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Metals, Ceramics, and
Materials

MASTER

DETERMINATION OF SELECTED MECHANICAL
AND PHYSICAL PROPERTIES OF CAST
VERY-HIGH-ASSAY URANIUM

D. J. Legacy
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UNION CARBIDE CORPORATION
NUCLEAR DIVISION
OAK RIDGE Y-12 PLANT

operated for the ATOMIC ENERGY COMMISSION under U. S. GOVERNMENT Contract W-7405 eng 26

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UNION CARBIDE CORPORATION
Nuclear Division

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With the US Atomic Energy Commission

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ABSTRACT

Mechanical and physical tests were performed on very-high-assay (97.5% U-235) uranium castings. The castings were sampled at locations selected to determine any edge-to-center or top-to-bottom variation in properties. The test results, subjected to statistical analysis, indicated that the properties were uniform within each casting and among castings.

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SUMMARY

Tensile, compressive, impact, Poisson's ratio, and thermal expansion tests were performed on very-high-assay uranium (97.5% U-235) castings. Where possible, these tests were made over the temperature range from -65 to 165° F.

A statistical analysis of the test results indicates that a high degree of uniformity of properties exists among castings and within castings. The slight scatter detected in the data is due to the variability inherent in a large-grain-size casting of relatively pure metal and/or the anisotropy of uranium.

INTRODUCTION

The availability of superoralloy (97.5% U-235) has made it possible to extend the data on the physical and mechanical properties of uranium to include this extra-high-assay material. For this study it was decided to use castings that were four inches in diameter and to perform the tests in sufficient quantity to obtain a statistical analysis of the data. Sampling would be carried out in a way that would detect any variability in properties from the edge to the center (longitudinal properties) and from the top to the bottom (transverse properties) of the castings. Where possible, the tests were to be performed over the temperature range from -65 to 165° F.

DETERMINATION OF THE PROPERTIES OF HIGH-ASSAY URANIUM

PERFORMANCE OF THE TESTS

Four uranium castings were poured using conventional foundry methods. A charge of the very-high-assay metal was vacuum-induction melted in a graphite crucible and bottom poured into a heated graphite mold, approximately 4 1/2 inches high. All four castings were smooth, symmetrical, and free of visible primary piping. The casting procedure was designed to produce the maximum yield of sound metal.

The tops of the castings were machined smooth and a portion of the metal chips from each casting was used for chemical analysis. The analytical results for all four castings are given in Table 1. Incidental contaminants were below the limits of detection of the analytical method used.

Table 1
CHEMICAL ANALYSIS OF FOUR-INCH-DIAMETER
HIGH-ASSAY URANIUM CASTINGS

Element	Casting Number (ppm)			
	1	2	3	4
Al	15	8	10	8
C	164	147	175	140
Cr	< 2	2	2	4
Cu	10	8	4	40
Fe	60	150	150	100
Mn	3	3	3	3
Mo	75	96	124	80
Ni	25	18	20	15
Si	60	40	35	50

Each casting was partitioned and sampled (Figures A-1 through A-4 of the Appendix). A total of 43 tensile specimens, 31 impact specimens, 22 compressive specimens, 21 shear specimens, and 21 thermal expansion specimens were machined from the four castings and tested. The compressive test specimens were also used for density determinations. Two tensile specimens were discarded because of minor casting flaws in the reduced section of the test specimen.

All tests were performed in accordance with the standards of the American Society of Testing and Materials.

Specimens for tensile testing were machined in accordance with the specifications given in Figure A-5 of the Appendix. Tensile tests were made over the temperature range of -65 to 165° F. Individual test results are presented in Table 2. A statis-

