HW-70607

UC-25, Metals, Ceramics
and Materials
(TID-4500, 17th Ed.)

THE IMPACT PROPERTIES OF UNALLOYED PLUTONIUM

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October, 1961

HANFORD ATOMIC PRODUCTS OPERATION
RICHLAND, WASHINGTON

Work performed under Contract No. AT(45-1)-1350 between the
Atomic Energy Commission and General Electric Company

Printed by/for the U. S. Atomic Energy Commission

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ABSTRACT

The effect of temperature on the unnotched and notched Charpy impact properties of plutonium was studied in the alpha, beta, gamma, and delta phases encompassing a temperature range of -43 to 330 C.

Impact energies for unnotched specimens generally increased with increasing test temperature in the alpha and beta phases. Brittle failures were obtained in these phases. The specimen tested in the gamma phase did not fracture but bent in a U-shape and pulled through the anvil.

Impact energies for the Charpy V-notched specimens are much lower than for the unnotched specimens at corresponding temperatures. Brittle failures were obtained in the alpha and beta phases; some ductility was evidenced in the gamma phase while the specimen tested in the delta phase did not fracture but bent in a U-shape.

It was concluded that the beta phase is quite sensitive to both strain rate and notch effects.

Fracture appearance in the alpha and beta phase is discussed from the standpoint of grain boundary effects and microcracking.

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THE IMPACT PROPERTIES OF UNALLOYED PLUTONIUM

INTRODUCTION

The wide variation in tensile and compressive properties which exist between the alpha, beta, gamma, and delta phases of plutonium indicates that a study of the impact properties would be a pertinent supplement to the study of the mechanical properties and formability of plutonium.

In tension the alpha phase is quite brittle with elongations of less than 1 per cent. When tested at normal speeds the beta phase is unusually ductile; elongations up to 621 per cent have been obtained. However, the beta phase is quite sensitive to strain rate, elongations decrease rapidly as strain rate is increased. The gamma and delta phases are less ductile than the beta phase with the delta phase the more ductile of the two. Neither are very sensitive to strain rate.

Considering the brittle nature of alpha plutonium in tension and compression and the strain rate sensitivity of beta phase plutonium, both unnotched Charpy specimens and standard V-notched Charpy specimens were fabricated for testing. In addition, since iron in amounts greater than 500 ppm forms a Pu-Pu_6Fe eutectic network which inhibits microcracking in as-cast plutonium,[(1)] it was decided to prepare impact specimens with both low and high iron contents.

SUMMARY AND CONCLUSIONS

Unnotched and notched plutonium impact specimens with low and high iron contents were tested at temperatures in the alpha, beta, gamma, and delta phases.

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(1) Gardner, H. R. and I. B. Mann. "Mechanical Property and Formability Studies on Unalloyed Plutonium," Second International Conference on Plutonium, Paper No. 36. Grenoble, France. April, 1960.

For the unnotched specimens, brittle failures were obtained in both alpha and beta phases. In general, impact strength increased as test temperatures increased. Extremely ductile behavior was noted in the gamma phase. Fracture did not occur and the specimen bent in a U-shape as it was pulled through the anvil.

Fractures in the alpha phase ranged from fine to coarse as test temperature increased. In the beta phase, fine and coarse fractures were observed at the 175 C test temperature. For both alpha and beta phases fractures are discussed from the standpoint of grain boundary effects and microcracking.

In the alpha phase, data indicated that iron additions which inhibited microcracking in plutonium resulted in a 30 per cent increase in impact strength.

It was concluded that the beta phase is very strain-rate sensitive, behaving in a brittle manner at test speeds corresponding to impact velocities.

The impact energies for the V-notched Charpy specimens are much lower than the unnotched values at corresponding temperatures. In addition, the beta phase is shown to be quite notch-sensitive.

