Argonne National Laboratory

**EFFECTS OF IRRADIATION ON POWDER
COMPACTS OF URANIUM AND SOME
URANIUM-BASE ALLOYS**

by

J. H. Kittel and S. H. Paine

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EFFECTS OF IRRADIATION ON POWDER COMPACTS OF URANIUM AND SOME URANIUM-BASE ALLOYS

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ABSTRACT

Results are given from irradiation experiments on powder compacts prepared from uranium, uranium hydride, and the following alloys: uranium - 1.0, 1.4, 2.0, 2.5, and 3.5 w/o molybdenum; uranium - 1.6 w/o niobium; and uranium - 0.42 w/o silicon. The methods by which the compacts were prepared included end-pressing, side-pressing, hot-rolling, and hot-swaging. When subjected to irradiation, the uranium compacts invariably shortened in the pressing direction, whereas the compacts prepared from uranium hydride elongated in the pressing direction. The alloy compacts elongated in the direction of pressing, rolling, or swaging. The surface smoothness of the irradiated molybdenum alloy compacts improved with increasing molybdenum content, although dimensional stability tended to decrease. The irradiated niobium alloy showed comparatively good surface smoothness and dimensional stability, but the silicon alloy specimens were badly roughened and elongated. Both the unalloyed and the alloyed compacts decreased in density under irradiation, and the rate of density decrease was found to depend strongly on the irradiation temperature.

INTRODUCTION

The dimensional instability which uranium exhibits when subjected to irradiation has been shown to be strongly influenced by the orientation and size of the individual grains in polycrystalline material.⁽¹⁾ In general, it can be stated that random grain orientation in uranium minimizes overall dimensional changes, and small grain size minimizes surface roughening. It is possible, by suitable heat treatment, to largely remove preferred orientations in wrought uranium.⁽²⁾ However, when wrought uranium specimens nominally stabilized by heat treatment are irradiated to atom burnups of only a few tenths per cent, the resulting dimensional changes may amount to length changes of several per cent and may also be accompanied by considerable surface roughening.⁽³⁾ An additional phenomenon described as "swelling" has also been observed at moderate burnup levels.⁽⁴⁾

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The difficulty of obtaining a simultaneous condition of random orientation and small grain size in uranium by conventional metallurgical techniques has led to consideration of other procedures. One of the methods that has been studied is powder metallurgy. Because of the inherent characteristics of the powder metallurgy process, the use of compacts prepared from metal powders for nuclear fuels might be expected to offer certain advantages:

- (1) As poured into the die, the metal powder would have a random orientation, and adequate control of subsequent pressing operations might minimize the introduction of preferred orientations into the compact.
- (2) Grain size might be kept small by control of powder size and sintering conditions.
- (3) Porosity could be intentionally left in the compact to perhaps enable gaseous fission product atoms to diffuse from the compact and thus minimize swelling.
- (4) Alloys difficult to prepare by conventional means could more readily be made.

Although powder metallurgy techniques for uranium are well established and have been comprehensively described,^(5,8) little information has appeared thus far concerning the behavior of uranium powder compacts under irradiation. The present paper describes such results, obtained in a recently completed series of irradiations on powder compacts made of uranium and several uranium-base alloys. All specimens used in the study were prepared by Sylvania Electric Products, Inc., Bayside, N.Y.

EXPERIMENTAL PROCEDURE AND SPECIMEN MATERIALS

The irradiations were made in the Materials Testing Reactor in Capsules containing NaK for heat transfer purposes.⁽⁹⁾ Irradiation procedures and atom burnup determinations using capsules of this type have been previously described.⁽¹⁰⁾ Corrections, obtained from another investigation,⁽³⁾ were also made to indicated atom burnups for plutonium buildup and subsequent contribution to total fissions.

Most of the irradiation specimens were in the form of cylinders, with diameters ranging from 0.219 to 0.375 in., and lengths from 0.750 to 1.00 in. A few specimens were also irradiated as small plates, 0.040 in. thick, 0.75 in. wide, and 1.00 in. long. Before irradiation, the dimensions of each specimen were measured with micrometers to the nearest 0.0001 in., and weights were obtained to the nearest 0.1 mg. In addition, densities were

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obtained on certain groups of specimens by immersion in CCl_4 . Although it was realized that density measurements made by the immersion method are not normally used for objects which may contain interconnecting pores, the method was used because it was felt that it would provide the most reliable measurements of specimens which had suffered surface distortion as a result of irradiation. Hardness measurements were also obtained on a number of specimens. Post-irradiation measurements were made with the same equipment described above, using remote handling methods. When specimens were badly distorted as a result of irradiation, dimensions were obtained from photographs, each of which also included a length standard.

All information on compositions, porosities, grain sizes, and fabrication details for the compacts was supplied by Sylvania Electric Products, Inc.

The experimental irradiations were made on unalloyed uranium compacts prepared as follows:

- (1) Uranium powder, -12 mesh, end-pressed under 12 tsi at 600°C to full density. Several of these compacts were modified prior to irradiation by drilling a 1/16-in. diameter hole through each specimen along its axis. It was hoped that the axial holes in these compacts might serve as escape paths for fission product gases diffusing to the center of the specimens during irradiation.
- (2) Uranium hydride powder, diameter 10 microns or less, end-pressed under 11 tsi at 600°C to full density. At this temperature UH_3 decomposes in the die into uranium and hydrogen, so that the "uranium hydride" specimens referred to in this report are actually pure uranium. The compacts were originally 1.3 in. in diameter and 4 in. long and had been used in a study of dimensional stability under thermal cycling between 50° and 550°C .(11)
- (3) Uranium powder, -12 mesh, end-pressed under 12 tsi at 600°C to 2 to 4% porosity.
- (4) Uranium powder, -12 +65 mesh, side-pressed at 600°C to porosities ranging from 0 to 13.0%. Pressing load for each specimen was varied, depending upon the desired porosity.
- (5) Uranium powder, - 12 +80 mesh, rolled in a steel sheath to average porosities ranging from 8.6 to 11.5%. This procedure was stated by the supplier to result in a structure such that most of the porosity was concentrated in the center of the compacts.

