0.36734	594	0.40583
520	0.56039	545	0.46879	570	0.47187	595	0.39411
521	0.55684	546	0.44730	571	0.46974	596	0.38109
522	0.54659	547	0.42535	572	0.46354	597	0.36724
523	0.53069	548	0.40364	573	0.45373	598	0.35299
524	0.51060	549	0.38264	574	0.44098	599	0.33869

Table I contd.

$(hk\ell)$	$d_{hk\ell}$	$(hk\ell)$	$d_{hk\ell}$	$(hk\ell)$	$d_{hk\ell}$	$(hk\ell)$	$d_{hk\ell}$
600	0.47575	625	0.42440	650	0.44090	675	0.38184
601	0.47357	626	0.40826	651	0.43917	676	0.36995
602	0.46722	627	0.39137	652	0.43409	677	0.35724
603	0.45717	628	0.37426	653	0.42599	678	0.34409
604	0.44414	629	0.35734	654	0.41539	679	0.33080
605	0.42891	630	0.46227	655	0.40285	680	0.39915
606	0.41227	631	0.46028	656	0.38897	681	0.39786
607	0.39489	632	0.45444	657	0.37428	682	0.39407
608	0.37734	633	0.44518	658	0.35923	683	0.38798
609	0.36002	634	0.43312	659	0.34419	684	0.37992
610	0.47419	635	0.41896	660	0.42782	685	0.37026
611	0.47204	636	0.40341	661	0.42623	686	0.35939
612	0.46575	637	0.38709	662	0.42158	687	0.34771
613	0.45579	638	0.37051	663	0.41416	688	0.33554
614	0.44287	639	0.35407	664	0.40440	689	0.32319
615	0.42777	640	0.45255	665	0.39280	690	0.38432
616	0.41126	641	0.45067	666	0.37990	691	0.38317
617	0.39400	642	0.44519	667	0.36617	692	0.37978
618	0.37656	643	0.43647	668	0.35205	693	0.37432
619	0.35935	644	0.42509	669	0.33786	694	0.36707
620	0.46962	645	0.41168	670	0.41376	695	0.35833
621	0.46752	646	0.39690	671	0.41233	696	0.34846
622	0.46141	647	0.38132	672	0.40811	697	0.33777
623	0.45172	648	0.36544	673	0.40137	698	0.32659
624	0.43914	649	0.34965	674	0.39246	699	0.31517

Table I contd.

<u>(hk_l)</u>	<u>dhk_l</u>	<u>(hk_l)</u>	<u>dhk_l</u>	<u>(hk_l)</u>	<u>dhk_l</u>	<u>(hk_l)</u>	<u>dhk_l</u>
700	0.40779	725	0.37405	750	0.38520	775	0.34393
701	0.40641	726	0.36285	751	0.38404	776	0.33516
702	0.40238	727	0.35084	752	0.38063	777	0.32563
703	0.39591	728	0.33836	753	0.37514	778	0.31557
704	0.38735	729	0.32570	754	0.36783	779	0.30523
705	0.37712	730	0.39920	755	0.35904	780	0.35641
706	0.36566	731	0.39791	756	0.34911	781	0.35549
707	0.35337	732	0.39412	757	0.33837	782	0.35278
708	0.34063	733	0.38804	758	0.32713	783	0.34840
709	0.32773	734	0.37997	759	0.31565	784	0.34252
710	0.40680	735	0.37031	760	0.37638	785	0.33539
711	0.40544	736	0.35944	761	0.37530	786	0.32725
712	0.40143	737	0.34775	762	0.37211	787	0.31836
713	0.39501	738	0.33558	763	0.36698	788	0.30894
714	0.38651	739	0.32322	764	0.36013	789	0.29922
715	0.37635	740	0.39289	765	0.35187	790	0.34574
716	0.36495	741	0.39166	766	0.34251	791	0.34490
717	0.35274	742	0.38804	767	0.33235	792	0.34242
718	0.34006	743	0.38223	768	0.32168	793	0.33841
719	0.32722	744	0.37452	769	0.31074	794	0.33302
720	0.40390	745	0.36525	770	0.36670	795	0.32645
721	0.40257	746	0.35481	771	0.36570	796	0.31893
722	0.39864	747	0.34355	772	0.36275	797	0.31068
723	0.39235	748	0.33180	773	0.35799	798	0.30191
724	0.38402	749	0.31984	774	0.35163	799	0.29282

Table I contd.

$(hk\ell)$	$dhk\ell$	$(hk\ell)$	$dhk\ell$	$(hk\ell)$	$dhk\ell$	$(hk\ell)$	$dhk\ell$
800	0.35681	825	0.33355	850	0.34138	875	0.31166
801	0.35589	826	0.32554	851	0.34058	876	0.30510
802	0.35317	827	0.31678	852	0.33819	877	0.29785
803	0.34877	828	0.30750	853	0.33432	878	0.29010
804	0.34288	829	0.29791	854	0.32912	879	0.28200
805	0.33573	830	0.35102	855	0.32278	880	0.32086
806	0.32756	831	0.35014	856	0.31551	881	0.32019
807	0.31864	832	0.34755	857	0.30751	882	0.31821
808	0.30920	833	0.34336	858	0.29900	883	0.31498
809	0.29946	834	0.33773	859	0.29016	884	0.31062
810	0.35615	835	0.33089	860	0.33520	885	0.30527
811	0.35524	836	0.32306	861	0.33444	886	0.29910
812	0.35253	837	0.31450	862	0.33218	887	0.29226
813	0.34816	838	0.30541	863	0.32851	888	0.28492
814	0.34230	839	0.29601	864	0.32357	889	0.27724
815	0.33518	840	0.34670	865	0.31754	890	0.31301
816	0.32705	841	0.34586	866	0.31061	891	0.31239
817	0.31817	842	0.34336	867	0.30297	892	0.31054
818	0.30877	843	0.33931	868	0.29482	893	0.30754
819	0.29907	844	0.33388	869	0.28633	894	0.30348
820	0.35420	845	0.32727	870	0.32831	895	0.29848
821	0.35330	846	0.31969	871	0.32759	896	0.29270
822	0.35064	847	0.31138	872	0.32547	897	0.28628
823	0.34633	848	0.30256	873	0.32201	898	0.27938
824	0.34056	849	0.29341	874	0.31736	899	0.27213

Table I contd.

<u>(hk_l)</u>	<u>dhk_l</u>	<u>(hk_l)</u>	<u>dhk_l</u>	<u>(hk_l)</u>	<u>dhk_l</u>	<u>(hk_l)</u>	<u>dhk_l</u>
900	0.31717	925	0.30049	950	0.30618	975	0.28419
901	0.31652	926	0.29460	951	0.30560	976	0.27919
902	0.31460	927	0.28806	952	0.30387	977	0.27360
903	0.31148	928	0.28103	953	0.30106	978	0.26756
904	0.30726	929	0.27365	954	0.29724	979	0.26117
905	0.30208	930	0.31308	955	0.29255	980	0.29112
906	0.29609	931	0.31245	956	0.28710	981	0.29062
907	0.28946	932	0.31061	957	0.28103	982	0.28913
908	0.28232	933	0.30760	958	0.27449	983	0.28670
909	0.27485	934	0.30354	959	0.26761	984	0.28340
910	0.31670	935	0.29854	960	0.30170	985	0.27932
911	0.31606	936	0.29276	961	0.30114	986	0.27457
912	0.31415	937	0.28634	962	0.29949	987	0.26925
913	0.31104	938	0.27943	963	0.29679	988	0.26348
914	0.30684	939	0.27217	964	0.29314	989	0.25737
915	0.30168	940	0.31000	965	0.28863	990	0.28521
916	0.29572	941	0.30940	966	0.28339	991	0.28474
917	0.28910	942	0.30761	967	0.27755	992	0.28334
918	0.28200	943	0.30469	968	0.27125	993	0.28106
919	0.27455	944	0.30074	969	0.26460	994	0.27794
920	0.31533	945	0.29587	970	0.29664	995	0.27409
921	0.31469	946	0.29024	971	0.29612	996	0.26960
922	0.31281	947	0.28398	972	0.29454	997	0.26456
923	0.30974	948	0.27724	973	0.29198	998	0.25908
924	0.30559	949	0.27015	974	0.28849	999	0.25326

Table II

Interplanar Spacing, d_{hkl} , in Angstroms for Alpha-Uranium at 25°C

Arranged in d_{hkl} Order

(without regard for extinctions, using $a_0 = 2.8545 \text{ \AA}$, $b_0 = 5.8681 \text{ \AA}$, $c_0 = 4.9566 \text{ \AA}$)

<u>(hkl)</u>	<u>d_{hkl}</u>	<u>(hkl)</u>	<u>d_{hkl}</u>	<u>(hkl)</u>	<u>d_{hkl}</u>	<u>(hkl)</u>	<u>d_{hkl}</u>
010	5.86810	132	1.35221	143	1.02398	224	0.89146
001	4.95660	211	1.33553	240	1.02299	321	0.89037
011	3.78657	140	1.30479	223	1.01357	302	0.88828
020	2.93405	123	1.28541	241	1.00188	035	0.88424
100	2.85450	220	1.28345	152	0.99427	312	0.87828
110	2.56691	042	1.26243	005	0.99132	243	0.86977
021	2.52485	033	1.26219	134	0.98278	162	0.86678
002	2.47830	141	1.26181	060	0.97802	330	0.85564
101	2.47362	221	1.24248	015	0.97747	054	0.85210
012	2.28304	004	1.23915	061	0.95952	252	0.85134
111	2.27938	202	1.23681	053	0.95680	322	0.85017
120	2.04598	014	1.21241	300	0.95150	135	0.84465
030	1.95603	212	1.21022	044	0.94664	234	0.84409
022	1.89329	050	1.17362	242	0.94560	331	0.84317
121	1.89120	142	1.15455	233	0.94550	063	0.84162
102	1.87140	133	1.15437	310	0.93923	070	0.83830
031	1.81948	230	1.15295	025	0.93916	071	0.82656
112	1.78293	051	1.14204	105	0.93646	006	0.82610
003	1.65220	024	1.14152	204	0.93570	303	0.82454
130	1.61355	222	1.13969	301	0.93444	045	0.82137
013	1.59036	104	1.13667	160	0.92522	016	0.81803
122	1.57778	231	1.12297	115	0.92475	313	0.81652
032	1.53541	114	1.11593	214	0.92402	154	0.81650
131	1.53430	043	1.09699	311	0.92281	205	0.81419
040	1.46703	150	1.08546	062	0.90974	332	0.80879
023	1.43964	203	1.08006	161	0.90951	163	0.80726
103	1.42995	213	1.06222	153	0.90719	260	0.80677
200	1.42725	052	1.06070	250	0.90650	215	0.80647
041	1.40670	151	1.06033	320	0.90510	170	0.80433
113	1.38929	124	1.05991	144	0.89852	340	0.79829
210	1.38682	034	1.04678	125	0.89212	261	0.79630
201	1.37152	232	1.04537	251	0.89171	026	0.79518

Table II contd.