EXPERIMENTAL PROCEDURE

Experimental Material

Rectangular plutonium bars of square cross section were cast four at a time *in vacuo* in MgO-coated graphite molds. The pouring temperature of the plutonium melt was approximately 950 C and the molds were heated to 300 C before pouring. The bars were removed at a mold temperature of approximately 150 C, cooled slowly to room temperature and cold treated at -34 C for 24 hours.

The cast bars were milled to the standard Charpy dimensions of 0.394 x 0.394 x 2.165 inches. Twenty-three bars were prepared with the standard 45-degree Charpy V-notch. The 32 remaining bars were left unnotched. Chemical analysis and density for the groups of impact specimens tested are presented in Table I.

Experimental Techniques

For testing at elevated temperatures, the impact specimens were heated in an agitated peanut oil bath. Below room temperature an agitated bath of trichlorethylene and dry ice was used. The immersion time in both baths prior to testing was approximately 30 minutes. Transfer times from heating or cooling medium to the anvil of the impact machine were less than 5 seconds. The 0 to 60 ft-lb energy range was used for all impact testing.

RESULTS AND DISCUSSION

A total of 55 impact specimens, 32 unnotched and 23 with the standard Charpy V-notch, were tested at temperatures from -43 to 330 C. The test results for both unnotched and notched specimens are presented in Table II and Figure 1.

Unnotched Testing

Unnotched specimens showed a general increase in impact energy with increasing temperature in the alpha and beta phases. Brittle failures (essentially no plastic deformation) were obtained in these phases, while extremely ductile behavior was observed in the gamma phase (Figure 2 and 3). Note that the specimen tested in the gamma phase did not fracture but bent in a U-shape as it was pulled through the anvil. These data confirm earlier observations concerning the high strain-rate sensitivity of the beta phase and the lack of strain rate effect in the gamma phase.

In the alpha phase, test temperature influenced the fracture appearance of the plutonium. As test temperature increased from -43 to 100 C the fracture appearance changed from fine to coarse (Figures 4, 5, and 6). A complete understanding of this phenomenon cannot be derived from this study; however, it should be of advantage to discuss some of the microstructural characteristics of alpha plutonium which may have an effect on fracture appearance.

TABLE I

CHEMICAL ANALYSIS* AND DENSITY*

Casting Heat	Al	Cr	Cu	Fe	Mg	Mn	Ni	Si	C	Total	Density (g/cc)	Iron Classification
19-10-9	--	L5	10	268	100	10	33	L5	--	431	19.67	Low
20-4-1&2	8	50	10	L50	5	50	20	5	80	278	19.64	Low
20-4-3&4	8	12	10	1142	25	45	30	5	100	1377	19.54	High
21-1-2	32	20	20	80	10	20	20	L1	--	203	--	Low
21-1-3	20	50	10	1200	20	50	100	10	--	1460	19.52	High

* Reported in parts per million

TABLE II

IMPACT TEST RESULTS

Test Temp., C	Unnotched Specimens Impact Energy, ft-lb			V-Notched Specimens Impact Energy, ft-lb		
	Average	Range	Number Tested	Average	Range	Number Tested
-43	4.6	4.2 - 5.0	5	1.8	1.7- 1.8	2
30	6.5	4.5- 8.8	9	1.9	--	2
70	5.6	5.5- 5.7	2	-	--	-
100	6.9	5.1-10.0	10	3.1	2.7- 3.5	3
130	9.9	8.2-12.9	3	1.9	1.8- 2.0	2
175	7.7	6.5- 9.0	3	1.8	1.7- 2.0	4
230	*	--	1	11.1	9.9-13.5	5
300	-	--	-	11.0	9.0-13.8	4
330	-	--	-	*	--	1

* Specimen bent in U-shape and did not break.