Figures 1 through 5 show photomicrographs of specimen materials described above under items 1, 3, 4, and 5.

Irradiations were also made of the following uranium alloy compacts prepared by cold-pressing -325 mesh elemental powders under 50 tsi, and sintering as indicated:

- (1) Uranium containing 1.0, 1.4, 2.0, and 2.5 w/o molybdenum, sintered at 1100°C.
- (2) Uranium - 1.6 w/o niobium, sintered at 1100°C.
- (3) Uranium - 0.42 w/o silicon sintered at 1050°C.

Figures 6 through 8 show microstructures of the 1.4, 2.0, and 2.5 w/o molybdenum alloys.

Finally, irradiations were made on hot-worked uranium - 3.5 w/o molybdenum compacts prepared as shown below by rolling or swaging pre-alloyed powder in sheaths at 600°C. After machining to size, the specimens were held at 850°C for 15 minutes.

- (1) Plates, rolled to theoretical density.
- (2) Plates, rolled to 96% theoretical density.
- (3) Rods, swaged to theoretical density.

Figures 9 through 12 show photomicrographs of the hot-worked molybdenum alloys.

EXPERIMENTAL RESULTS

Tables I through VI show the irradiation histories of the various specimens. The irradiation conditions and the changes which were observed in the specimens are summarized in Tables VII through XIII. The latter tables also show the instantaneous growth rate, G_i , which was calculated from the relation

$$G_i = \frac{1}{L} \frac{dL}{dN} = \frac{\ln(L/L_0)}{\text{fraction of total atoms fissioned}} = \frac{\text{micron./in.}}{\text{fission}/10^6 \text{ total atoms}}$$

where

L_0 = initial length

L = final length

N = unit of total atom burnup.

The above expression thus takes into account the fact that the amount of growth at any given level of burnup is dependent upon the instantaneous length of the specimen at that time. It has been found both convenient and accurate to express the growth rate in microunits of length change per unit length for one fission per million total atoms. For length changes less than about five per cent the following approximation may be used:

$$G_i = \frac{\% \text{ length change}}{a/o \text{ burnup}} .$$

As used in this report, a/o burnup refers to the per cent burnup of all atoms in the fuel, including both fissile and nonfissile uranium and alloying elements. Burnups calculated in the specimens ranged from 0.039 to 0.70 a/o, and temperatures in the centers of the specimens during irradiation were calculated to range from 70° to 730° C.

Unalloyed Uranium, Full Density

As shown in Tables VII and X, the compacts which were prepared from uranium powders were invariably found to shorten in the pressing direction when subjected to irradiation, while a corresponding elongation developed perpendicular to the pressing direction. This was true in both end-pressed and side-pressed specimens. Therefore, the end-pressed specimens generally shortened in length under irradiation and increased in diameter, whereas the side-pressed compacts elongated and their cross sections became somewhat elliptical. The shortening of the end-pressed specimens, both solid and cored, has been shown as a function of burnup in Figure 13. The shortening of the end-pressed specimens was at an average rate of $G_i = -23 \text{ microin./in./fission}/10^6 \text{ total atoms}$.

Irradiation temperature was found to have a large influence on the ability of the specimens to resist irradiation damage. Figure 14 shows photographs of specimens after 0.4 a/o burnup which illustrate the damaging effects of irradiation in the high alpha phase. Figure 15 shows the effects of irradiation on a group of end-pressed specimens which contained axial core holes. No particular improvement seems to have been gained by the use of a core hole.

The irradiation specimens prepared from end-pressed uranium hydride powder were machined from the original compacts, as shown in Figure 16. As shown in the figure, each specimen was identified by a letter, depending upon its location in the original compact. It was anticipated that some of the irradiation specimens, particularly those taken from near the outside of the original compact, might show a tendency to warp under irradiation because of nonuniform texture. In order to investigate the feasibility of restraining any such distortion, half of the "uranium hydride" specimens were irradiated in stainless steel jackets. Jacket thicknesses were 0.005,

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0.010, and 0.020 in., and the radial clearance between specimen and jacket was approximately 0.003 in. No end closures were used.

The unclad and the jacketed "uranium hydride" specimens are described respectively in Tables VIII and IX, and typical specimens after irradiation are shown in Figures 17 and 18. As shown in the tables, all specimens elongated in the pressing direction, in contrast to the specimens prepared from uranium powder. The elongations were erratic and the individual specimens varied considerably in values of G_i , the rate of growth. The average value of G_i for the unclad specimens and the clad specimens which could be separated from their jackets was 19 micronin./in./fission/ 10^6 total atoms.

Contrary to expectations, very little warping was found in the irradiated "uranium hydride" specimens. Those specimens which were tightly lodged in their jackets after irradiation appeared to be so as a result of an over-all diameter increase, so that the jackets provided an indication of the feasibility of restraining swelling, rather than warping. As shown in Table IX, their ability to restrain swelling was greater with increasing thickness.