Table 2
TENSILE TESTS OF CAST HIGH-ASSAY URANIUM

Specimen Identity	Temperature Tested (° F)	Tensile Strength (psi)	Yield Strength ⁽¹⁾ (psi)	Elongation ⁽²⁾ (%)	Reduction in Area (%)
1111	-65	52,250	35,400	2	6.5
1112	0	50,400	21,850	5	2.4
1113	RT	65,050	26,200	5	5.7
1114	115	64,350	22,250	7	6.8
1115	165	82,400	29,450	15	7.6
1116	RT	53,350	32,950	5	5.5
1117	RT	59,200	25,750	5	5.1
1118	RT	65,800	24,850	7	11.0
1119	RT	49,800	19,800	7	11.3
2111	-65	45,800	26,850	2	3.1
2112	0	54,100	25,250	5	1.6
2113	RT	57,850	32,900	7	6.4
2114	115	71,500	19,700	9	11.6
2115	165	70,850	20,850	20	23.8
2116	RT	66,950	22,650	7	4.4
2117	RT	54,800	30,950	5	3.5
2118	RT	56,750	20,650	5	12.0
2119	RT	64,900	32,650	6	5.3
2212	RT	66,600	28,350	5	5.1
3111	-65	53,750	33,300	3	2.0
3112	0	52,350	27,650	5	3.1
3113	RT	62,150	22,350	7	10.8
3114	RT	66,850	29,400	5	9.0
3115	115	75,100	27,700	7	8.6
3116	165	77,300	21,221	18	14.6
3117	RT	62,250	24,950	5	9.4
3118	RT	58,100	23,750	5	6.8
3119	RT	63,000	37,450	6	5.9
3211	RT	70,900	34,750	5	8.0
3212	RT	64,250	22,250	9	13.1
3213	RT	61,900	19,650	8	13.5
3214	RT	67,950	24,850	9	10.8
4111	-65	52,250	29,350	3	3.5
4112	115	72,750	36,400	7	7.6
4113	RT	62,350	35,100	5	4.7
4114	165	71,750	24,950	14	16.4
4116	RT	63,200	29,400	5	9.0
4117	RT	51,550	26,800	5	11.6
4118	RT	68,750	35,250	6	13.5
4212	RT	61,750	22,050	8	13.8
4213	RT	64,650	17,050	6	25.9
4214	RT	55,600	31,100	4	5.5
4215	RT	60,400	23,350	6	9.0

(1) 0.2 percent offset.

(2) In one inch.

tical evaluation of the tensile tests is summarized in Table 3. In this report, the specimens designated as "longitudinal" were taken in the axial direction of the castings while those designated as "transverse" were taken at right angles to the cylinder axis.

Table 3

STATISTICAL EVALUATION OF THE TENSILE TESTS

Specimen Direction	Temperature (° F)	Number of Measurements	Average Tensile Strength (psi)	Limit of Error of Average (psi) ⁽¹⁾	Limits within which Approximately 95% of the Measurements would be Included (psi) ⁽¹⁾
Transverse	RT	9	63,778	±3,167	54,279 - 73,277
Longitudinal	RT	18	61,269	±2,728	49,701 - 72,837
Longitudinal	-65	4	51,012	±4,637	41,738 - 60,286
	0	3	52,283	±5,361	43,009 - 61,557
	115	4	70,938	±4,637	61,664 - 80,212
	165	4	75,575	±4,637	66,301 - 84,849
Average Yield Strength (psi)					
Transverse	RT	9	24,822	±5,080	9,583 - 40,061
Longitudinal	RT	19	28,095	±2,610	16,714 - 39,476
Longitudinal	-65	4	31,225	±5,484	20,256 - 42,194
	0	3	24,917	±6,340	13,948 - 35,886
	115	4	26,512	±5,484	15,543 - 37,481
	165	4	24,112	±5,484	13,143 - 35,081
Average Elongation (%)					
Transverse	RT	9	6.7	± 1.4	2.4 - 11.0
Longitudinal	RT	19	5.7	± 0.4	3.7 - 7.7
Longitudinal	-65	4	2.5	± 1.7	0.0 - 5.9
	0	3	5.0	± 2.0	1.6 - 8.4
	115	4	7.5	± 1.7	4.1 - 10.9
	165	4	16.8	± 1.7	13.4 - 20.2
Average Reduction in Area (%)					
Transverse	RT	8	9.8	± 3.0	1.4 - 18.2
Longitudinal	RT	18	7.7	± 1.4	1.9 - 13.5
Longitudinal	-65	4	3.8	± 3.1	0.0 - 9.9
	0	3	2.4	± 1.9	0.0 - 5.6
	115	4	8.6	± 3.3	1.9 - 15.3
	165	4	15.6	±10.6	0.0 - 36.8

(1) Except as noted.

RESULTS

The following statements can be made as a result of this study:

Tensile Strength

The data indicate that there is no significant difference between castings for the tensile strength of transverse specimens and there is no significant difference in tensile strength between the locations of the transverse specimens. The data also indicate that there is no significant difference in tensile strength between castings for the longitudinal specimens nor are the longitudinal specimens significantly different from the transverse specimens. One measurement, the center longitudinal result for Casting 1, was omitted as a deviant result.

It is further indicated that a significant correlation exists between temperature and tensile-strength results for the longitudinal specimens. Approximately 68 percent of the variation in the tensile results can be explained by a linear dependence on the test temperature.

Yield Strength

From the results it appears that there is no significant difference between castings or locations for the yield strength of the transverse specimens and that there is no significant difference in yield strength between castings for the longitudinal specimens. The yield strengths of the longitudinal specimens are not significantly different from the transverse specimens. No significant statistical relation exists between the temperature and the yield strength of the longitudinal specimens.