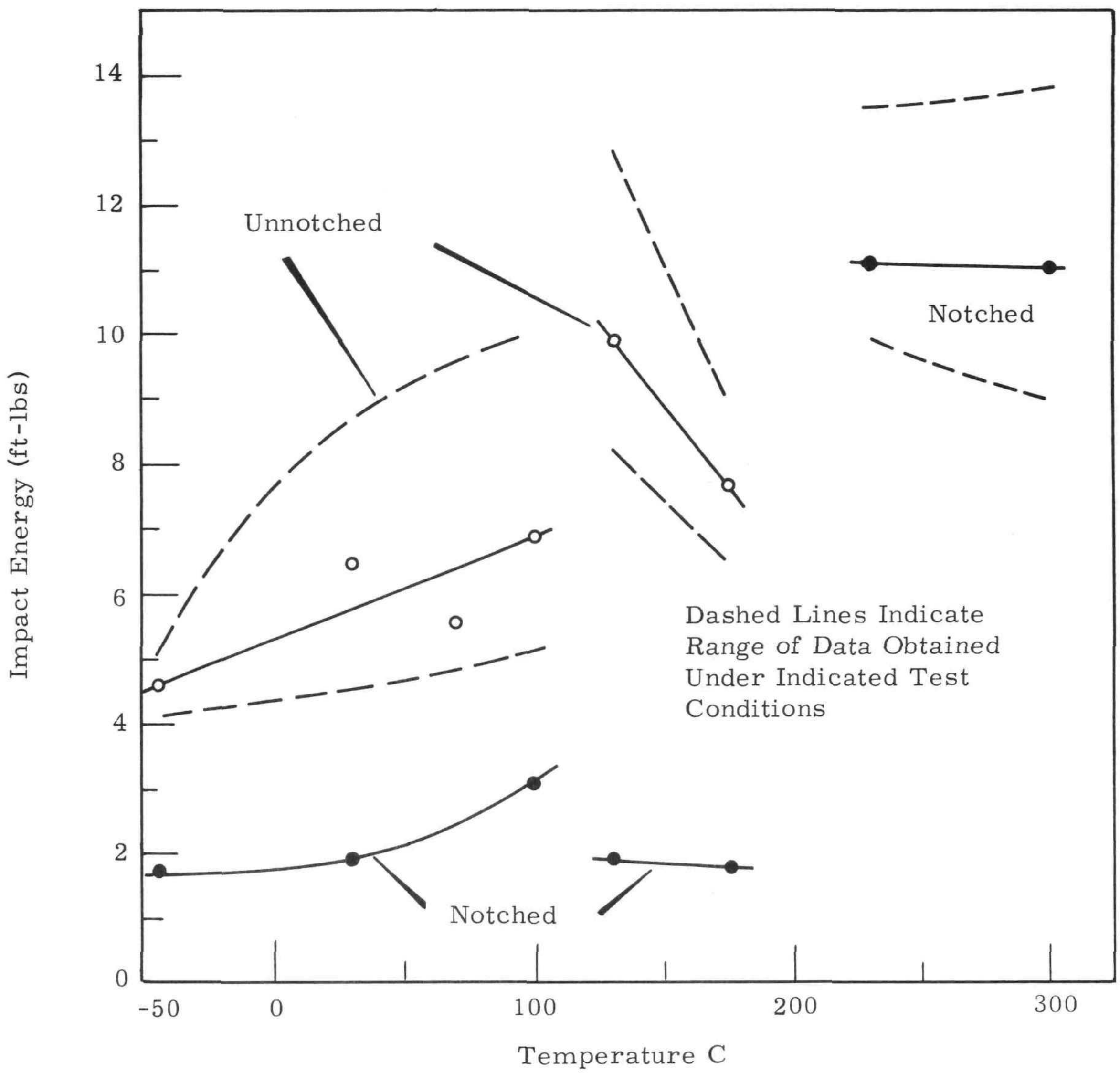
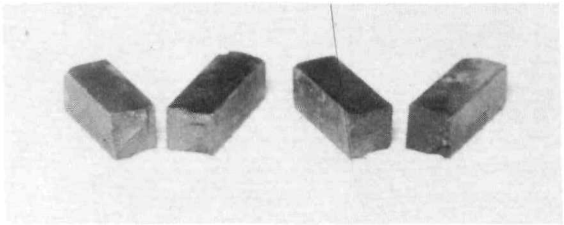