The onset of swelling appeared to be highly dependent on irradiation temperature, as shown in Figure 19. The data shown in the figure were obtained from unclad specimens and those clad specimens which could be separated from their jackets. It appears that the critical irradiation temperature for the beginning of swelling in compacts made from UH_3 is about $430^\circ C$. It is of interest that specimen AE-17, which showed the largest density decrease (Table VIII) was the only specimen which showed a drop in hardness. This apparent lowering of hardness is believed to be due to the formation of a sponge-like structure, as has also been observed by British investigators.⁽⁴⁾

Unalloyed Uranium, Less Than Full Density

As was mentioned earlier, it appeared that a possible means of overcoming the swelling tendency of fuel specimens irradiated in the high alpha phase was to use compacts containing pores which might serve as sinks or escape paths for fission product gases. Several specimens of this type were therefore irradiated, with results summarized in Tables X and XI.

The side-pressed specimens described in Table X ranged in porosity from 0 to 13.0%, but there appeared to be no trend in the irradiation results to indicate any improvement that might have been conferred by this range of porosity. The average lengthwise growth rates exhibited by the side-pressed compacts were equal to a G_i value of 31 microin./in./fission/ 10^6 total atoms. The cross sections of the specimens were distorted into oval shapes, with shortening of the diameter occurring in the pressing direction. The large

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weight increases observed in this group are believed to be due to the infiltration of NaK during irradiation into interconnected pores in the compacts. The effects of increasing burnup and increasing irradiation temperature on specimens with approximately 12.5% porosity are shown in Figure 20.

Although the rolled specimens described in Table XI showed both shortening and lengthening under irradiation, all were found to have increased in diameter at rather rapid rates. Again, no improvement seems to have resulted from this porosity, which in this case was concentrated along the center of the specimens. The effects of irradiation on a typical specimen are shown in Figure 21.

Uranium-Base Alloys

Thermal cycling and other tests made by Sylvania Electric Products, Inc., had shown that small additions of molybdenum, niobium and silicon to uranium were beneficial in reducing the grain size in cold-pressed and sintered compacts. Accordingly, as shown in Tables XII and XIII, the irradiation experiments on alloys were confined to these materials.

Most of the irradiated alloy specimens contained small amounts of molybdenum. The first group which was irradiated contained 1.0 w/o molybdenum and, after burnups up to 0.38 a/o, showed an average growth rate of $G_i = 10$ microin./in./fission/ 10^6 total atoms. Photographs of typical specimens after irradiation are shown in Figure 22, and it can be noted that an undesirably large amount of surface roughening occurred. Grain size in the compacts was stated to be 0.05 mm. Meanwhile, investigators at Sylvania Electric Products had found that increasing the molybdenum content of the compacts lowered the grain size; therefore, a group of specimens containing up to 2.5 w/o molybdenum was irradiated. As shown in Figure 23, an improvement in surface smoothness was obtained in the higher alloyed specimens, which does not appear to have been entirely due to the lesser burnups they received. On the other hand, as shown in Table XII, increasing the molybdenum content appeared to increase the lengthwise growth rate.

In further studies on uranium-molybdenum alloys, compacts containing 3.5 w/o molybdenum were hot-worked, as shown in Table XIII, and irradiated to burnups ranging up to 0.1 a/o. The rolled plates included both full density and 96% theoretical density specimens. In this case a clear superiority was shown by the porous material. It not only was more stable dimensionally, but, as shown in Figure 24, it remained free of the roughening shown by the fully dense material. The swaged specimens were less stable under irradiation and elongated at an average G_i value of 26 microin./in./fission/ 10^6 total atoms. However, as shown in Figure 24, they maintained good surface smoothness.

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Several cold-pressed and sintered specimens of an alloy containing 1.6 w/o niobium were irradiated to burnups ranging up to 0.37 a/o and, as shown in Table XII, were found to show fairly good stability. An average G_i value of 8.0 microin./in./fission/ 10^6 total atoms was obtained. Several specimens are shown after irradiation in Figure 25, and it can be noted that good surface smoothness was also obtained. This alloy was stated by the supplier to have a grain size of 0.02 mm.

In contrast, the compacts containing 0.42 w/o silicon were stated to have the much larger grain size of 0.3 mm. As shown in Figure 26, the resulting surface roughening and general distortion of these specimens after 0.3 a/o burnup was such that they could not be removed from the holders in which they were irradiated. However, it was possible to obtain length measurements on the specimens, and they were found to have elongated at an average G_i value of 61 microin./in./fission/ 10^6 total atoms.

DISCUSSION AND CONCLUSIONS

Although texture studies have indicated that uranium powder compacts are essentially randomly oriented,⁽²⁾ the present results show that compacts prepared by either hot pressing or hot working are sufficiently oriented to develop substantial dimensional changes when subjected to irradiation. With the exception of the compacts prepared from uranium hydride, it was found that the hot-pressed unalloyed compacts generally shortened in the pressing direction. On the other hand, most of the hot-worked alloy specimens elongated in the direction of rolling or swaging. Since the present results show that unidirectional pressing results in dimensionally unstable material, some improvement might be expected if hydrostatic pressing methods were used. It is planned, therefore, to investigate the behavior under irradiation of hydrostatically pressed compacts.

Considering only the unalloyed end-pressed material, the dimensional instability of the uranium compacts, $G_i = 23$ microin./in./fission/ 10^6 total atoms, is comparable in amount to the growth rate of $G_i = 25$ to 30 microin./in./fission/ 10^6 total atoms shown by rolled and beta-quenched uranium.⁽³⁾ Including theunjacketed "uranium hydride" compacts, for which $G_i = 19$ microin./in./fission/ 10^6 total atoms, little improvement in dimensional stability is therefore shown by powder compacts over wrought and heat treated material. However, the surface smoothness of the compacts was considerably better than that shown by rolled and beta-quenched material.