<u>(hkl)</u>	<u>d_{hkl}</u>	<u>(hkl)</u>	<u>d_{hkl}</u>	<u>(hkl)</u>	<u>d_{hkl}</u>	<u>(hkl)</u>	<u>d_{hkl}</u>
253	0.79474	173	0.72319	360	0.68199	246	0.64271
072	0.79410	270	0.72284	315	0.68181	440	0.64173
171	0.79395	046	0.71982	412	0.68113	075	0.64011
323	0.79379	343	0.71879	165	0.67639	423	0.63938
106	0.79354	271	0.71527	264	0.67610	047	0.63769
145	0.78935	206	0.71497	361	0.67563	441	0.63642
244	0.78889	400	0.71363	056	0.67553	190	0.63564
341	0.78814	245	0.71190	353	0.67468	354	0.63477
116	0.78638	180	0.71043	174	0.67466	207	0.63431
225	0.78455	216	0.70972	236	0.67152	084	0.63121
064	0.76771	410	0.70841	344	0.67109	066	0.63110
262	0.76715	352	0.70828	083	0.67041	282	0.63090
126	0.76602	007	0.70809	430	0.67040	217	0.63064
172	0.76505	401	0.70634	127	0.66915	092	0.63055
036	0.76101	334	0.70409	255	0.66897	191	0.63048
342	0.75985	082	0.70335	325	0.66841	363	0.63040
333	0.75979	181	0.70324	422	0.66776	370	0.62900
055	0.75731	017	0.70299	037	0.66580	265	0.62574
304	0.75468	411	0.70128	431	0.66435	175	0.62460
235	0.75168	146	0.69797	273	0.66223	274	0.62437
314	0.74851	065	0.69622	362	0.65755	371	0.62400
073	0.74758	226	0.69465	156	0.65737	306	0.62380
164	0.74136	074	0.69434	403	0.65513	147	0.62235
350	0.73911	272	0.69392	183	0.65265	345	0.62176
136	0.73533	420	0.69341	280	0.65240	442	0.62124
080	0.73351	027	0.68832	090	0.65201	433	0.62121
155	0.73199	107	0.68726	413	0.65108	316	0.62030
254	0.73163	421	0.68672	137	0.64840	227	0.61999
351	0.73103	305	0.68646	335	0.64773	008	0.61958
324	0.73089	402	0.68576	432	0.64714	404	0.61841
081	0.72561	182	0.68293	281	0.64682	184	0.61632
263	0.72496	117	0.68259	091	0.64644	166	0.61621

Table II contd.

<u>(hkl)</u>	<u>d_{hkl}</u>	<u>(hkl)</u>	<u>d_{hkl}</u>	<u>(hkl)</u>	<u>d_{hkl}</u>	<u>(hkl)</u>	<u>d_{hkl}</u>
018	0.61615	247	0.58222	462	0.56149	471	0.54016
192	0.61571	380	0.58093	374	0.56088	406	0.54003
414	0.61500	405	0.57971	520	0.56039	503	0.53959
256	0.61059	138	0.57840	148	0.55968	445	0.53870
326	0.61016	185	0.57746	293	0.55819	186	0.53864
450	0.60975	284	0.57728	257	0.55802	119	0.53848
372	0.60967	266	0.57719	228	0.55796	158	0.53809
283	0.60680	094	0.57701	327	0.55770	390	0.53785
093	0.60649	381	0.57698	521	0.55684	416	0.53776
057	0.60628	292	0.57677	502	0.55633	513	0.53733
028	0.60621	460	0.57648	435	0.55533	532	0.53511
108	0.60548	415	0.57637	512	0.55385	195	0.53509
451	0.60519	176	0.57629	356	0.55083	294	0.53495
424	0.60511	346	0.57406	009	0.55073	391	0.53471
237	0.60338	067	0.57355	086	0.54850	267	0.53218
118	0.60228	461	0.57262	019	0.54832	540	0.53203
443	0.59819	453	0.57204	383	0.54804	129	0.53180
364	0.59748	500	0.57090	530	0.54803	177	0.53148
336	0.59431	048	0.57076	058	0.54791	426	0.53111
193	0.59325	444	0.56985	454	0.54710	375	0.53111
290	0.59306	208	0.56833	522	0.54659	472	0.53079
157	0.59306	510	0.56822	238	0.54576	523	0.53069
128	0.59298	425	0.56820	337	0.54551	039	0.53012
355	0.59254	307	0.56805	285	0.54497	248	0.52996
452	0.59209	501	0.56715	095	0.54474	347	0.52973
038	0.59065	218	0.56569	531	0.54472	541	0.52899
085	0.58965	382	0.56560	463	0.54430	384	0.52600
434	0.58964	194	0.56557	276	0.54399	366	0.52593
291	0.58886	317	0.56541	470	0.54340	392	0.52561
076	0.58841	511	0.56452	029	0.54128	068	0.52339
373	0.58784	167	0.56231	077	0.54094	464	0.52268
275	0.58406	365	0.56187	109	0.54076	139	0.52121

Table II contd.

<u>(hkl)</u>	<u>d_{hkl}</u>	<u>(hkl)</u>	<u>d_{hkl}</u>	<u>(hkl)</u>	<u>d_{hkl}</u>	<u>(hkl)</u>	<u>d_{hkl}</u>
436	0.52056	552	0.50271	562	0.48357	571	0.46974
542	0.52018	407	0.50264	296	0.48177	506	0.46966
533	0.52017	338	0.50183	490	0.48135	620	0.46962
455	0.51937	187	0.50152	069	0.47988	545	0.46879
308	0.51920	385	0.50121	287	0.47980	516	0.46816
504	0.51852	534	0.50120	097	0.47964	408	0.46785
318	0.51718	482	0.50094	535	0.47962	621	0.46752
514	0.51650	417	0.50081	491	0.47910	602	0.46722
473	0.51619	376	0.50045	309	0.47665	188	0.46695
049	0.51560	059	0.49857	475	0.47650	418	0.46637
168	0.51481	465	0.49834	600	0.47575	612	0.46575
209	0.51381	078	0.49826	447	0.47550	526	0.46376
550	0.51338	474	0.49765	386	0.47520	572	0.46354
286	0.51199	239	0.49695	319	0.47508	339	0.46310
219	0.51185	427	0.49542	358	0.47482	630	0.46227
096	0.51180	505	0.49472	554	0.47429	493	0.46214
258	0.51151	394	0.49338	610	0.47419	457	0.46205
480	0.51150	560	0.49305	601	0.47357	428	0.46201
393	0.51143	515	0.49298	088	0.47332	622	0.46141
357	0.51131	268	0.49139	169	0.47324	079	0.46029
328	0.51126	367	0.49121	197	0.47301	631	0.46028
551	0.51065	159	0.49113	484	0.47280	368	0.45859
524	0.51060	178	0.49084	466	0.47275	564	0.45811
087	0.50944	561	0.49062	395	0.47275	603	0.45717
295	0.50894	456	0.49059	492	0.47252	536	0.45668
481	0.50879	553	0.49026	563	0.47246	555	0.45588
149	0.50739	348	0.48945	611	0.47204	613	0.45579
446	0.50679	544	0.48888	570	0.47187	438	0.45501
543	0.50642	483	0.48862	259	0.47068	269	0.45486
229	0.50611	525	0.48784	329	0.47048	297	0.45466
277	0.50583	437	0.48682	278	0.47042	485	0.45455
196	0.50377	249	0.48493	377	0.47026	632	0.45444

Table II contd.

<u>(hkl)</u>	<u>d_{hkl}</u>	<u>(hkl)</u>	<u>d_{hkl}</u>	<u>(hkl)</u>	<u>d_{hkl}</u>	<u>(hkl)</u>	<u>d_{hkl}</u>
179	0.45442	651	0.43917	388	0.42378	672	0.40811
476	0.45399	624	0.43914	584	0.42341	700	0.40779
573	0.45373	279	0.43807	566	0.42337	710	0.40680
349	0.45332	643	0.43647	592	0.42321	701	0.40641
640	0.45255	556	0.43604	468	0.42205	398	0.40616
623	0.45172	409	0.43600	662	0.42158	594	0.40583
396	0.45074	189	0.43526	289	0.42083	711	0.40544
641	0.45067	486	0.43488	099	0.42073	567	0.40462
580	0.45052	419	0.43480	508	0.41984	664	0.40440
288	0.44926	583	0.43466	635	0.41896	720	0.40390
098	0.44913	458	0.43459	518	0.41877	548	0.40364
387	0.44912	652	0.43409	449	0.41793	299	0.40356
494	0.44869	537	0.43339	199	0.41623	636	0.40341
581	0.44868	634	0.43312	496	0.41590	655	0.40285
546	0.44730	495	0.43301	593	0.41570	721	0.40257
467	0.44705	429	0.43126	557	0.41563	702	0.40238
448	0.44573	477	0.43109	528	0.41561	712	0.40143
642	0.44519	590	0.42952	654	0.41539	673	0.40137
633	0.44518	605	0.42891	487	0.41463	389	0.39968
507	0.44444	369	0.42847	379	0.41435	730	0.39920
604	0.44414	298	0.42842	663	0.41416	680	0.39915
198	0.44368	397	0.42830	670	0.41376	722	0.39864
582	0.44326	591	0.42791	671	0.41233	469	0.39822
517	0.44317	660	0.42782	606	0.41227	497	0.39808
614	0.44287	615	0.42777	645	0.41168	731	0.39791
359	0.44162	661	0.42623	616	0.41126	681	0.39786
565	0.44146	575	0.42606	538	0.41049	646	0.39690
378	0.44140	653	0.42599	585	0.41015	509	0.39637
574	0.44098	439	0.42555	576	0.40974	703	0.39591
650	0.44090	547	0.42535	459	0.40870	586	0.39553
089	0.44041	644	0.42509	478	0.40853	519	0.39546
527	0.43943	625	0.42440	626	0.40826	558	0.39531

Table II contd.

