Compressibilities and Hardnesses

The compressibilities plotted against composition of delta-stabilized Pu-Al, Pu-Zn, and Pu-Ce alloys below their transformation pressures and of beta-phase Pu-Ce alloys between the first and second transformations are shown in Figure 12.   Compressibilities of the Pu-Al alloys decrease linearly with increasing aluminum content at the approximate rate of 0.1×10^{-6}/atm/atom per cent, and the compressibilities of the Pu-Zn, delta-phase Pu-Ce, and beta-phase Pu-Ce alloys increase linearly with increasing zinc or cerium content at the approximate rates of 0.6, 1.1, and 0.3×10^{-6}/atm/atom per cent, respectively.   The values of compressibilities are probably accurate to only ±25% of the value reported.

Figure 13 shows the variation of hardness as a function of composition in these alloys.   The hardnesses can be increased and controlled
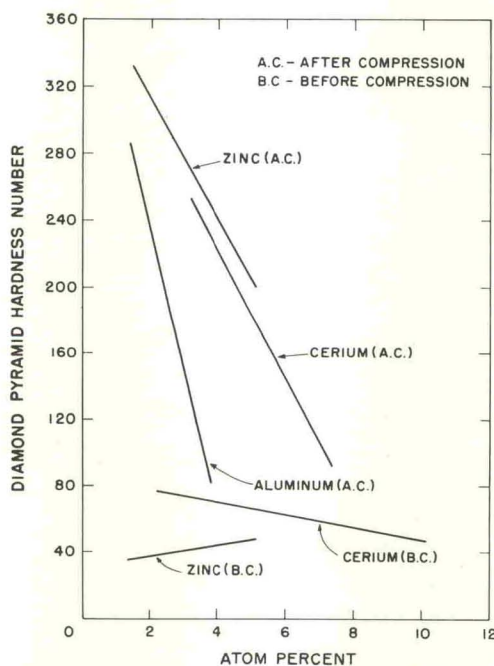

Fig. 13. The effects of concentration of alloying elements (aluminum, cerium, and zinc) and of pressures up to about 10,000 atm on the hardness of delta-stabilized plutonium alloys.

over a limited range by selecting the proper combination of alloying element and pressure. Also, less aluminum than either zinc or cerium is required in order to change the hardness by a given amount.

Phase Diagrams

Effects of pressure on metastable, single-phase, binary alloys do not appear to have been determined previously. Some interesting correlations between the behaviors of such alloys under pressure and their respective phase diagrams can be inferred from the results of this study. The Pu-rich portion of the Pu-Al,[5] Pu-Zn,[6] and Pu-Ce[7] phase diagrams are shown in Figures 14(a), 14(b), and 14(c), respectively.

The intersection of the Pu-Al density curves at 4.5 a/o Al, referred to earlier in this paper, can be extrapolated to atmospheric pressure by assuming that this composition does not vary with pressure. This composition is then interpreted to be on the alpha plus delta/delta solvus phase boundary at room temperature [see Fig. 14(a)]. This value, 4.5 a/o Al, is intermediate between the reported values of 2.0 ± 0.2 a/o Al[8] and about 8 or 9 a/o Al,[5] but these results are in disagreement with another version of the Pu-Al diagram.[9] This latter version shows a eutectoidal decomposition of delta phase into beta phase plus Pu_3Al at about 175°C, and on cooling to room temperature alpha phase plus Pu_3Al become the equilibrium state of such decomposed alloys.[9] No evidence was found during the present study to substantiate this type of Pu-Al diagram. The metastable delta Pu-Al alloys transformed under pressure into either alpha or mixtures of alpha plus beta with some untransformed delta, and at no time was $PuAl_3$ identified in any of the alloys by microscopic or x-ray methods, either before or after compression.

The intersection of the Pu-Ce density curves at 7.1 a/o Ce can also be extrapolated to atmospheric pressure in the same way as described above for the Pu-Al alloys. Again, this composition represents the beta plus delta/delta solvus phase boundary, and it agrees reasonably well with the value of 5 a/o Ce, obtained by extrapolation of high-temperature x-ray and metallographic data[7] [see Figure 14(c)].

One of the authors (K. A. G.) has calculated that pure delta plutonium will transform to either gamma or delta prime at 1300 atm and at elevated temperatures; i.e., at pressures greater than 1300