Swelling of specimens irradiated in the upper alpha phase, which was most clearly shown by the compacts prepared from uranium hydride, was not removed either by an axial core hole or by the deliberate inclusion of interconnected pores within the compacts. Similar results on porous compacts have evidently been obtained by British investigators.⁽⁴⁾ It appears, however, that swelling of fuel material can be largely restrained by thin stainless steel jackets.

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The cold-pressed and sintered alloy specimens did not shorten in any direction and may therefore have contained a more nearly random texture. However, although these specimens decreased in density more or less erratically, the rates of decrease of density were all much greater than those shown by the hot-pressed "uranium hydride" compacts, the only other group upon which density measurements were made. In addition, irradiation temperatures of the cold-pressed compacts were quite low (90 to 150°C), so that it would appear that the large density decreases in these specimens may not have been due to the same causes which appeared in the "uranium hydride" specimens.

The degrees of surface roughening observed in the cold-pressed and sintered group of compacts can be correlated with the reported preirradiation grain sizes. Results from this group of specimens indicate that, in order to avoid surface roughening under irradiation, the grain size in fuel material should be no larger than about 0.02 mm.

In conclusion, with regard to possible reactor applications, it should be borne in mind that most specimens in this study were completely unrestrained during irradiation, and maximum dimensional changes were therefore obtained. Fuel elements, on the other hand, will normally always be clad in some manner which will restrict, at least to some degree, any tendency of the fuel material to change dimensionally when subjected to irradiation.

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TABLE I

Irradiation History of End-Pressed Unalloyed Uranium Powder Compacts

Spec. No.	Date Placed in Reactor	Date Removed from Reactor	Exposure, MWD	Location in Reactor	Average Thermal nv ($\times 10^{-14}$)
AB-44	2-17-55	3-28-55	990	L-58	0.52
AB-46	2-17-55	3-28-55	990	L-58	2.75
AB-48	2-17-55	3-28-55	990	L-58	1.57
AB-50	2-17-55	3-28-55	990	L-58	2.74
AB-113	12-27-55	3-19-56	2358	A-30 NW	0.24
AB-114	12-27-55	3-19-56	2358	A-30 NW	0.40
AB-115	12-27-55	3-19-56	2358	A-30 NW	0.55
AB-116	12-27-55	3-19-56	2358	A-30 NW	0.68
AB-117	12-27-55	3-19-56	2358	A-30 NW	0.75
AB-118	12- 5-55	3-19-56	2970	A-36 SW	0.23
BD-1-1	1-27-55	8-22-55	4828	A-36 SE, A-31 SW	0.66
BD-2-1	1-27-55	8-22-55	4828	A-36 SE, A-31 SW	0.77
BD-3-1	1-27-55	8-22-55	4828	A-36 SE, A-31 SW	0.81
BD-4-1	1-27-55	8-22-55	4828	A-36 SE, A-31 SW	0.72
BD-5-1	1-27-55	8-22-55	4828	A-36 SE, A-31 SW	0.57
BD-6-1	1-27-55	8-22-55	4828	A-36 SE, A-31 SW	0.41
G-13	2-17-55	6-20-55	2886	L-53, A-30 SW, A-6 SE	1.69
G-18	2-17-55	6-20-55	2886	L-53, A-30 SW, A-6 SE	1.81
G-19	2-17-55	6-20-55	2886	L-53, A-30 SW, A-6 SE	1.49
G-20	2-17-55	6-20-55	2886	L-53, A-30 SW, A-6 SE	1.85
G-21	2-17-55	6-20-55	2886	L-53, A-30 SW, A-6 SE	0.60
G-22	2-17-55	6-20-55	2886	L-53, A-30 SW, A-6 SE	1.51

TABLE II

Irradiation History of Unjacketed Uranium Compacts Made from UH_3

Spec. No.	Date Placed in Reactor	Date Removed from Reactor	Exposure, MWD	Location in Reactor	Average Thermal nv ($\times 10^{-14}$)
AE-1	9- 8-54	1-25-55	2135	L-57	0.59
AE-2	9- 8-54	1-25-55	2135	L-57	3.36
AE-3	9- 8-54	1-25-55	2135	L-57	1.89
AE-4	9- 8-54	1-25-55	2135	L-57	4.17
AE-6	9- 8-54	1-25-55	2135	L-57	2.16
AE-7	9- 8-54	1-25-55	2135	L-57	3.70
AE-8	9- 8-54	1-25-55	2135	L-57	0.52
AE-9	9-28-54	1-25-55	1715	L-53	0.57
AE-10	9-28-54	1-25-55	1715	L-53	2.62
AE-11	9-28-54	1-25-55	1715	L-53	1.66
AE-12	9-28-54	1-25-55	1715	L-53	3.12
AE-13	9-28-54	1-25-55	1715	L-53	3.16
AE-14	9-28-54	1-25-55	1715	L-53	0.69
AE-15	9-28-54	1-25-55	1715	L-53	2.25
AE-16	9- 8-54	1-25-55	2135	L-57	3.82
AE-17	9- 8-54	1-25-55	2135	L-57	4.51
AE-18	9- 8-54	1-25-55	2135	L-57	2.90
AE-19	9- 8-54	1-25-55	2135	L-57	3.76
AE-20	9- 8-54	1-25-55	2135	L-57	1.24

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TABLE IIIIrradiation History of Jacketed Uranium Compacts Made from UH_3