<u>(hkl)</u>	<u>d_{hkl}</u>	<u>(hkl)</u>	<u>d_{hkl}</u>	<u>(hkl)</u>	<u>d_{hkl}</u>	<u>(hkl)</u>	<u>d_{hkl}</u>
713	0.39501	743	0.38223	569	0.36734	811	0.35524
607	0.39489	675	0.38184	597	0.36724	746	0.35481
488	0.39445	647	0.38132	694	0.36707	820	0.35420
732	0.39412	596	0.38109	763	0.36698	639	0.35407
595	0.39411	752	0.38063	770	0.36670	707	0.35337
682	0.39407	498	0.38012	667	0.36617	821	0.35330
617	0.39400	587	0.38011	771	0.36570	802	0.35317
740	0.39289	734	0.37997	706	0.36566	598	0.35299
665	0.39280	684	0.37992	648	0.36544	782	0.35278
529	0.39280	666	0.37990	745	0.36525	717	0.35274
577	0.39267	692	0.37978	716	0.36495	812	0.35253
674	0.39246	608	0.377734	588	0.36438	668	0.35205
723	0.39235	705	0.37712	726	0.36285	765	0.35187
741	0.39166	618	0.37656	772	0.36275	774	0.35163
627	0.39137	760	0.37638	499	0.36243	830	0.35102
656	0.38897	715	0.37635	764	0.36013	727	0.35084
539	0.38847	559	0.37553	609	0.36002	822	0.35064
742	0.38804	578	0.37539	736	0.35944	831	0.35014
733	0.38804	761	0.37530	686	0.35939	649	0.34965
683	0.38798	753	0.37514	619	0.35935	756	0.34911
704	0.38735	489	0.37479	658	0.35923	803	0.34877
637	0.38709	744	0.37452	755	0.35904	589	0.34871
479	0.38681	693	0.37432	695	0.35833	696	0.34846
714	0.38651	657	0.37428	579	0.35833	783	0.34840
568	0.38580	628	0.37426	773	0.35799	813	0.34816
750	0.38520	725	0.37405	629	0.35734	737	0.34775
399	0.38479	762	0.37211	677	0.35724	687	0.34771
690	0.38432	638	0.37051	800	0.35681	832	0.34755
751	0.38404	735	0.37031	780	0.35641	840	0.34670
724	0.38402	685	0.37026	810	0.35615	823	0.34633
691	0.38317	676	0.36995	801	0.35589	841	0.34586
549	0.38264	754	0.36783	781	0.35549	790	0.34574

Table II contd.

<u>(hkl)</u>	<u>d_{hkl}</u>	<u>(hkl)</u>	<u>d_{hkl}</u>	<u>(hkl)</u>	<u>d_{hkl}</u>	<u>(hkl)</u>	<u>d_{hkl}</u>
791	0.34490	776	0.33516	855	0.32278	931	0.31245
659	0.34419	861	0.33444	873	0.32201	891	0.31239
678	0.34409	853	0.33432	768	0.32168	875	0.31166
775	0.34393	844	0.33388	880	0.32086	903	0.31148
747	0.34355	825	0.33355	881	0.32019	847	0.31138
842	0.34336	794	0.33302	749	0.31984	913	0.31104
833	0.34336	767	0.33235	846	0.31969	769	0.31074
804	0.34288	862	0.33218	796	0.31893	797	0.31068
784	0.34252	748	0.33180	807	0.31864	884	0.31062
766	0.34251	835	0.33089	787	0.31836	932	0.31061
792	0.34242	679	0.33080	882	0.31821	866	0.31061
814	0.34230	854	0.32912	817	0.31817	892	0.31054
850	0.34138	863	0.32851	865	0.31754	940	0.31000
708	0.34063	870	0.32831	874	0.31736	923	0.30974
851	0.34058	709	0.32773	900	0.31717	941	0.30940
824	0.34056	871	0.32759	827	0.31678	808	0.30920
718	0.34006	806	0.32756	910	0.31670	788	0.30894
843	0.33931	845	0.32727	901	0.31652	818	0.30877
599	0.33869	786	0.32725	911	0.31606	942	0.30761
793	0.33841	719	0.32722	759	0.31565	933	0.30760
757	0.33837	758	0.32713	778	0.31557	893	0.30754
728	0.33836	816	0.32705	856	0.31551	857	0.30751
852	0.33819	698	0.32659	920	0.31533	828	0.30750
669	0.33786	795	0.32645	699	0.31517	904	0.30726
697	0.33777	729	0.32570	883	0.31498	914	0.30684
834	0.33773	777	0.32563	921	0.31469	950	0.30618
805	0.33573	826	0.32554	902	0.31460	951	0.30560
738	0.33558	872	0.32547	837	0.31450	924	0.30559
688	0.33554	864	0.32357	912	0.31415	838	0.30541
785	0.33539	739	0.32322	930	0.31308	885	0.30527
860	0.33520	689	0.32319	890	0.31301	779	0.30523
815	0.33518	836	0.32306	922	0.31281	876	0.30510

Table II contd.

<u>(hkl)</u>	<u>d_{hkl}</u>	<u>(hkl)</u>	<u>d_{hkl}</u>	<u>(hkl)</u>	<u>d_{hkl}</u>	<u>(hkl)</u>	<u>d_{hkl}</u>
943	0.30469	868	0.29482	984	0.28340	969	0.26460
952	0.30387	926	0.29460	966	0.28339	997	0.26456
934	0.30354	972	0.29454	992	0.28334	988	0.26348
894	0.30348	849	0.29341	908	0.28232	979	0.26117
867	0.30297	964	0.29314	918	0.28200	998	0.25908
848	0.30256	799	0.29282	879	0.28200	989	0.25737
905	0.30208	936	0.29276	993	0.28106	999	0.25326
798	0.30191	896	0.29270	957	0.28103		
960	0.30170	955	0.29255	928	0.28103		
915	0.30168	887	0.29226	938	0.27943		
961	0.30114	973	0.29198	898	0.27938		
953	0.30106	980	0.29112	985	0.27932		
944	0.30074	981	0.29062	976	0.27919		
925	0.30049	946	0.29024	994	0.27794		
962	0.29949	859	0.29016	967	0.27755		
809	0.29946	878	0.29010	948	0.27724		
789	0.29922	907	0.28946	889	0.27724		
886	0.29910	982	0.28913	909	0.27485		
819	0.29907	917	0.28910	986	0.27457		
858	0.29900	965	0.28863	919	0.27455		
935	0.29854	974	0.28849	958	0.27449		
895	0.29848	927	0.28806	995	0.27409		
829	0.29791	956	0.28710	929	0.27365		
877	0.29785	983	0.28670	977	0.27360		
954	0.29724	937	0.28634	939	0.27217		
963	0.29679	869	0.28633	899	0.27213		
970	0.29664	897	0.28628	968	0.27125		
971	0.29612	990	0.28521	949	0.27015		
906	0.29609	888	0.28492	996	0.26960		
839	0.29601	991	0.28474	987	0.26925		
945	0.29587	975	0.28419	959	0.26761		
916	0.29572	947	0.28398	978	0.26756		

Table III

Interplanar Spacings, d_{hkl} , in Angstroms for U_3Si at 25°C
 Arranged in (hkl) Order
(without regard for extinctions, using $a_0 = 6.0290 \text{ \AA}$ and $c_0 = 8.6963 \text{ \AA}$)

<u>$(hk\ell)$</u>	<u>$d_{hk\ell}$</u>	<u>$(hk\ell)$</u>	<u>$d_{hk\ell}$</u>	<u>$(hk\ell)$</u>	<u>$d_{hk\ell}$</u>	<u>$(hk\ell)$</u>	<u>$d_{hk\ell}$</u>
001	8.69630	210	2.69625	320	1.67214	420	1.34813
002	4.34815	211	2.57531	321	1.64206	421	1.33221
003	2.89877	212	2.29146	322	1.56071	422	1.28766
004	2.17408	213	1.97425	323	1.44843	423	1.22240
005	1.73926	214	1.69243	324	1.32545	424	1.14573
006	1.44938	215	1.46156	325	1.20541	425	1.06552
100	6.02900	216	1.27662	326	1.09522	426	0.98713
101	4.95473	220	2.13157	330	1.42105	430	1.20580
102	3.52666	221	2.07029	331	1.40245	431	1.19437
103	2.61249	222	1.91396	332	1.35074	432	1.16195
104	2.04517	223	1.71727	333	1.27597	433	1.11332
105	1.67111	224	1.52205	334	1.18949	434	1.05447
106	1.40923	225	1.34758	335	1.10045	435	0.99095
110	4.26315	226	1.19856	336	1.01470	436	0.92696
111	3.82792	300	2.00967	400	1.50725	440	1.06579
112	3.04411	301	1.95806	401	1.48511	441	1.05787
113	2.39711	302	1.82424	402	1.42412	442	1.03514
114	1.93677	303	1.65158	403	1.33728	443	1.00032
115	1.61040	304	1.47575	404	1.23868	444	0.95698
116	1.87225	305	1.31513	405	1.13905	445	0.90874
200	3.01450	306	1.17555	406	1.04473	446	0.85863
201	2.84823	310	1.90654	410	1.46225	500	1.20580
202	2.47737	311	1.86231	411	1.44200	501	1.19437
203	2.08945	312	1.74606	412	1.38597	502	1.16195
204	1.76333	313	1.59289	413	1.30555	503	1.11332
205	1.50649	314	1.43344	414	1.21334	504	1.05447
206	1.30624	315	1.28492	415	1.11925	505	0.99095
		316	1.15382	416	1.02939	506	0.92696

Table III contd.