FIGURE 1

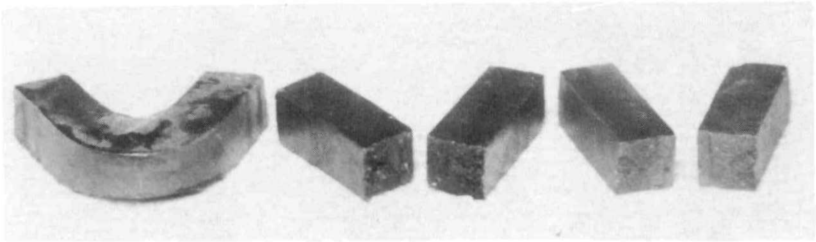
Effect of Temperature
on Unnotched and Notched Impact Properties of Plutonium



-43 C 100 C

FIGURE 2

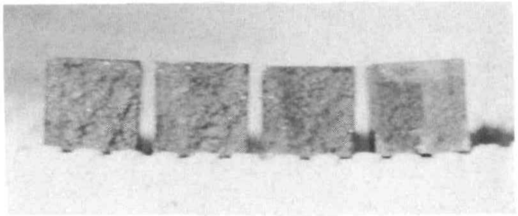
Unnotched Impact Specimens
Tested at -43 and 100 C in the Alpha Phase. 1/2X



Gamma	Beta	Beta
230 C	175 C	130 C

FIGURE 3

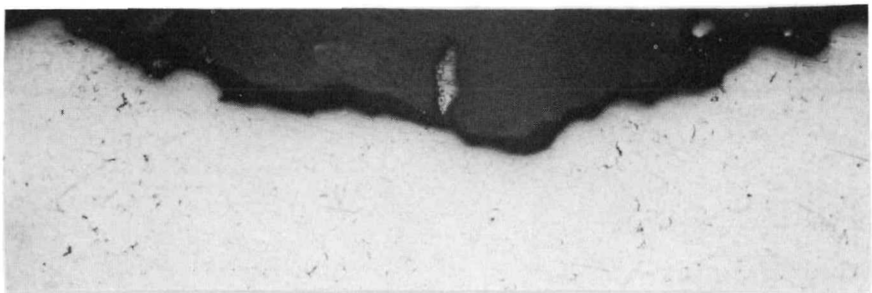
Unnotched Impact Specimens
Tested at 230, 175, and 130 C. 3/4X



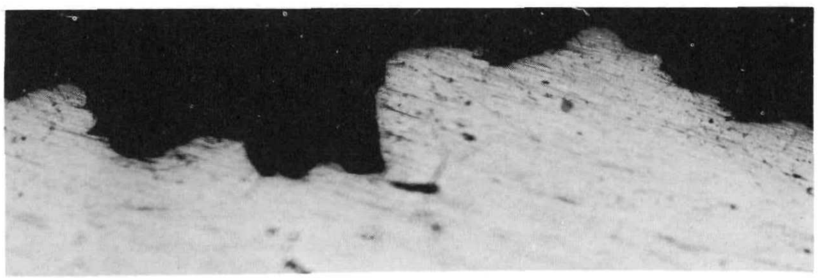
100 C 70 C 30 C 43C

FIGURE 4

Unnotched Impact Specimens Tested at 100, 70, 30 and -43 C in the Alpha Phase. Note Decrease in Fracture Grain Size as Test Temperature is Lowered. 1X