Percent Elongation

Percent elongations of the transverse specimens are not significantly different between castings or locations. The longitudinal specimens are not significantly different between castings, and there is no significant difference between the longitudinal and transverse specimens.

A significant linear correlation exists between temperature and percent-elongation results for the longitudinal specimens from -65 to 115° F. Approximately 70 percent of the variation in the elongation results can be explained by a linear dependence on the test temperature used from -65 to 115° F.

Reduction in Area

There is no significant difference between castings for the reduction in area of transverse specimens. There is no significant difference in the reduction-in-area results between locations of transverse specimens. One measurement from Casting 4 was considered a deviant result and omitted from the analysis. There is no significant difference between castings for the reduction in area of longitudinal specimens. The longitudinal specimens are not significantly different from the transverse specimens. One measurement, an outside longitudinal result from Casting 2, was omitted as a deviant result.

A significant correlation exists between temperature and reduction-in-area results for the longitudinal specimens. Approximately 44 percent of the variation can be explained by a linear dependence on the temperature used.

Impact Strength

There is no significant difference in the impact strength between castings for the transverse specimens and there is no significant difference between the locations of the transverse specimens. The data indicate that the impact strength of the longitudinal specimens for Casting 2 is significantly greater than that for specimens of the other castings by about 4.2 ± 2.3 foot pounds. Impact strengths of the longitudinal specimens for the other castings are not significantly different from that of the transverse specimens.

Charpy impact test samples of the type shown in Figure A-6 (Appendix) were tested. The individual test results are reported in Table 4. A statistical evaluation of these Charpy tests is given in Table 5.

A significant correlation exists between the test temperature and Charpy test results for the longitudinal specimens. Approximately 82 percent of the variation in the results can be explained by a linear dependence on the test temperature. One measurement, the 115° F result for Casting 3, was considered a deviant result and omitted from the analysis.

Compressive Yield Strength

The compressive specimens were the type shown in Figure A-7, Appendix. The individual test results are listed in Table 6. Statistical evaluation of the yield strength determined in compression tests is presented in Table 7.

Table 4
CHARPY TESTS OF CAST HIGH-ASSAY URANIUM

Specimen Identity	Temperature (° F)	Impact Strength (ft lbs)
1121	-65	12.5
1122	0	13.0
1123	RT	17.0
1124	165	26.5
1125	RT	16.5
1126	RT	18.0
1221	RT	16.5
1222	RT	22.5
1223	RT	16.0
2121	-65	8.0
2122	115	
2123	165	24.0
2124	RT	22.5
2125	RT	21.0
2221	RT	18.0
2222	RT	17.0
2223	RT	11.0
3121	0	11.0
3122	115	14.0
3123	RT	18.0
3124	RT	20.5
3221	RT	20.0
3222	RT	25.5
3223	RT	15.0
4121	-65	11.0
4122	115	21.0
4123	165	22.5
4124	RT	16.0
4125	RT	17.0
4221	RT	18.5
4222	RT	14.0

As indicated, the transverse compressive-yield specimens are not significantly different between castings; the yield strengths of the longitudinal compressive specimens are not significantly different between castings or locations. There is no significant difference between the longitudinal and transverse compressive-yield specimens.

Poisson's Ratio

Test specimens for the determination of Poisson's ratio were prepared in accordance with the drawing shown in Figure A-8 of the Appendix. Test data were obtained by attaching pairs of strain gages, oriented at right angles to each other, on opposite faces of the test specimens. The individual test results are reported in Table 8; a statistical evaluation of the Poisson's ratio measurements is presented in Table 9.

Table 5
STATISTICAL EVALUATION OF THE CHARPY IMPACT TESTS

Test Direction	Temperature (° F)	Number of Measurements	Average Charpy Value (ft lbs)	Limit of Error Average (ft lbs)	Limits within which Approximately 95% of the Measurements would be Included (ft lbs)
Transverse	RT	11	17.6	±2.9	7.6 - 27.6
Longitudinal					
Casting 2	RT	2	21.8	±2.0	19.0 - 24.6
Castings 1, 3, and 4	RT	7	17.6	±1.1	14.6 - 20.6
Longitudinal	-65	3	10.6	±3.1	5.3 - 15.9
	0	2	11.9	±3.8	6.6 - 17.2
	115	1 ⁽¹⁾	21.2	±5.3	15.9 - 26.5
	165	3	24.2	±3.1	18.9 - 29.5

(1) One measurement appeared deviant and was excluded from the analysis evaluation.