$(hk\ell)$	$d_{hk\ell}$	$(hk\ell)$	$d_{hk\ell}$	$(hk\ell)$	$d_{hk\ell}$	$(hk\ell)$	$d_{hk\ell}$
510	1.18238	550	0.85263	630	0.89875	700	0.86129
511	1.17160	551	0.84856	631	0.89399	701	0.85709
512	1.14095	552	0.83670	632	0.88015	702	0.84487
513	1.09481	553	0.81798	633	0.85844	703	0.82561
514	1.03871	554	0.79377	634	0.83058	704	0.80074
515	0.97783	555	0.76558	635	0.79845	705	0.77183
516	0.91619	556	0.73490	636	0.76382	706	0.74042
520	1.11956	600	1.00483	640	0.83607	710	0.85263
521	1.11039	601	0.99819	641	0.83223	711	0.84856
522	1.08420	602	0.97903	642	0.82103	712	0.83670
523	1.04437	603	0.94941	643	0.80333	713	0.81798
524	0.99534	604	0.91212	644	0.78036	714	0.79377
525	0.94139	605	0.87007	645	0.75353	715	0.76558
526	0.88601	606	0.82579	646	0.72422	716	0.73490
530	1.03397	610	0.99116	650	0.77193	720	0.82815
531	1.02673	611	0.98479	651	0.76891	721	0.82442
532	1.00592	612	0.96637	652	0.76005	722	0.81352
533	0.97387	613	0.93785	653	0.74594	723	0.79629
534	0.93374	614	0.90186	654	0.72744	724	0.77390
535	0.88877	615	0.86114	655	0.70556	725	0.74771
536	0.84173	616	0.81815	656	0.68133	726	0.71905
540	0.94157	620	0.95327	660	0.71052	730	0.79165
541	0.93610	621	0.94759	661	0.70816	731	0.78839
542	0.92024	622	0.93115	662	0.70122	732	0.77884
543	0.89551	623	0.90556	663	0.69010	733	0.76368
544	0.86402	624	0.87303	664	0.67537	734	0.74387
545	0.82802	625	0.83594	665	0.65776	735	0.72052
546	0.78959	626	0.79645	666	0.63799	736	0.69477

Table III contd.

<u>(hk_l)</u>	<u>d_{hk_l}</u>	<u>(hk_l)</u>	<u>d_{hk_l}</u>	<u>(hk_l)</u>	<u>d_{hk_l}</u>	<u>(hk_l)</u>	<u>d_{hk_l}</u>
740	0.74781	800	0.75363	840	0.67406	910	0.66579
741	0.74506	801	0.75081	841	0.67205	911	0.66385
742	0.73699	802	0.74255	842	0.66611	912	0.65812
743	0.72410	803	0.72938	843	0.65655	913	0.64890
744	0.70714	804	0.71206	844	0.64383	914	0.63661
745	0.68700	805	0.69150	845	0.62851	915	0.62179
746	0.66456	806	0.66864	846	0.61120	916	0.60501
750	0.70086	810	0.74781	850	0.63907	920	0.65394
751	0.69859	811	0.74506	851	0.63735	921	0.65210
752	0.69193	812	0.73699	852	0.63228	922	0.64666
753	0.68123	813	0.72410	853	0.62409	923	0.63791
754	0.66705	814	0.70714	854	0.61313	924	0.62622
755	0.65006	815	0.68700	855	0.59986	925	0.61210
756	0.63096	816	0.66456	856	0.58475	926	0.59607
760	0.65394	820	0.73112	860	0.60290	930	0.63551
761	0.65210	821	0.72855	861	0.60146	931	0.63382
762	0.64666	822	0.72100	862	0.59719	932	0.62883
763	0.63791	823	0.70892	863	0.59027	933	0.62077
764	0.62622	824	0.69299	864	0.58097	934	0.60999
765	0.61210	825	0.67400	865	0.56965	935	0.59691
766	0.59607	826	0.65277	866	0.55666	936	0.58202
770	0.60902	830	0.70564	900	0.66989	940	0.61215
771	0.60753	831	0.70333	901	0.66791	941	0.61064
772	0.60313	832	0.69653	902	0.66208	942	0.60617
773	0.59601	833	0.68562	903	0.65269	943	0.59894
774	0.58645	834	0.67117	904	0.64019	944	0.58924
775	0.57480	835	0.65388	905	0.62512	945	0.57743
776	0.56147	836	0.63444	906	0.60808	946	0.56392

Table IV

Interplanar Spacing, d_{hkl} , in Angstroms for U_3Si at 25°C d_{hkl} order(without regard for extinctions, using $a_0 = 6.0290 \text{ \AA}$ and $c_0 = 8.6963 \text{ \AA}$)

(hkl)	d_{hkl}	(hkl)	d_{hkl}	(hkl)	d_{hkl}	(hkl)	d_{hkl}
001	8.69630	302	1.82424	116	1.37225	316	1.15382
100	6.02900	204	1.76333	332	1.35074	424	1.14573
101	4.95473	312	1.74606	420	1.34813	512	1.14095
002	4.34815	005	1.73926	225	1.34758	405	1.13905
110	4.26315	223	1.71727	403	1.33728	520	1.11956
111	3.82792	214	1.69243	421	1.33221	415	1.11925
102	3.52666	320	1.67214	324	1.32545	433	1.11332
112	3.04411	105	1.67111	305	1.31513	503	1.11332
200	3.01450	303	1.65158	206	1.30624	521	1.11039
003	2.89877	321	1.64206	413	1.30555	335	1.10045
201	2.84823	115	1.61040	422	1.28766	326	1.09522
210	2.69625	313	1.59289	315	1.28492	513	1.09481
103	2.61249	322	1.56071	216	1.27662	522	1.08420
211	2.57531	224	1.52205	333	1.27597	440	1.06579
202	2.47737	400	1.50725	404	1.23868	425	1.06552
113	2.39711	205	1.50649	423	1.22240	441	1.05787
212	2.29146	401	1.48511	414	1.21334	434	1.05447
004	2.17408	304	1.47575	430	1.20580	504	1.05447
220	2.13157	410	1.46225	500	1.20580	406	1.04473
203	2.08945	215	1.46156	325	1.20541	523	1.04437
221	2.07029	006	1.44938	226	1.19856	514	1.03871
104	2.04517	323	1.44843	431	1.19437	442	1.03514
300	2.00967	411	1.44200	501	1.19437	530	1.03397
213	1.97425	314	1.43344	334	1.18949	416	1.02939
301	1.95806	402	1.42412	510	1.18238	531	1.02673
114	1.93677	330	1.42105	306	1.17555	336	1.01470
222	1.91396	106	1.40923	511	1.17160	532	1.00592
310	1.90654	331	1.40245	432	1.16195	600	1.00483
311	1.86231	412	1.38597	502	1.16195	443	1.00032

Table IV contd.

<u>(hkl)</u>	<u>d_{hkl}</u>	<u>(hkl)</u>	<u>d_{hkl}</u>	<u>(hkl)</u>	<u>d_{hkl}</u>	<u>(hkl)</u>	<u>d_{hkl}</u>
601	0.99819	614	0.90186	545	0.82802	733	0.76368
524	0.99534	630	0.89875	606	0.82579	652	0.76005
610	0.99116	543	0.89551	703	0.82561	800	0.75363
435	0.99095	631	0.89399	721	0.82442	645	0.75353
505	0.99095	535	0.88877	642	0.82103	801	0.75081
426	0.98713	526	0.88601	616	0.81815	740	0.74781
611	0.98479	632	0.88015	553	0.81798	810	0.74781
602	0.97903	624	0.87303	713	0.81798	725	0.74771
515	0.97783	605	0.87007	722	0.81352	653	0.74594
533	0.97387	544	0.86402	643	0.80333	741	0.74506
612	0.96637	700	0.86129	704	0.80074	811	0.74506
444	0.95698	615	0.86114	635	0.79845	734	0.74387
620	0.95327	446	0.85863	626	0.79645	802	0.74255
603	0.94941	633	0.85844	723	0.79629	706	0.74042
621	0.94759	701	0.85709	554	0.79377	742	0.73699
540	0.94157	550	0.85263	714	0.79377	812	0.73699
525	0.94139	710	0.85263	730	0.79165	556	0.73490
613	0.93785	551	0.84856	546	0.78959	716	0.73490
541	0.93610	711	0.84856	731	0.78839	820	0.73112
534	0.93374	702	0.84487	644	0.78036	803	0.72938
622	0.93115	536	0.84173	732	0.77884	821	0.72855
436	0.92696	552	0.83670	724	0.77390	654	0.72744
506	0.92696	712	0.83670	650	0.77193	646	0.72422
542	0.92024	640	0.83607	705	0.77183	743	0.72410
516	0.91619	625	0.83594	651	0.76891	813	0.72410
604	0.91212	641	0.83223	555	0.76558	822	0.72100
445	0.90874	634	0.83058	715	0.76558	735	0.72052
623	0.90556	720	0.82815	636	0.76382	726	0.71905

Table IV contd.