Spec. No.	Date Placed in Reactor	Date Removed from Reactor	Exposure, MWD	Location in Reactor	Average Thermal nv ($\times 10^{-14}$)
AE-21	9- 8-54	1-25-54	2135	L-57	1.23
AE-22	9- 8-54	1-25-54	2135	L-57	3.82
AE-23	9- 8-54	1-25-54	2135	L-57	2.55
AE-24	9- 8-54	1-25-54	2135	L-57	3.95
AE-25	9- 8-54	1-25-54	2135	L-57	4.12
AE-26	9- 8-54	1-25-54	2135	L-57	1.22
AE-27	9- 8-54	1-25-54	2135	L-57	3.15
AE-28	9-28-54	1-25-54	1715	L-53	0.28
AE-29	9-28-54	1-25-54	1715	L-53	1.25
AE-30	9-28-54	1-25-54	1715	L-53	2.92
AE-31	9-28-54	1-25-54	1715	L-53	2.22
AE-32	9-28-54	1-25-54	1715	L-53	3.23
AE-33	9-28-54	1-25-54	1715	L-53	2.80
AE-34	9- 8-54	1-25-54	2135	L-57	3.40
AE-35	9-28-54	1-25-54	1715	L-53	1.51
AE-36	9- 8-54	1-25-54	2135	L-57	4.22
AE-37	9- 8-54	1-25-54	2135	L-57	4.70
AE-38	9- 8-54	1-25-54	2135	L-57	2.08
AE-40	9- 8-54	1-25-54	2135	L-57	0.49

TABLE IV

Irradiation History of Both Side-Pressed and
Rolled Unalloyed Uranium Powder Compacts

Spec. No.	Date Placed in Reactor	Date Removed from Reactor	Exposure, MWD	Location in Reactor	Average Thermal nv ($\times 10^{-14}$)
AB-51	2-17-55	3-28-55	990	L-58	0.90
AB-52	2-17-55	3-28-55	990	L-58	2.36
AB-124	1-16-56	2-27-56	1154	L-59	2.19
AB-126	1-16-56	2-27-56	1154	L-59	2.15
AB-127	1-16-56	2-27-56	1154	L-59	3.02
AB-128	1-16-56	2-27-56	1154	L-59	1.57
AB-129	1-16-56	2-27-56	1154	L-59	1.42
AB-130	1-16-56	2-27-56	1154	L-59	2.61
AB-131	1-16-56	2-27-56	1154	L-59	2.88
AB-132	1-16-56	2-27-56	1154	L-59	2.81
AB-133	1-16-56	2-27-56	1154	L-59	0.73
AB-134	1-16-56	2-27-56	1154	L-59	0.95
G-24	2-17-55	6-20-55	2886	L-53, A-30 SW, A-6 SE	1.76
G-26	2-17-55	6-20-55	2886	L-53, A-30 SW, A-6 SE	1.12
CD-1-4	12-27-55	3-19-56	2358	A-30 NW	0.75
CD-2-4	12-27-55	3-19-56	2358	A-30 NW	0.71
CD-3-4	12-27-55	3-19-56	2358	A-30 NW	0.65
CD-4-4	12-27-55	3-19-56	2358	A-30 NW	0.57
CD-5-4	12-27-55	3-19-56	2358	A-30 NW	0.47
CD-6-4	12-27-55	3-19-56	2358	A-30 NW	0.36

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TABLE V

Irradiation History of Cold-Pressed and
Sintered Uranium Alloy Powder Compacts

Spec. No.	Date Placed in Reactor	Date Removed from Reactor	Exposure, MWD	Location in Reactor	Average Thermal nv ($\times 10^{-14}$)
BD-1-2	1-27-55	8-22-55	4828	A-36 SE, A-31 SW	0.66
BD-1-3	1-27-55	8-22-55	4828	A-36 SE, A-31 SW	0.68
BD-2-2	1-27-55	8-22-55	4828	A-36 SE, A-31 SW	0.76
BD-2-3	1-27-55	8-22-55	4828	A-36 SE, A-31 SW	0.76
BD-3-2	1-27-55	8-22-55	4828	A-36 SE, A-31 SW	0.82
BD-3-3	1-27-55	8-22-55	4828	A-36 SE, A-31 SW	0.81
BD-4-2	1-27-55	8-22-55	4828	A-36 SE, A-31 SW	0.69
BD-4-3	1-27-55	8-22-55	4828	A-36 SE, A-31 SW	0.71
BD-5-2	1-27-55	8-22-55	4828	A-36 SE, A-31 SW	0.57
BD-5-3	1-27-55	8-22-55	4828	A-36 SE, A-31 SW	0.58
BD-6-2	1-27-55	8-22-55	4828	A-36 SE, A-31 SW	0.40
BD-6-3	1-27-55	8-22-55	4828	A-36 SE, A-31 SW	0.41
BD-7-1	1-27-55	8-22-55	4828	A-36 SE, A-31 SW	0.82
BD-7-2	1-27-55	8-22-55	4828	A-36 SE, A-31 SW	0.82
BD-7-3	1-27-55	8-22-55	4828	A-36 SE, A-31 SW	0.83
BD-8-1	1-27-55	8-22-55	4828	A-36 SE, A-31 SW	0.85
BD-8-2	1-27-55	8-22-55	4828	A-36 SE, A-31 SW	0.84
BD-8-3	1-27-55	8-22-55	4828	A-36 SE, A-31 SW	0.86
CD-1-2	12-27-55	3-19-56	2358	A-30 NW	0.75
CD-2-2	12-27-55	3-19-56	2358	A-30 NW	0.71
CD-3-2	12-27-55	3-19-56	2358	A-30 NW	0.65
CD-4-2	12-27-55	3-19-56	2358	A-30 NW	0.57
CD-5-2	12-27-55	3-19-56	2358	A-30 NW	0.47
CD-6-2	12-27-55	3-19-56	2358	A-30 NW	0.36