Table 6
COMPRESSION TESTS OF CAST HIGH-ASSAY URANIUM

Specimen Identity	Yield Strength ⁽¹⁾ (psi)
1141	27,650
1142	31,900
1241	34,550
1242	40,750
1243	47,100
2143	34,400
2144	39,200
2142	28,500
2241	24,150
2242	30,200
2243	26,800
3141	29,450
3142	37,100
3143	36,250
3241	33,700
3242	36,700
4141	46,850
4142	45,450
4143	44,450
4241	28,350
4242	31,900
4243	37,550

(1) 0.2 percent offset.

Table 7

STATISTICAL EVALUATION OF THE ROOM-TEMPERATURE COMPRESSIVE-YIELD-STRENGTH TESTS

Specimen Direction	Number of Measurements	Average Yield Strength (psi)	Limit of Error of Average (psi)	Limits within which Approximately 95% of the Measurements would be Included (psi)
Transverse	11	33,795	$\pm 3,232$	23,065 - 44,525
Longitudinal	11	36,473	$\pm 2,747$	27,353 - 45,593

Table 8

POISSON'S RATIO OF CAST HIGH-ASSAY URANIUM

Specimen Identity	Poisson's Ratio
1161 Side A	0.21
Side B	0.18
1162 Side A	0.19
Side B	0.21
1164 Side A	0.16
Side B	0.15
2161 Side A	0.33
Side B	0.25
2162 Side A	0.28
Side B	0.26
3161 Side A	0.24
Side B	0.24
4161 Side A	0.20
Side B	0.23
4162 Side A	0.17
Side B	0.14

Table 9

STATISTICAL EVALUATION OF POISSON'S RATIO

Casting Number	Measurements	Average Poisson's Ratio (%)	Limit of Error of Average (%)	Limits within which Approximately 95% of the Measurements would be Included (%)
1 and 4	10	0.18	± 0.02	0.11 - 0.25
2 and 3	6	0.27	± 0.03	0.20 - 0.34

The specimen side-to-side variation for Poisson's ratio is estimated to be ± 0.06 . The data indicate that Poisson's ratio for Castings 2 and 3 is significantly greater than for Castings 1 and 4 by about 0.09 ± 0.03 .

Coefficient of Thermal Expansion

Determinations of the coefficient of thermal expansion were made on 1/4-inch-round rods. It was not possible with the available equipment to obtain data for continuous heating and cooling on the entire range of temperature from -65 to 165° F. Therefore, two thermal expansion coefficients were obtained: (1) an average of the expansion and contraction in heating and cooling from room temperature to 165° F; (2) the average of the contraction and expansion in going from room temperature to -65° F and warming again to room temperature.

The individual test results are presented in Table 10; a statistical evaluation of the results is presented in Table 11. The data indicate that, within a temperature range, there is no significant difference in the thermal coefficient of expansion between castings for the transverse specimens. (A decrease of about 0.6×10^{-6} inch per inch per degree fahrenheit was observed from the top to the bottom of the casting for the transverse specimens within each temperature range.) Within each temperature range, there is no significant difference between castings or between locations for the longitudinal specimens, and there is no significant difference for the coefficient of thermal expansion between the two temperature ranges studied.

The data indicate that there is no significant difference for measurement repeatability between the two temperature ranges. In both cases, the measurement repeatability is estimated to be $\pm 0.4 \times 10^{-6}$ inch per inch per degree fahrenheit.

Density

The compression test specimens were only tested to a stress which just exceeded the yield stress at 0.2 percent offset and thus were suitable for density measurements. The individual results obtained by the water-displacement method are recorded in Table 12; a statistical evaluation of the density determinations is given in Table 13.

CONCLUSIONS

The results of the statistical study of the properties of cast high-assay uranium indicated that the properties were uniform within each casting and among castings. Some slight scatter in the data is due to the variability inherent in a large-grain-size casting of relatively pure metal and/or the anisotropy of the uranium.