<u>(hkl)</u>	<u>dhkl</u>	<u>(hkl)</u>	<u>dhkl</u>	<u>(hkl)</u>	<u>dhkl</u>	<u>(hkl)</u>	<u>dhkl</u>
804	0.71206	900	0.66989	763	0.63791	916	0.60501
660	0.71052	806	0.66864	923	0.63791	772	0.60313
823	0.70892	901	0.66791	851	0.63735	860	0.60290
661	0.70816	754	0.66705	914	0.63661	861	0.60146
744	0.70714	842	0.66611	930	0.63551	855	0.59986
814	0.70714	910	0.66579	836	0.63444	943	0.59894
830	0.70564	746	0.66456	931	0.63382	862	0.59719
655	0.70556	816	0.66456	852	0.63228	935	0.59691
831	0.70333	911	0.66385	756	0.63096	766	0.59607
662	0.70122	902	0.66208	932	0.62883	926	0.59607
750	0.70086	912	0.65812	845	0.62851	773	0.59601
751	0.69859	665	0.65776	764	0.62622	863	0.59027
832	0.69653	843	0.65655	924	0.62622	944	0.58924
736	0.69477	760	0.65394	905	0.62512	774	0.58645
824	0.69299	920	0.65394	853	0.62409	856	0.58475
752	0.69193	835	0.65388	915	0.62179	936	0.58202
805	0.69150	826	0.65277	933	0.62077	864	0.58097
663	0.69010	903	0.65269	854	0.61313	945	0.57743
745	0.68700	761	0.65210	940	0.61215	775	0.57480
815	0.68700	921	0.65210	765	0.61210	865	0.56965
833	0.68562	755	0.65006	925	0.61210	946	0.56392
656	0.68133	913	0.64890	846	0.61120	776	0.56147
753	0.68123	762	0.64666	941	0.61064	866	0.55666
664	0.67537	922	0.64666	934	0.60999		
840	0.67406	844	0.64383	770	0.60902		
825	0.67400	904	0.64019	906	0.60808		
841	0.67205	850	0.63907	771	0.60753		
834	0.67117	666	0.63799	942	0.60617		

For the tetragonal case, $a=b$ and for the cubic case, $a=b=c$.

Table V lists the angles between the (hkl) plane and the three cardinal planes (100) , (010) and (001) for U_3Si using the same $25^\circ C$ lattice constants as for the d spacings in Tables III and IV. Again, the table has been abbreviated since h and k may be interchanged if the angular values for the reference planes (100) and (010) are also interchanged. Since the angle between the poles of two planes is the same as the angle between the planes themselves, this information can be used to plot a pole figure for U_3Si . Figure 1 shows a standard (001) projection for U_3Si plotted without regard for extinctions from the above data. Figure 2 shows a similar plot of the (001) projection for alpha-uranium prepared by Mueller and Knott⁵ of ANL. These two stereographic projections and the well known Polar and Wulff provide the basic tools for uranium crystallographic manipulations. With these it is possible to identify twin planes and slip planes from their traces and to determine crystal orientation relationships when crystal matrix and precipitate diffraction patterns are superimposed. Other manipulations are possible but these serve to illustrate why the pole figures are necessary. Chapter two of Barrett³ gives an excellent introduction to stereographic projection and its uses. Since a stereographic projection of alpha-uranium was already available, it was not necessary to calculate the interplanar angles to obtain one. However, it was desirable to know the angles between the uranium twin planes and the three cardinal planes. Calculations for all of these angles were not available, especially for some which do not have rational indices. Table VI is a compilation of the calculated values for angles between the uranium twin planes (hkl) and the three cardinal planes (100) , (010) and (001) . Again, since the angle between planes equals the angles between poles, they may be conveniently plotted on a stereographic projection. Table VII is a listing of the calculated values of angles between the uranium twin direction $[hkl]$ and the three cardinal directions $[100]$, $[010]$ and $[001]$. Appendix III of Barrett³ lists a formula for calculating this angle, which in modified symbols is as follows:

$$\cos \phi = \frac{h_1 h_2 a^2 + k_1 k_2 b^2 + l_1 l_2 c^2}{\sqrt{h_1^2 a^2 + k_1^2 b^2 + l_1^2 c^2} \cdot \sqrt{h_2^2 a^2 + k_2^2 b^2 + l_2^2 c^2}}$$

Tables VI and VII are based on the $25^\circ C$ lattice parameters² for uranium of $a_0 = 2.8545 \text{ \AA}$, $b_0 = 5.8681 \text{ \AA}$, and $c_0 = 4.9566 \text{ \AA}$. The planes and directions represented in these two tables reflect the possible twinning modes for uranium given by A. G. Crocker.⁶

AGEING STUDIES OF URANIUM-SILICON ALLOYS WITH THE ELECTRON MICROSCOPE.

Heat Treatment of Samples

Samples of uranium containing 330, 530, and 1500 ppm of silicon were solution-annealed in the beta phase for periods of 24 to 48 hours. The samples were then quenched in water to retain the silicon in solid solution. All of the

Table V

Interplanar Angles for U_3Si at $25^\circ C$
 (using $a_0 = 6.0290 \text{ \AA}$ and $c_0 = 8.6963 \text{ \AA}$)

(hkl)	Angle between Planes in Degrees			(hkl)	Angle between Planes in Degrees		
	(100)	(010)	(001)		(100)	(010)	(001)
001	90.000	90.000	0.000	210	26.565	63.435	90.000
002	90.000	90.000	0.000	211	31.317	64.713	72.774
003	90.000	90.000	0.000	212	40.523	67.662	58.198
004	90.000	90.000	0.000	213	49.087	70.886	47.073
005	90.000	90.000	0.000	214	55.846	73.697	38.881
006	90.000	90.000	0.000	215	60.998	75.971	32.825
100	0.000	90.000	90.000	216	64.945	77.776	28.261
101	34.733	90.000	55.267	220	45.000	45.000	90.000
102	54.201	90.000	35.800	221	46.625	46.625	76.228
103	64.322	90.000	25.679	222	50.586	50.586	63.885
104	70.171	90.000	19.830	223	55.273	55.273	53.672
105	73.908	90.000	16.092	224	59.675	59.675	45.566
106	76.483	90.000	13.518	225	63.447	63.447	39.213
110	45.000	45.000	90.000	226	66.572	66.572	34.214
111	50.586	50.586	63.885	300	0.000	90.000	90.000
112	59.675	59.675	45.566	301	13.012	90.000	76.988
113	66.572	66.572	34.214	302	24.806	90.000	65.194
114	71.262	71.262	27.020	303	34.733	90.000	55.267
115	74.508	74.508	22.194	304	42.750	90.000	47.251
116	76.844	76.844	18.777	305	49.126	90.000	40.875
200	0.000	90.000	90.000	306	54.201	90.000	35.800
201	19.119	90.000	70.882	310	18.435	71.565	90.000
202	34.733	90.000	55.267	311	22.078	72.008	77.635
203	46.121	90.000	43.879	312	29.677	73.166	66.324
204	54.201	90.000	35.800	313	37.570	74.681	56.667
205	60.017	90.000	29.984	314	44.499	76.246	48.751
206	64.322	90.000	25.679	315	50.255	77.695	42.373
				316	54.961	78.967	37.243

Table V contd.

<u>(hkl)</u>	<u>(100)</u>	<u>(010)</u>	<u>(001)</u>	<u>(hkl)</u>	<u>(100)</u>	<u>(010)</u>	<u>(001)</u>
320	33.690	56.310	90.000	420	26.565	63.435	90.000
321	35.206	56.995	79.116	421	27.887	63.773	81.188
322	39.049	58.820	68.965	422	31.317	64.713	72.774
323	43.885	61.283	60.022	423	35.805	66.077	65.059
324	48.736	63.916	52.435	424	40.523	67.662	58.198
325	53.144	66.430	46.127	425	45.015	69.301	52.220
326	56.977	68.696	40.918	426	49.087	70.886	47.073
330	45.000	45.000	90.000	430	36.870	53.130	90.000
331	45.745	45.745	80.720	431	37.588	53.536	82.106
332	47.769	47.769	71.902	432	39.565	54.678	74.501
333	50.586	50.586	63.885	433	42.384	56.360	67.414
334	53.709	53.709	56.830	434	45.605	58.352	60.986
335	56.799	56.799	50.750	435	48.894	60.456	55.267
336	59.675	59.675	45.566	436	52.048	62.533	50.242
400	0.000	90.000	90.000	440	45.000	45.000	90.000
401	9.833	90.000	80.167	441	45.424	45.424	83.013
402	19.119	90.000	70.882	442	46.625	46.625	76.228
403	27.473	90.000	62.527	443	48.420	48.420	69.813
404	34.733	90.000	55.267	444	50.586	50.586	63.885
405	40.912	90.000	49.088	445	52.921	52.921	58.501
406	46.121	90.000	43.879	446	55.273	55.273	53.672
410	14.036	75.964	90.000	500	0.000	90.000	90.000
411	16.920	76.162	80.456	501	7.894	90.000	82.106
412	23.141	76.710	71.413	502	15.499	90.000	74.501
413	29.983	77.494	63.232	503	22.586	90.000	67.414
414	36.390	78.390	56.076	504	29.014	90.000	60.986
415	42.049	79.302	49.945	505	34.733	90.000	55.267
416	46.925	80.170	44.747	506	39.759	90.000	50.242

Table V contd.