TABLE VI

Irradiation History of Hot-Worked Uranium - 3.5 w/o
Molybdenum Alloy Powder Compacts

Spec. No.	Date Placed in Reactor	Date Removed from Reactor	Exposure, MWD	Location in Reactor	Average Thermal nv ($\times 10^{-14}$)
CD-1-1	12-27-55	3-19-56	2358	A-30 NW	0.75
CD-1-3	12-27-55	3-19-56	2358	A-30 NW	0.75
CD-2-1	12-27-55	3-19-56	2358	A-30 NW	0.71
CD-2-3	12-27-55	3-19-56	2358	A-30 NW	0.71
CD-3-1	12-27-55	3-19-56	2358	A-30 NW	0.65
CD-3-3	12-27-55	3-19-56	2358	A-30 NW	0.65
CD-4-1	12-27-55	3-19-56	2358	A-30 NW	0.57
CD-4-3	12-27-55	3-19-56	2358	A-30 NW	0.57
CD-5-1	12-27-55	3-19-56	2358	A-30 NW	0.47
CD-5-3	12-27-55	3-19-56	2358	A-30 NW	0.47
CD-6-1	12-27-55	3-19-56	2358	A-30 NW	0.36
CD-6-3	12-27-55	3-19-56	2358	A-30 NW	0.36

TABLE VII

Effect of Irradiation on End-Pressed Unalloyed Uranium Powder Compacts^(a)

Spec. No.	Cross-Section	Total Atom Burnup, a/o	Calc. Temp., °C		Length Change, %	Growth Rate, $G_i^{(b)}$	Maximum Diameter Change, %	Weight Change, mg	Density Change, %	Hardness Change, R_A
			Surface	Center						
AB-44	Solid	0.046	110	160	- 0.03	- 0.11	0.27	- 16.2	-	-
BD-6-1	Solid	0.19	85	100	- 3.10	-17	3.12	- 9.7	-0.51	7.4
BD-5-1	Solid	0.27	110	120	- 5.70	-22	4.00	1.8	-0.64	10.8
AB-46	Solid	0.28	380	660	- 6.5	-24	7.3	- 1.4	-	-
BD-1-1	Solid	0.32	120	130	- 5.92	-19	5.51	1.1	-1.01	8.6
BD-4-1	Solid	0.33	120	140	- 8.49	-27	5.76	0.9	-0.82	11.1
BD-2-1	Solid	0.37	130	140	- 7.46	-21	6.15	2.6	-0.85	9.9
BD-3-1	Solid	0.38	130	150	- 9.04	-25	6.16	2.0	-1.02	9.1
G-19	Solid	0.41	460	610	- 3.30	- 8.2	30	411.7	-	-
G-13	Solid	0.45	560	740	(c)	-	-	-	-	-
G-18	Solid	0.47	590	780	(c)	-	-	-	-	-
AB-48	Cored ^(d)	0.14	240	400	- 2.6	-19	2.1	23.6	-	-
G-21	Cored	0.16	210	290	- 3.9	-25	3.3	-830.2	-	-
AB-50	Cored	0.28	380	660	- 8.3	-31	10.2	15.9	-	-
G-22	Cored	0.43	510	670	-12	-30	24	120.8	-	-
G-20	Cored	0.48	580	770	-26	-63	71	(e)	-	-
AB-113	Porous ^(f)	0.039	70	95	- 0.18	- 4.6	- 0.16	242.9	-	-
AB-118	Porous	0.047	70	90	- 0.44	- 9.3	- 0.03	5.2	-	-
AB-114	Porous	0.064	90	130	- 0.67	-11	- 0.08	10.2	-	-
AB-115	Porous	0.087	110	170	0.51	5.9	0.11	5.8	-	-
AB-116	Porous	0.10	130	200	- 1.73	-21	1.38	3.8	-	-
AB-117	Porous	0.11	130	220	3.35	28	- 1.04	3.5	-	-

(a) Specimens were made from -12 mesh powder pressed for 15 minutes at 600°C at 24,000 psi.

(b) G_i = microin./in. per fission/ 10^6 total atoms.

(c) Specimen could not be removed from its irradiation capsule.

(d) Cored specimens contained a 1/16-in. dia. hole along the axis of the specimen.

(e) Specimen spontaneously ignited and burned to oxide before weight and density measurements were obtained.

(f) Porous specimens contained from 2 to 4% porosity, uniformly distributed.

TABLE VIII

Effect of Irradiation on Unjacketed Specimens Taken from Previously Thermally Cycled Hot-Pressed Uranium Hydride Compacts