50X

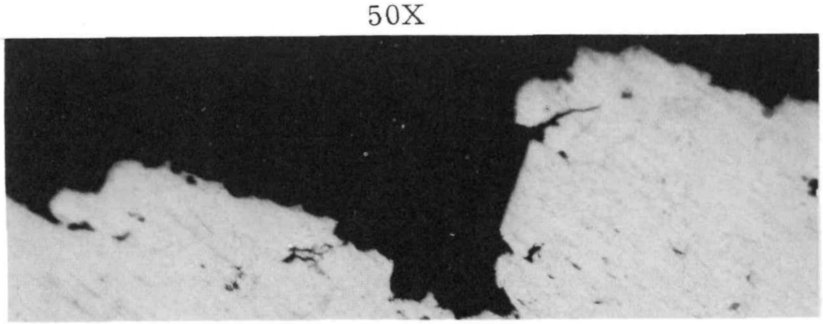


250X

FIGURE 5

Impact Fracture Interface at -43 C in Alpha Phase

50X



250X

FIGURE 6

Impact Fracture Interface at 100 C in Alpha Phase.
Note that the Fracture Interface is Coarser for the 100 C Test Temperature

It has been observed in plutonium containing greater than 500 ppm Fe,[1] that upon continuous cooling to room temperature after casting, the alpha grain size is approximately a factor of two finer than the size of the Pu-Pu_6Fe eutectic network. Therefore, the microstructure of alpha plutonium contains two sets of boundaries of different sizes and probably different strengths. Considering that the boundary strengths are sensitive to temperature and each to a different degree, a graph of strengths versus temperature will show an intersection at a particular temperature. Since alpha plutonium fractures become more coarse as temperature increases, the alpha grain-boundary strength must decrease at a slower rate with increasing temperature than the Pu-Pu_6Fe eutectic-boundary strength. Thus, at low alpha temperatures a fine, brittle intercrystalline fracture occurs at the alpha grain boundaries; while at higher temperatures the brittle intercrystalline fracture at the eutectic boundaries is more coarse. This explanation will also apply to the low impact iron plutonium specimens if it is assumed that the substantially decreased amount of eutectic present still forms a thin film of eutectic network.

Another explanation for fracture change with temperature may relate to the influence of temperature on the rate of propagation of the microcracks commonly present in alpha plutonium. The propagate a crack, it is necessary that the stress at the tip of the crack be greater than the cohesive strength of the material. Since the strength of alpha-phase plutonium increases markedly as temperature decreases, it is suggested that the rate of crack propagation decreases resulting in a finer fracture appearance at the lower test temperatures. Of course, it must be realized that interrelations affecting fracture probably exist between microcrack propagation, grain boundary, and Pu-Pu_6Fe eutectic network strengths.

Since the alpha phase temperature range is seldom exceeded for many applications of plutonium, sufficient impact specimens were tested at 30 and 100 C to obtain an indication of the effect of small iron additions on the impact

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(1) Ibid.

properties of plutonium. As indicated earlier, when iron is present in plutonium in amounts greater than 500 ppm, a continuous network of $Pu-Pu_6Fe$ eutectic is present which has an inhibiting effect on the formation of microcracks in cast plutonium. Thus, low-iron plutonium has microcracking of varying degrees while high-iron plutonium has little or no microcracking. In Table III the unnotched impact properties of high- and low-iron plutonium tested at 30 and 100 C are presented.