Table 10
COEFFICIENT OF THERMAL EXPANSION OF
CAST HIGH-ASSAY URANIUM

Materials Evaluation Sample Number	Transactor Sample Number	Requester's Sample Number	$\bar{\alpha}$ ($\times 10^{-6}/^{\circ}\text{F}$) ⁽¹⁾	
			-65 to 75° F	75 to 170° F
9200-9041-25	8980-0021	3131	7.9	8.7
-26	-0022	3233	8.1	7.4
-27	-0023	3133	8.4	8.0
-28	-0024	3132	8.1	8.8 (8.5)
-29	-0025	3231	8.2	8.2
-30	-0026	3232	8.2 (8.5)	7.9
-31	-0057	4131	8.7	8.6
-32	-0058	4132	8.8	9.3
-33	-0059	4231	8.9 (8.8)	8.7
-34	-0060	4232	8.5	8.5
-35	-0094	2131	8.9	8.5 (8.6)
-36	-0095	2132	8.6	8.0 (8.2)
-37	-0096	2133	8.1	8.4
-38	-0097	2231	7.8 (7.8)	8.3
-39	-0098	2232	7.1 (6.7)	7.1
-40	-0099	2233	7.8 (7.9)	8.0 (8.3)
-41	-0131	1131	7.9 (7.8)	8.3
-42	-0132	1132	8.2 (8.0)	7.8
-43	-0133	1231	8.4 (8.9)	9.0
-44	-0134	1232	7.6 (7.5)	7.2
-45	-0135	1233	8.3	8.2
Average			8.1	8.3
Limit of Error (95% CL)			±1.1	±1.1

(1) Values obtained from a second test used to determine repeatability are listed in parentheses.

Table 11
STATISTICAL EVALUATION OF THE COEFFICIENT OF THERMAL EXPANSION

Specimen Direction	Measurements	Average Expansion, $\bar{\alpha}$ ($\times 10^{-6}$ in/in/ $^{\circ}$ F)	Limit of Error of Average	Limits within which Approximately 95% of Measurements would be Included ($\times 10^{-6}$ in/in/ $^{\circ}$ F)
			($\times 10^{-6}$ in/in/ $^{\circ}$ F)	
<u>-65 to 75° F</u>				
Transverse	10	8.1	± 0.3	7.0 - 9.2
Longitudinal	8	8.4	± 0.3	7.6 - 9.2
<u>75 to 165° F</u>				
Transverse	10	8.0	± 0.5	6.5 - 9.5
Longitudinal	8	8.5	± 0.3	7.7 - 9.3

Table 12
DENSITY RESULTS

Casting 1 (gms/cc)		Casting 2 (gms/cc)		Casting 3 (gms/cc)		Casting 4 (gms/cc)	
Gross Casting	Individual Specimen	Gross Casting	Individual Specimen	Gross Casting	Individual Specimen	Gross Casting	Individual Specimen
18.75	18.78	18.77	18.77	18.78	18.76	18.79	18.76
	18.77		18.77		18.77		18.75
	18.71		18.77		18.73		18.76
	18.78		18.77		18.76		18.77
	18.77		18.77		18.76		18.77
	18.76		18.76		-		18.76

Table 13
STATISTICAL EVALUATION OF DENSITY

Number of Measurements	Average Density (gms/cc)	Limit of Error of Average (%)	Limits within which 95% of Measurements would be Included (gms/cc)
22	18.762	± 0.008	18.72 - 18.80

APPENDIX

SPECIMEN DRAWINGS

Figure A-1. SPECIMEN LAYOUT FOR CASTING 1.

Figure A-2. SPECIMEN LAYOUT FOR CASTING 2.

Figure A-3. SPECIMEN LAYOUT FOR CASTING 3.

Figure A-4. SPECIMEN LAYOUT FOR CASTING 4.

Center Drill and/or
C'sink. Permissible
to Max Depth of 1/2"
(see note 2)

Notes:

1. Diameter of reduced section may vary ± 0.002 " at the center. However, the reduced section shall be tapered with each end 0.001 " to 0.002 " larger than center.
2. Centering drills and countersinks to be coaxial within 0.001 " TIR.
3. The two 70° conical tapered sections to be concentric and with the gage length diameter within 0.002 " TIR.
4. Finish the $1 \frac{1}{4}$ " min reduced section as follows:
 - a. Final two machining cuts not more than 0.005 " deep.
 - b. Surface finish 32 microinch or better.
 - c. Remove all circumferential tool marks with emery paper and crocus cloth.
5. Finish of all surfaces beyond reduced section to be 125 microinch or better except ends, which may be saw cut and have no surface finish requirements.
6. Flat surfaces on the $1/2$ " dia ends are permissible provided they do not extend to the 70° conical section.
7. Ref ASTM E8-61T, Fig 8.

Figure A-5. TENSILE TEST SPECIMEN.

Finishing Sequence:

1. For notch, polish with No. 00 emery cloth.
2. Polish with crocus cloth to better than 32 microinch/inch finish.
3. Required finish, all surfaces, < 100 microinch/inch except ends.
4. All sides square to 0.001 ".

Figure A-6. IMPACT TEST SPECIMEN.

Figure A-7. COMPRESSIVE TEST SPECIMEN.

Figure A-8. POISSON'S RATIO SPECIMEN.