Spec. No.	Compact No.	Location in Compact ^(a)	No. of Prior Thermal Cycles ^(b)	Total Atom Burnup, a/o	Calc. Temp., °C		Length Change, %	Growth Rate, $G_i^{(c)}$	Diameter Change, %	Weight Change, mg	Density Change, %	Hardness Change, R_A
					Surface	Center						
AE-9	35	A	250	0.087	75	100	3.1	35	-1.4	34.8	0.21	8.8
AE-1	26	A	700	0.13	75	110	4.4	33	-1.6	1.9	0.39	8.2
AE-13	36	A	250	0.49	240	390	(d)	-	-	-	-	-
AE-17	48	A	700	0.70	320	540	6.6	9.1	19.2	1.3	-21.59	-0.4
AE-14	36	B	250	0.11	80	120	5.5	49	-1.9	1.1	0.018	4.2
AE-10	35	B	250	0.43	200	340	0.79	1.8	1.1	2.0	- 1.29	10.1
AE-6	31	B	250	0.44	170	280	3.8	8.5	-0.080	- 0.4	- 0.95	12.1
AE-18	48	B	700	0.53	220	370	4.2	7.8	1.7	2.0	- 0.93	10.6
AE-2	26	B	700	0.58	250	420	4.7	7.9	0.60	- 2.4	- 1.19	10.2
AE-11	35	C	250	0.30	140	230	4.9	16	-0.92	1.9	- 0.64	10.9
AE-15	36	C	250	0.39	180	290	4.1	10	-1.1	1.1	- 0.48	9.8
AE-3	26	C	700	0.40	160	250	7.2	17	-1.0	0.5	- 0.73	7.9
AE-7	31	C	250	0.64	270	450	2.0	3.1	7.6	10.0	- 7.97	11.5
AE-19	48	C	700	0.64	270	460	7.8	12	2.4	2.4	- 5.34	8.5
AE-8	31	D	250	0.11	70	100	3.8	34	-1.0	1.9	0.061	6.5
AE-20	48	D	700	0.27	120	180	6.8	24	-0.56	1.7	- 0.25	9.8
AE-12	35	D	250	0.49	230	390	(d)	-	-	-	-	-
AE-16	36	D	250	0.64	280	470	7.8	12	6.5	- 4.5	-12.10	10.9
AE-4	26	D	700	0.66	300	510	11.4	16	9.7	- 2.2	-17.58	4.6

(a) The manner in which the uranium hydride compacts were sectioned for irradiation specimens is shown in Figure 16.

(b) Each thermal cycle consisted of heating from 100°C to 500°C within 10 to 12 minutes followed by cooling back to 100°C within 25 to 30 minutes.

(c) G_i = microin./in. per fission/ 10^6 total atoms.

(d) Measurements could not be obtained after irradiation because the specimen was so highly distorted it was wedged in its irradiation capsule.

TABLE IX

Effect of Irradiation on Stainless Steel-Jacketed Specimens Taken from Previously Thermally Cycled Hot-Pressed Uranium Hydride Compacts

Spec. No.	Com- pact No.	Location in Com- pact ^(a)	No. of Prior Thermal Cycles ^(b)	Jacket Wall Thick- ness, in.	Total Atom Burnup, a/o	Calc. Temp., °C			Length Change, %	Growth Rate, G_1 ^(c)	Diameter Change, %	Weight Change, mg	Density Change, %	Hardness Change, R_A
						Surface	Center	Jacket						
AE-35	36	C	250	0.005	0.27	140	220	135	4.7	17	-0.19 ^(d)	-	-	-
AE-21	26	A	700	0.005	0.28	120	180	115	6.7	23	-1.9	1.6	-0.071	7.6
AE-33	36	A	250	0.005	0.44	230	370	220	1.7	3.8	1.24 ^(d)	-	-	-
AE-23	26	C	700	0.005	0.48	210	340	200	2.4	4.9	0.64	3.3	-1.36	10.3
AE-34	36	B	250	0.005	0.60	270	440	260	8.8	14	1.12 ^(d)	-	-	-
AE-22	26	B	700	0.005	0.62	300	490	290	(e)	-	1.16 ^(d)	-	-	-
AE-24	26	D	700	0.005	0.64	300	500	290	18.0	26	1.65 ^(d)	-	-	-
AE-36	36	D	250	0.005	0.68	320	540	310	18.8	25	1.16 ^(d)	-	-	-
AE-28	31	D	250	0.010	0.046	55	70	55	1.2	26	-0.52	22.0	-0.058	7.6
AE-40	48	D	700	0.010	0.092	70	100	65	5.4	57	-2.2	2.5	-0.021	7.2
AE-26	31	B	250	0.010	0.27	130	190	120	2.9	11	0.0	1.5	-0.64	8.3
AE-38	48	B	700	0.010	0.43	190	300	180	8.3	19	0.11 ^(d)	-	-	-
AE-27	31	C	250	0.010	0.57	270	430	250	3.6	6.2	0.60 ^(d)	-	-	-
AE-25	31	A	250	0.010	0.65	340	550	315	7.7	11	0.21 ^(d)	-	-	-
AE-37	48	A	700	0.010	0.72	360	600	335	8.5	11	1.17 ^(d)	-	-	-
AE-29	35	A	250	0.020	0.21	140	210	130	2.9	14	0.00 ^(d)	-	-	-
AE-31	35	C	250	0.020	0.37	230	340	210	3.1	8.2	-0.17 ^(d)	-	-	-
AE-30	35	B	250	0.020	0.45	280	440	255	3.0	6.6	-0.10 ^(d)	-	-	-
AE-32	35	D	250	0.020	0.49	310	480	280	9.6	19	-0.20 ^(d)	-	-	-

(a) The manner in which the uranium hydride compacts were sectioned for irradiation specimens is shown in Figure 16.

(b) Each thermal cycle consisted of heating from 100°C to 500°C within 10 to 12 minutes, followed by cooling back to 100°C within 25 to 30 minutes.

(c) G_1 = microin./in. per fission/ 10^6 total atoms.

(d) The specimen could not be separated from its jacket. Diameter change is therefore the change observed in jacket diameter, rather than specimen diameter.

(e) Length measurement could not be obtained because of interference of jacket.