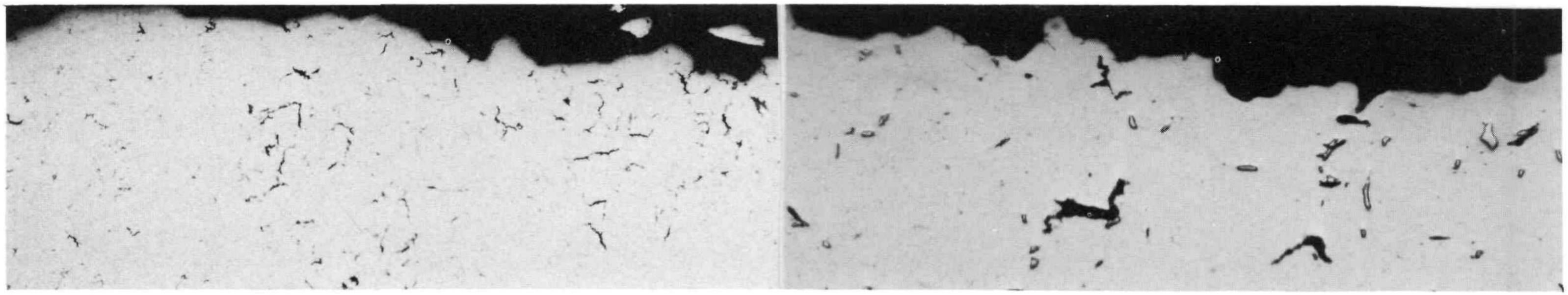
TABLE III

UNNOTCHED IMPACT TEST DATA SEGREGATED ON BASIS OF IRON CONTENT

Test Temp., C	High Iron: 1200 ppm Eutectic Present Impact Energy, ft-lb			Low Iron: 100 ppm Eutectic Absent Impact Energy, ft-lb		
	Average	Range	No. Tested	Average	Range	No. Tested
30	7.5	5.3- 8.8	4	5.7	4.5-7.8	5
100	7.7	5.7-10.0	6	5.8	5.1-6.2	4

When the eutectic network is present, microcracking is essentially absent and impact energies average roughly 2 ft-lbs or 30 per cent higher than when the eutectic network is absent and microcracking is present. These data indicate that iron additions, presumably because of their influence in inhibiting microcracks, are beneficial to the unnotched impact properties of alpha-phase plutonium.

In the beta phase, at 175 C, two extremes of fracture appearance were observed in specimens where the alpha grain sizes were essentially the same, 0.024 mm average grain diameter. The relatively fine fracture interface (Figure 7) may have been caused by the extensive microcracking apparent in the photomicrographs. The absence of microcracking resulted in the much coarser fracture illustrated in Figure 8.



50X 250X

FIGURE 7

Fine Impact Fracture Interface at 175 C in Beta Phase Caused by Extensive Microcracking

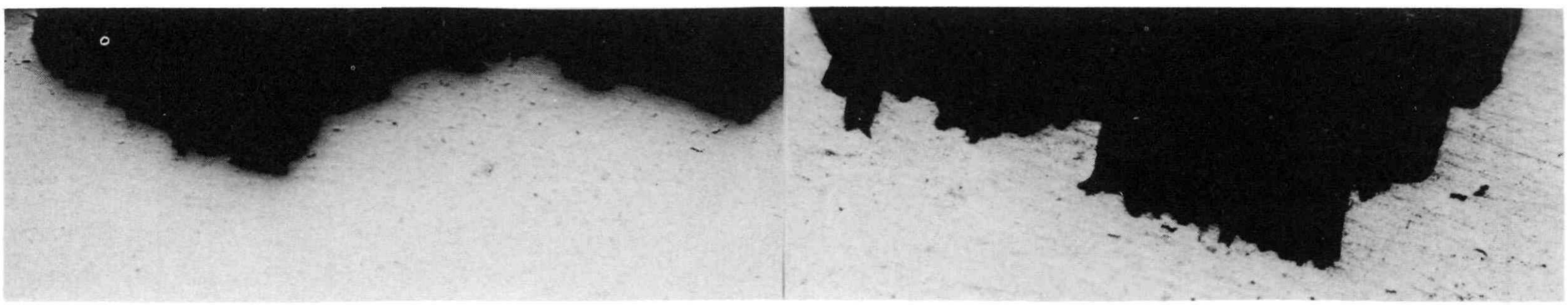


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FIGURE 8

Coarse Impact Fracture Interface at 175 C in Beta Phase Which Results when Microcracking is Inhibited by Iron Additions