<u>(hkl)</u>	<u>(100)</u>	<u>(010)</u>	<u>(001)</u>	<u>(hkl)</u>	<u>(100)</u>	<u>(010)</u>	<u>(001)</u>
510	11.310	78.690	90.000	550	45.000	45.000	90.000
511	13.678	78.795	82.258	551	45.273	45.273	84.401
512	18.876	79.092	74.788	552	46.061	46.061	78.906
513	24.776	79.538	67.810	553	47.284	47.284	73.610
514	30.523	80.080	61.460	554	48.830	48.830	68.586
515	35.813	80.666	55.792	555	50.586	50.586	63.885
516	40.552	81.260	50.793	556	52.449	52.449	59.533
520	21.801	68.199	90.000	600	0.000	90.000	90.000
521	22.945	68.386	82.664	601	6.591	90.000	83.409
522	25.954	68.921	75.561	602	13.012	90.000	76.988
523	29.989	69.730	68.883	603	19.119	90.000	70.882
524	34.365	70.720	62.754	604	24.806	90.000	65.194
525	38.674	71.803	57.231	605	30.017	90.000	59.984
526	42.710	72.908	52.316	606	34.733	90.000	55.267
530	30.964	59.036	90.000	610	9.462	80.538	90.000
531	31.625	59.277	83.220	611	11.464	80.599	83.498
532	33.464	59.965	76.624	612	15.904	80.777	77.159
533	36.133	61.015	70.369	613	21.038	81.051	71.123
534	39.252	62.314	64.565	614	26.166	81.397	65.492
535	42.517	63.753	59.269	615	31.018	81.788	60.322
536	45.728	65.239	54.497	616	35.490	82.201	55.634
540	38.660	51.340	90.000	620	18.435	71.565	90.000
541	39.074	51.606	83.821	621	19.433	71.679	83.745
542	40.255	52.371	77.782	622	22.078	72.008	77.635
543	42.041	53.549	72.006	623	25.683	72.519	71.797
544	44.229	55.024	66.583	624	29.677	73.166	66.324
545	46.631	56.677	61.571	625	33.703	73.901	61.274
546	49.094	58.409	56.991	626	37.570	74.681	56.667

Table V contd.

<u>(hkl)</u>	<u>(100)</u>	<u>(010)</u>	<u>(001)</u>	<u>(hkl)</u>	<u>(100)</u>	<u>(010)</u>	<u>(001)</u>
630	26.565	63.435	90.000	700	0.000	90.000	90.000
631	27.166	63.587	84.100	701	5.656	90.000	84.344
632	28.847	64.027	78.322	702	11.204	90.000	78.796
633	31.317	64.713	72.774	703	16.548	90.000	73.452
634	34.251	65.589	67.540	704	21.612	90.000	68.389
635	37.382	66.591	62.673	705	26.345	90.000	63.656
636	40.523	67.662	58.198	706	30.721	90.000	59.280
640	33.690	56.310	90.000	710	8.130	81.870	90.000
641	34.083	56.485	84.509	711	9.861	81.909	84.401
642	35.206	56.995	79.116	712	13.724	82.023	78.906
643	36.921	57.794	73.911	713	18.246	82.203	73.610
644	39.049	58.820	68.965	714	22.838	82.435	68.586
645	41.418	60.004	64.326	715	27.267	82.705	63.885
646	43.885	61.283	60.022	716	31.432	82.999	59.533
650	39.806	50.195	90.000	720	15.945	74.055	90.000
651	40.074	50.381	84.928	721	16.825	74.129	84.560
652	40.853	50.926	79.933	722	19.171	74.344	79.217
653	42.068	51.784	75.089	723	22.402	74.684	74.056
654	43.619	52.895	70.452	724	26.033	75.124	69.147
655	45.399	54.187	66.067	725	29.757	75.639	64.539
656	47.309	55.595	61.961	726	33.399	76.201	60.258
660	45.000	45.000	90.000	730	23.199	66.802	90.000
661	45.190	45.190	85.329	731	23.743	66.903	84.799
662	45.745	45.745	80.720	732	25.274	67.198	79.682
663	46.625	46.625	76.228	733	27.542	67.666	74.725
664	47.769	47.769	71.902	734	30.269	68.276	69.992
665	49.112	49.112	67.779	735	33.221	68.990	65.527
666	50.586	50.586	63.885	736	36.229	69.775	61.357

Table V contd.

<u>(hkl)</u>	<u>(100)</u>	<u>(010)</u>	<u>(001)</u>	<u>(hkl)</u>	<u>(100)</u>	<u>(010)</u>	<u>(001)</u>
740	29.745	60.255	90.000	800	0.000	90.000	90.000
741	30.112	60.376	85.085	801	4.953	90.000	85.047
742	31.165	60.728	80.242	802	9.833	90.000	80.167
743	32.784	61.288	75.535	803	14.573	90.000	75.427
744	34.812	62.020	71.019	804	19.119	90.000	70.882
745	37.095	62.884	66.735	805	23.427	90.000	66.573
746	39.503	63.838	62.709	806	27.473	90.000	62.527
750	35.538	54.463	90.000	810	7.125	82.875	90.000
751	35.796	54.595	85.393	811	8.649	82.902	85.085
752	36.548	54.982	80.844	812	12.062	82.979	80.242
753	37.726	55.601	76.408	813	16.091	83.102	75.535
754	39.242	56.413	72.133	814	20.228	83.265	71.019
755	40.996	57.377	68.053	815	24.274	83.457	66.735
756	42.897	58.448	64.194	816	28.137	83.672	62.709
760	40.601	49.399	90.000	820	14.036	75.964	90.000
761	40.789	49.537	85.700	821	14.821	76.014	85.195
762	41.339	49.943	81.447	822	16.920	76.162	80.456
763	42.214	50.592	77.288	823	19.833	76.399	75.844
764	43.358	51.449	73.260	824	23.141	76.710	71.413
765	44.710	52.472	69.395	825	26.577	77.081	67.200
766	46.206	53.615	65.716	826	29.983	77.494	63.232
770	45.000	45.000	90.000	830	20.556	69.444	90.000
771	45.140	45.140	85.994	831	21.051	69.515	85.361
772	45.551	45.551	82.027	832	22.446	69.721	80.782
773	46.212	46.212	78.135	833	24.528	70.053	76.319
774	47.087	47.087	74.351	834	27.052	70.490	72.018
775	48.135	48.135	70.702	835	29.815	71.013	67.917
776	49.316	49.316	67.208	836	32.663	71.597	64.041

Table V contd.

<u>(hkℓ)</u>	<u>(100)</u>	<u>(010)</u>	<u>(001)</u>	<u>(hkℓ)</u>	<u>(100)</u>	<u>(010)</u>	<u>(001)</u>
840	26.565	63.435	90.000	910	6.340	83.660	90.000
841	26.906	63.521	85.568	911	7.700	83.679	85.622
842	27.887	63.773	81.188	912	10.755	83.733	81.295
843	29.404	64.177	76.910	913	14.382	83.822	77.065
844	31.317	64.713	72.774	914	18.136	83.939	72.974
845	33.490	65.355	68.816	915	21.844	84.081	69.053
846	35.805	66.077	65.059	916	25.425	84.241	65.328
850	32.006	57.995	90.000	920	12.529	77.471	90.000
851	32.251	58.091	85.797	921	13.235	77.507	85.700
852	32.967	58.375	81.639	922	15.131	77.613	81.447
853	34.095	58.831	77.568	923	17.776	77.783	77.288
854	35.553	59.437	73.620	924	20.802	78.011	73.260
855	37.254	60.167	69.825	925	23.973	78.285	69.395
856	39.112	60.991	66.206	926	27.151	78.596	65.716
860	36.870	53.130	90.000	930	18.435	71.565	90.000
861	37.053	53.233	86.034	931	18.887	71.616	85.821
862	37.588	53.536	82.106	932	20.164	71.766	81.685
863	38.442	54.025	78.251	933	22.078	72.008	77.635
864	39.565	54.678	74.501	934	24.415	72.331	73.706
865	40.898	55.465	70.882	935	26.993	72.722	69.928
866	42.384	56.360	67.414	936	29.677	73.166	66.324
900	0.000	90.000	90.000	940	23.963	66.038	90.000
901	4.405	90.000	85.595	941	24.279	66.101	85.974
902	8.758	90.000	81.242	942	25.192	66.286	81.987
903	13.012	90.000	76.988	943	26.608	66.586	78.076
904	17.125	90.000	72.875	944	28.405	66.987	74.275
905	21.065	90.000	68.936	945	30.460	67.474	70.610
906	24.806	90.000	65.194	946	32.668	68.029	67.103

Table VI

The Angle between the Twin Planes (hkl) and the (100) , (010) , and (001) Planes for Alpha-Uranium at 25°C with $a_0 = 2.8545 \text{ \AA}$, $b_0 = 5.8681 \text{ \AA}$ and $c_0 = 4.9566 \text{ \AA}$

Angle between Planes in Degrees				Angle between Planes in Degrees			
(hkl)	(100)	(010)	(001)	(hkl)	(100)	(010)	(001)
1 1 1	37.011	67.143	62.622	8 32 5	63.190	28.644	80.657
1 1 2	51.347	72.312	43.994	1 7 0	73.634	16.366	90.000
0 2 1	90.000	30.623	59.377	2 2 5	56.654	74.491	37.682
0 0 1	90.000	90.000	0.000	3 3 5	47.098	70.662	49.202
1 1 0	25.940	64.060	90.000	2 1 0	13.670	76.330	90.000
4 2 1	15.782	76.465	82.037	8 2 3	13.920	83.221	77.900
0 1 1	90.000	49.813	40.187	24 32 13	35.743	58.236	75.334
2 6 1	56.088	35.492	80.755	2 0 1	16.064	90.000	73.937
1 7 1	73.851	18.721	80.783	0 4 1	90.000	16.487	73.513
0 1 0	90.000	0.000	90.000	2 6 13	76.024	69.362	25.295
1 1 3	60.876	76.305	32.768	3 5 1	39.800	51.473	81.519
0 2 3	90.000	60.616	29.385	4 16 5	64.266	32.344	71.786
2 2 1	29.479	64.947	75.483	1 1 5	71.097	80.933	21.116
1 1 2	51.347	72.312	43.994	3 3 10	63.208	77.334	30.083
1 3 1	57.486	38.336	71.968	40 32 29	29.716	70.247	68.739
1 7 2	74.454	24.130	72.019	1 2 1	48.507	49.867	67.570
1 1 3	60.876	76.305	32.768	1 0 1	29.938	90.000	60.063
2 1 1	20.653	76.845	74.369	0 1 2	90.000	67.104	22.896
1 3 2	61.725	46.267	56.933	8 6 3	22.975	70.373	78.532
1 1 4	66.988	79.038	25.769	4 0 3	23.361	90.000	66.640
3 5 1	39.800	51.473	81.519	8 96 37	81.142	25.984	65.785
4 2 3	26.368	77.414	67.233	9 19 14	53.729	52.588	57.996
1 9 7	80.462	43.493	48.086	3 5 0	39.033	50.967	90.000
1 7 2	74.454	24.130	72.019	1 2 3	63.237	64.017	38.922
8 2 1	8.044	83.084	85.913	8 32 15	65.802	37.103	63.730
4 0 1	8.193	90.000	81.807	7 7 5	32.500	65.779	69.700
1 3 0	55.579	34.421	90.000				