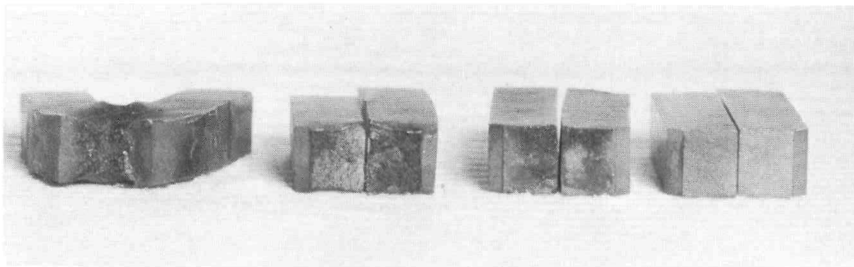
Notched Testing

As expected, the impact energies of the V-notched specimens are much lower than the unnotched values at corresponding temperatures. It is interesting to note that for notched specimens the average impact energies at -43 and 30 C in the alpha phase are equivalent to the average beta phase impact energies. However at 100 C in the alpha phase the impact energy is almost twice as high as the beta phase value. In contrast, impact energies for unnotched beta-phase plutonium are 12 to 44 per cent higher than the impact energy of alpha phase at 100 C. These data indicate that beta-phase plutonium is very notch-sensitive for strain rates corresponding to impact velocities.

Brittle failures were obtained in the alpha and beta phases. A relatively ductile failure was observed in the gamma phase while the delta phase specimen did not fracture completely, but bent in a U-shape. This indicated extremely ductile behavior (Figures 9 and 10). As observed in the unnotched specimens tested in the alpha phase, the fracture appearance of the V-notched specimens changed from fine to coarse when test temperature was increased from -43 to 100 C.

ACKNOWLEDGEMENT

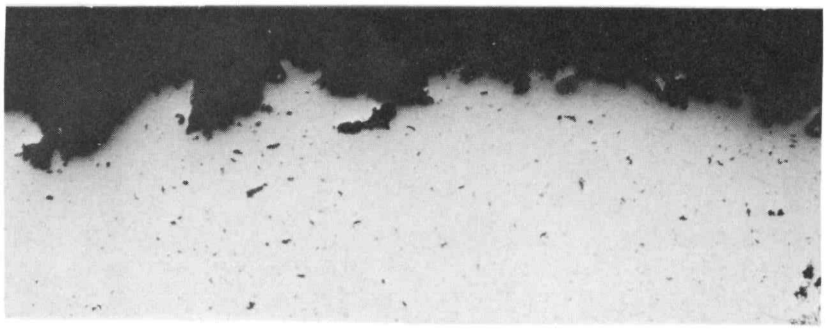
The author is very appreciative of the excellent technical assistance provided by I. B. Mann in the experimental area of this study. Thanks are also extended to W. D. Leahy for milling the impact specimens and to J. P. Keiser for metallography.



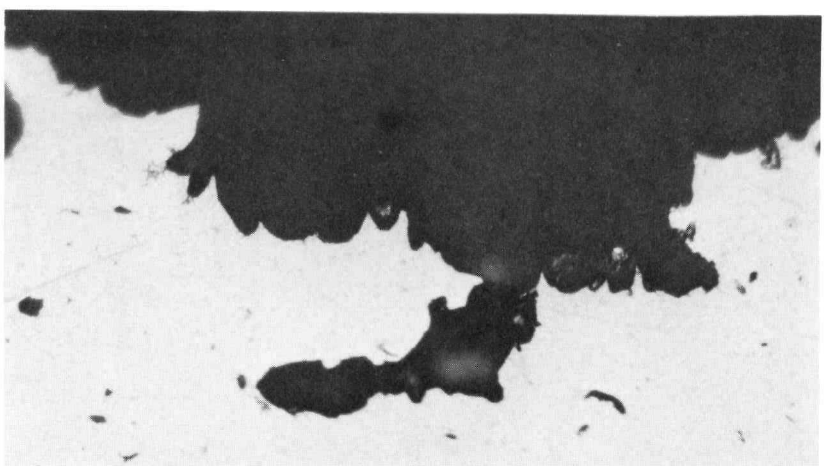
Delta	Gamma	Beta	Alpha
330 C	230 C	175 C	100 C

FIGURE 9

Charpy V-Notched Impact Specimens
Tested at 330, 230, 175, and 100 C



50 X



250 X

FIGURE 10

Impact Fracture Interface at 230 C in the Gamma Phase

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