Table VII

The Angle between the Twinning Directions $[hk\ell]$ and the $[100]$,
 $[010]$ and $[001]$ Directions for Alpha-Uranium at 25°C with
 $a_0 = 2.8545 \text{ \AA}$, $b_0 = 5.8681 \text{ \AA}$ and $c_0 = 4.9566 \text{ \AA}$

Angle between Directions in Degrees				Angle between Directions in Degrees			
$[hk\ell]$	$[100]$	$[010]$	$[001]$	$[hk\ell]$	$[100]$	$[010]$	$[001]$
1 5 6	86.092	45.519	44.748	2 1 2	63.638	62.844	39.552
3 7 2	78.544	17.688	76.708	5 1 2	38.908	71.341	57.284
1 0 0	0.000	90.000	90.000	3 1 2	53.374	65.870	46.321
1 1 0	64.060	25.940	90.000	1 3 2	81.958	30.370	60.933
0 1 1	90.000	40.187	49.813	1 0 4	81.807	90.000	8.193
2 1 2	63.638	62.844	39.552	1 1 8	85.927	81.604	9.345
67 5 32	40.145	83.266	50.657	7 1 0	16.366	73.634	90.000
1 4 1	83.215	13.695	78.161	1 2 0	76.330	13.670	90.000
3 1 0	34.421	55.579	90.000	1 1 2	76.083	60.367	33.356
2 3 2	74.221	33.017	61.825	3 1 8	77.941	81.769	14.671
0 1 0	90.000	0.000	90.000	1 0 2	73.937	90.000	16.064
0 1 2	90.000	59.377	30.623	0 1 4	90.000	73.513	16.487
10 7 3	56.839	38.081	73.445	2 1 1	53.379	52.183	58.809
14 12 1	60.485	29.764	86.497	1 1 4	82.140	73.672	18.218
5 7 16	80.921	62.989	28.737	2 0 1	40.965	90.000	49.035
79 7 64	54.817	83.976	35.851	5 1 8	70.402	82.073	21.265
15 9 2	51.452	39.767	81.705	2 1 4	74.565	74.124	22.438
7 6 8	69.353	51.588	45.594	1 1 1	69.614	44.267	52.781
5 1 0	22.350	67.650	90.000	3 0 1	30.063	90.000	59.938
2 1 0	45.788	44.213	90.000	0 2 1	90.000	22.896	67.104
7 1 1	21.028	74.091	76.613	3 3 2	67.030	36.654	63.144
3 4 1	70.356	22.857	78.780	3 0 4	66.640	90.000	23.361
0 0 1	90.000	90.000	0.000	1 3 8	86.236	66.116	24.216
1 3 0	80.790	9.210	90.000	5 3 0	50.967	39.033	90.000
41 17 46	64.815	68.732	33.999	1 2 1	77.371	25.983	67.688
16 4 5	36.774	65.691	64.237	3 3 8	78.835	66.542	26.276
1 0 1	60.063	90.000	29.938	101 67 32	55.783	39.928	71.979

samples except the 1500 ppm Si alloy were free of U_3Si precipitates. The 1500 ppm alloy, being quenched from a two-phase region in the beta phase, would be expected to retain its two-phase nature. It should, however, have the maximum possible amount of silicon in solid solution. Samples of the 330 ppm alloy were annealed at 500°C or 600°C for periods of time ranging from 1 hour up to 300 hours. The 530 ppm alloy and the 1500 ppm alloy were annealed at 600°C only. At the end of the annealing treatments, the samples were quenched in water.

Observations

In order to determine the annealing times which would be favorable for studying the formation of U_3Si precipitates, samples were annealed at 500°C or 600°C and then examined in the electron microscope. Equilibrium precipitates of U_3Si were not observed in any of the samples annealed at 500°C for periods of time of up to 300 hrs. Figure 3 is typical of photomicrographs of samples which had received the maximum time at temperature. The sample does contain numerous dislocations some of which occur in pairs, which may be an indication of incipient ordering.

An annealing temperature of 500°C was therefore viewed as being much too low to achieve precipitation within any treatment duration that would be at all reasonable in the preparation of samples. Thus, all samples annealed after this preliminary experiment were heat treated at 600°C.

In those samples of the 530 ppm Si alloy, annealed at 600°C for the longer annealing times, U_3Si precipitates were observed. For example, in the sample annealed for 100 hrs at 600°C there were numerous U_3Si precipitates that had grown to over a micron in length and were about 0.1 micron in width. There were other precipitates observable which were in the process of growing at various dislocation sites. The precipitates grew as rod-shaped particles and occurred within grains as well as at grain boundaries.

Figure 4 shows a typical photomicrograph of the sample annealed for 100 hrs. Trace analysis revealed that the precipitates were growing at dislocations associated with the slip and twinning planes in uranium. Figure 5 is the diffraction patterns from the central area in Figure 4. Figure 6 is the analysis of the principal plane traces found in Figure 4 and is based on the diffraction pattern shown in Figure 5. It should be noted that in general it is not possible to identify unambiguously a particular trace unless additional information can be supplied. A first approximation can be obtained by assuming a uniform foil thickness for the area examined. Then by measuring the width of the trace, a foil thickness can be calculated using each assumed plane for each trace. It then should be possible to pick out a set of plane traces which give a fairly uniform foil thickness. Although this has not been done for this particular trace, this procedure has been quite useful in other analyses.

It is also noteworthy in Figure 4 that the precipitate at "A" is forming at a pair of dislocations. This could mean that local ordering may be a stage in

the formation of the U_3Si precipitate.

Examination of the photomicrographs and the electron micrographs of the 530 ppm and 1500 ppm alloys showed increasing precipitation with increasing time at the 600°C annealing temperature. Figure 7 contains a series of photomicrographs at 100X. It can be noted that no fine U_3Si precipitates are visible in the as-quenched 530 ppm Si specimen although large U_3Si precipitates are visible in the 1500 ppm alloy. It is evident that the amount of very fine U_3Si precipitate increases with increasing annealing time as would be expected. Figure 8 shows an electron micrograph of the 530 ppm alloy that had been annealed at 600°C for 7 hours. In the lower half of the picture several U_3Si precipitates labeled "A" are visible. In the upper half of the photomicrograph, several very small areas indicated by arrows show what are believed to be Guinier-Preston zones. These zones are approximately 100 Å in diameter and rather sparsely populate this particular alloy. The role of Guinier-Preston zones in the formation or nucleation of U_3Si has not been postulated. The onset of precipitation was also evidenced in the diffraction photographs taken of the specimens. The as-quenched samples showed a simple uranium pattern. The patterns for annealed samples became increasingly complex with annealing time up to the point where good U_3Si patterns also appeared. Further annealing again yielded the simple uranium pattern plus the additional U_3Si pattern. The complexity in the pattern revealed itself in the form of rows of related diffraction spots superimposed on the pattern for uranium. Figure 9 shows such a complex pattern. The large spots comprise the main uranium pattern, the smaller spots lined up in rows are anomalous spots due to double diffraction effects from the thin plate-like U_3Si . The orientation of the double diffraction spots, in this particular pattern, suggests that the early stages of precipitation occurred on planes which were approximately 90° from the (001) plane of uranium. The most probable planes would be those which lie within a few degrees (possibly 10°) of the plane of the foil. This relationship is suggested by the fact that the anomalous spots can be indexed in a fashion to show that they are related to each other by a difference of (hkl).

Only a limited amount of crystallographic data has been fully interpreted to date in this study. Figure 9 is typical of this type of data. The patterns for uranium (large dots) and U_3Si (open circles) can be graphically manipulated to reveal orientation relationship between the precipitate and the matrix. Figure 10 shows the relationships obtained from the patterns in Figure 9. The following orientation relationships, as well as others, can be seen on the stereographic projection:

$$(\bar{1}00)_m \parallel (\bar{1}01)_p$$

$$(\bar{0}\bar{1}\bar{1})_m \sim \parallel (\bar{0}\bar{1}0)_p$$

$$(001)_m \sim \parallel (122)_p,$$

where m = matrix and p = precipitate.

Due to the fact that the precipitate has been observed to form on slip or twinning planes, many other orientation relationships are possible. In all cases where anomalous spots were observed the plane of the foil was within 10° of a twinning plane.

The crystallographic relationships quoted above should be regarded as strictly arbitrary since it was necessary to assign arbitrary plus or minus signs to the hkl 's of the diffraction spots when indexing the pattern. However, by performing tilting experiments, it should be possible to index in three dimensions and thereby eliminate any doubt as to the correct sign of the Miller indices for any spot. If Kikuchi patterns were easier to obtain, this would also be a means of eliminating such uncertainty.

Figure 11 shows three diffraction patterns as well as a polar diagram of the position of the perpendicular to the plane of the sample relative to the electron beam. Patterns 1 and 2 both contain a row of spots labeled (021), (042), and (063) but no others which index alike. In patterns 2 and 3, the common row is the one containing the (200) and (400) reflections. Patterns 1 and 3 are tilted 5° in relation to pattern 2 but in mutually perpendicular directions as shown on the polar diagram. The patterns represent three planar sections through an array of points in space, and the common rows of spots are along the line of intersection of the two planes involved. In this way an unambiguous determination of spacial relationships can be made between the matrix and the precipitate since the orientation of the specimen can be uniquely determined.

EXAMINATION OF A URANIUM-ALUMINUM ALLOY BY TRANSMISSION ELECTRON MICROSCOPY

At the request of R. Schierding and L. Ferguson, who were working on uranium phase diagrams, a sample of a uranium alloy was examined by transmission electron microscopy. The sample contained 2000 ppm aluminum and had been annealed for 4 months at 550°C and water quenched. The sample when examined by light microscopy showed a very fine second-phase material whose size was about at the resolution limit of optical microscopy and not as large size agglomerates as expected.

Normal sample preparation procedures were followed for the preparation of a thin foil from this material. When examined the foil revealed rod or needle shaped particles with a diameter of about 1000 Å to 1500 Å and were from 4000 Å to 10,000 Å in length. An electron diffraction pattern from an area containing one of these particles was obtained. The pattern contained both the uranium pattern and the precipitate pattern. Figure 12 shows the two patterns with the measured d spacing for the precipitate pattern shown beside the spots.

The diffraction spots cannot be indexed as UAl_2 but could be indexed as UAl_3 as shown in Table VIII. However, this was not consistent with the composition of the sample. Further study revealed that the pattern could be indexed as U_3Si with an expanded lattice, having a_0 expanded from 6.029 Å to 6.080 Å. This is more consistent with the sample composition since it did contain a

small amount of silicon. Other samples from this metal and one prepared especially as a standard for UAl_2 gave patterns which indexed perfectly for UAl_2 . It is easy to see from this experience that some common sense is needed along with the facility to index patterns.

Table VIII

Comparative Indexing of the Diffraction
Pattern in Figure 12

UAl_3 $a_0 = 4.287 \text{ \AA}$			U_3Si with an expanded lattice $a_0 = 6.080 \text{ \AA}$	
<u>d measured</u>	<u>hkl</u>	<u>d</u>	<u>hkl</u>	<u>d</u>
4.298	100	4.287	110	4.299
2.149	200	2.143	220	2.150
3.042	110	3.031	200	3.040
1.919	210	1.917	310	1.923
1.529	220	1.516	400	1.520

STUDIES OF FLOW IN URANIUM BY TRANSMISSION ELECTRON MICROSCOPY

Foil Tensile Samples

Attempts have been made to produce tensile specimens suitable for use in the transmission electron microscope. The desired configuration would be an hour-glass shape where the deformation could be restricted to the reduced cross section. So far, such attempts have been unsuccessful. The added polishing necessary to produce this configuration has resulted in highly unsatisfactory thin sections at the constriction. This area of the specimen has become highly oxidized, and the removal of this oxide without destroying the specimen has been the major problem.

Mechanisms of Flow in Standard Hot Tensile Tests

Thin sections of full-sized tensile specimens pulled at room temperature, 300°C and 500°C have been examined. The samples came from centrifugally cast cores with the room temperature specimen analyzing 190 ppm Fe, 160 ppm Si, 530 ppm C, and 1.7 ppm H_2 . The similar 300°C and 500°C test specimens analyzed 174 ppm Fe, 320 ppm Si, 1200 ppm C, and 18 ppm H_2 .

The room temperature specimen, Figure 13 was very heavily twinned and had a very high concentration of dislocations. In spite of the small (2000 $\text{\AA}$ wide)

poorly formed twins, it was possible to identify the twin system operating through diffraction and trace analysis. There were four systems that would fit the trace analysis:

System	K_1	K_2	η_1	η_2	S
1	(021)	(821)	[100]	[132]	0.286
2	(421)	(021)	[232]	[100]	0.566
3	(021)	(863)	[100]	[332]	0.849
4	(8,96,37)	(001)	[138]	[130]	0.900

The above are illustrated in Figure 14. The notation K_1 refers to the twin plane, K_2 the reciprocal twin plane, η_1 the twinning direction, η_2 the reciprocal twinning direction, and S is the amount of shear. Thus K_{11} is the K_1 plane for System 1, K_{21} is the reciprocal twin plane for System 1, and K_{12} is the twin plane for twin System 2. P_1 and P_2 represent the normals to the two crystal systems in the diffraction pattern and since the section examined was a transverse section, they represent the tensile axis.

The decision as to which twin system was operating is determined by a process of elimination. System No. 4 can be excluded since η_1 , the twinning or shear direction [138], is over 70° from the tensile axis and the amount of shear is very high, 0.900. A decision between Systems 1 and 3 must be made on the basis of the much greater amount of shear needed for System No. 3, since the other factors are about equal. Systems 1 and 2 are almost conjugate systems. The η_{11} is 35° from P_1 while η_{12} is only 9° from P_2 , but S_1 is 0.286 while S_2 is 0.566. The twin System No. 2 has the greatest resolved shear but also requires more shear to operate. The choice is between Systems 1 and 2 and in all probability both systems were operating.

The 300°C specimen, Figure 15 appeared to be twinned also, but the twins were up to 1μ in width or five times the size of those in the room temperature specimen. The twin boundaries were very straight; the dislocation density was very much lower and well separated from the boundaries. Trace and diffraction analyses have not been completed on this sample, but it appears to be at least partially polygonized due to the slow cooling in the furnace after the tensile test.

Transverse sections from the 500°C tensile specimen were examined. The photograph, Figure 16, shows what appear to be twins that range in width from 0.1 micron to 0.3 micron and have slightly curved boundaries. The diffraction pattern, Figure 17, from a selected area, shows a series of spot patterns about an axis normal to the plane on the foil. Each spot pattern is rotated only a few degrees from the other spots. Analysis of the bands of dislocation networks shows them to be on (172), (111), and (112) planes. A calculation of foil thickness from a

narrow dislocation band and a wide dislocation band shows the foil to be 154 Å and 166 Å thick, respectively, at these bands. Since the locations were within 0.5 μ of each other, it appears that the data on the planes are mutually consistent.

The fact that essentially one diffraction pattern was obtained and that the dislocation networks are on known slip planes suggests that the deformation at 500°C was occurring by slip. If twinning had occurred, it would have produced two or more diffraction patterns and the boundaries between the twins would have been coherent and showed striking fault contrast rather than dislocation networks. This condition is quite apparent when the grain boundaries in Figure 13 and Figure 16 are carefully examined.

Conclusions

Even though the investigation is not complete, it has been demonstrated that a post-mortem of a tensile specimen by thin-foil analysis can be used to study the deformation mechanisms occurring in uranium. Thin-foil analyses, coupled with a knowledge of second-phase morphology, should permit an assessment of deformation mechanisms and metal stability in relation to alloying and heat treatment.

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Figure 1. Standard (001) Projection for U_3Si .

Prepared by H. C. Kloepper, Jr.,
Mallinckrodt Chemical Works, Uranium Division,
St. Charles, Missouri

Figure 2. Standard (100) Projection for Alpha-Uranium.

Prepared by M. H. Mueller and H. W. Knott,
Argonne National Laboratory, Lemont, Illinois.

Figure 3. Uranium with 330 PPM Si, Solution-Treated 24 Hours at 700°C and Water-Quenched, Annealed 306 Hours at 500°C and Water-Quenched. (Plate 7; 54,600X)

Figure 4. Uranium with 530 PPM Si, Solution-Treated 48 Hours at 750°C and Water-Quenched, Annealed 100 Hours at 600°C and Water-Quenched. The precipitates (A's) are forming on a pair of dislocations. (Plate 522; 51,600X)

Figure 7. Polarized Light Photomicrographs (100X) of Solution Heat-Treated Alloys of Uranium Containing 530 PPM Silicon (Left Column) and 1500 PPM Silicon (Right Column). The precipitation resulting from annealing at 600°C for 0, 7, and 30 hours, respectively, is shown (top to bottom).

Figure 8. Uranium with 530 PPM Si, Solution-Treated and Aged 7 Hours at 600°C.
Note the U_3Si precipitates (A's) and the Guinier-Preston zones (arrows).

Figure 9. Scale Drawing of the Diffraction Pattern from an Alloy of Uranium Containing 1500 PPM Si, solution-treated and annealed 7 hours at 600°C. The open circles are U_3Si ; the large solid dots are uranium; the small solid dots are anomalous uranium spots obtained by doubled diffraction.

Figure 10. Stereographic Projection of the Data Obtained from the Diffraction Pattern Shown in Figure 9. The open circles are the location of the poles from the U_3Si precipitate. The solid circles represent the poles from the uranium matrix.

Pattern 1

Pattern 2

Pattern 3

Figure 11. Diffraction Patterns from the Same Area of a Foil. The foil was perpendicular to the beam in Pattern 2. In Patterns 1 and 3, the foil was tilted so that the direction perpendicular to the foil was in position indicated in the polar diagram.

Figure 12. Diffraction Pattern from a 2000-PPM Al Alloy of Uranium. The open circles are the uranium pattern. The dots with their " d " spacings beside them are from a precipitate particle. The pattern appears to be UAl_3 , but is not consistent with the composition. A better solution is U_3Si with an expanded lattice.

Figure 13. A Transmission Electron Micrograph of the Uranium Tensile Specimen at Room Temperature, Showing the Transverse Section Near the Break. Note the coherent boundaries (parallel lines) between twins. (Plate 855; 86,100X)

Figure 14. Possible Twin Systems in the Room-Temperature Tensile Specimen Shown on an (001) Projection for Uranium. Note that for any twin system K_1 , K_2 , η_1 , and η_2 lie in the same plane.

Figure 15. A Typical Twin in the 300°C Tensile Specimen Occupies Nearly the Entire Field. Note the sparcity of dislocations in the twins. (Plate 775; 86,100X)

Figure 16. A Tensile Specimen of Uranium Pulled at 500°C Shown in a Transverse Section Near the Break. The dislocation networks (network of lines) in the boundaries are between the slipped areas. (Plate 990; 86,100X)

Figure 17. Diffraction Pattern from the Central Area of Figure 16.
The repeated patterns are slightly rotated from each other
because of a slight reorientation of each slipped area.