TABLE X

Effect of Irradiation on Side-Pressed Unalloyed Uranium Powder Compacts^(a)

Spec. No.	Porosity, %	Total Atom Burnup, a/o	Calc Temp., °C		Length Change, %	Growth Rate, G_1 ^(b)	Diameter Change, %		Weight Change, mg
			Surface	Center			to pressing direction	⊥ to pressing direction	
AB-124	0.0	0.16	310	540	4.72	28	-4.69	3.26	3.3
AB-126	1.2	0.16	300	530	4.77	27	-4.64	3.54	- 10.3
AB-128	1.8	0.12	230	400	1.98	16	0.055	1.49	8.0
AB-127	1.8	0.22	410	720	7.10	31	-5.39	5.65	- 4.2
AB-129	4.2	0.11	220	360	2.04	18	-0.054	0.35	15.7
AB-130	4.4	0.19	360	630	6.09	31	-4.49	5.92	23.7
AB-131	5.1	0.21	390	690	7.15	33	-2.41	3.81	46.4
AB-132	6.5	0.21	390	680	7.94	37	-2.74	0.54	99.6
AB-133	7.5	0.058	130	210	0.85	15	0.57	3.49	-215.6
AB-134	8.0	0.076	160	260	0.81	11	1.56	0.37	76.3
AB-51	12.4	0.080	155	250	3.4	42	1.08	1.88	200.2
AB-52	12.5	0.24	380	580	10.8	43	1.41	4.10	67.0
G-26	12.5	0.31	310	410	19.4	57	5.50	8.82	589.4
G-24	13.0	0.46	550	730	22	43	-5.46	45.5	931.4

(a) Specimens were pressed at 600°C in a side molding die using -12 +65 mesh powder.

(b) G_1 = microin./in. per fission/ 10^6 total atoms.

TABLE XI

Effect of Irradiation on Rolled Unalloyed Uranium Powder Compacts^(a)

Spec. No.	Total Porosity, %	Total Atom Burnup, a/o	Length Change, %	Growth Rate, G_1 ^(b)	Diameter Change, %	Weight Change, mg	Hardness Change, R_A
CD-5-4	8.6	0.076	-2.78	-37	2.08	49.4	11.3
CD-4-4	8.8	0.090	-2.43	-27	2.84	-311.0	11.5
CD-2-4	9.8	0.110	0.26	2.4	4.67	138.5	10.5
CD-6-4	10.8	0.058	-1.15	-20	1.27	133.6	8.4
CD-1-4	11.4	0.114	1.43	12	4.53	197.7	8.1
CD-3-4	11.5	0.100	0.94	9.4	3.49	194.2	- 0.4

(a) Specimens were prepared from -12 +80 mesh powder rolled in a steel sheath at 600°C. Maximum temperature during irradiation is estimated to have ranged between 100° and 200°C, depending upon the amount of burnup.

(b) G_1 = microin./in. per fission/ 10^6 total atoms.

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TABLE XII

Effect of Irradiation on Cold-Pressed and Sintered Uranium Alloy Powder Compacts^(a)

Spec. No.	Composition, w/o	Grain Size, mm	Total Atom Burnup, a/o	Calc. Temp., °C		Length Change, %	Growth Rate, G_i (b)	Diameter Change, %	Weight Change, mg	Density Change, %	Hardness Change, R_A
				Surface	Center						
BD-6-2	1.0 Mo	0.05	0.17	75	90	2.76	16	5.41	- 4.1	-3.42	(c)
BD-5-2	1.0 Mo	0.05	0.26	95	120	3.41	13	5.72	0.6	-5.17	(c)
BD-1-3	1.0 Mo	0.05	0.32	100	130	2.84	8.8	6.75	1.9	-2.31	(c)
BD-2-3	1.0 Mo	0.05	0.33	110	140	3.36	10	5.95	-18.5	-4.34	(c)
BD-7-2	1.0 Mo	0.05	0.36	120	150	2.56	7.0	5.06	- 1.0	-2.08	(c)
BD-8-2	1.0 Mo	0.05	0.38	120	150	2.63	6.8	5.83	0.3	-2.37	(c)
CD-2-2	1.4 Mo	-	.106	-	(d)	1.46	14	0.046	1.2	-	9.1
CD-1-2	1.4 Mo	-	.110	-	(d)	1.80	16	0.50	3.0	-	9.6
CD-5-2	2.0 Mo	-	.072	-	(d)	1.47	20	0.14	2.6	-	8.8
CD-4-2	2.0 Mo	-	.085	-	(d)	0.75	8.7	0.47	5.9	-	9.7
CD-3-2	2.0 Mo	-	.095	-	(d)	1.89	20	0.37	6.6	-	7.2
CD-6-2	2.5 Mo	-	.055	-	(d)	1.21	22	0.091	1.9	-	7.4
BD-6-3	1.6 Nb	0.02	0.19	85	95	1.82	9.5	0.96	0.5	-1.88	6.2
BD-5-3	1.6 Nb	0.02	0.26	95	120	2.46	9.4	2.20	0.7	-3.22	- 4.3
BD-4-3	1.6 Nb	0.02	0.32	110	130	2.43	7.5	3.22	0.9	-4.00	4.9
BD-3-3	1.6 Nb	0.02	0.35	120	150	3.59	10	3.34	1.7	-5.30	0.5
BD-7-3	1.6 Nb	0.02	0.37	120	150	2.49	6.6	1.16	1.0	-1.68	(e)
BD-8-3	1.6 Nb	0.02	0.37	120	150	1.78	4.8	1.00	1.0	-1.25	11.3
BD-1-2	0.42 Si	0.3	0.30	100	130	16.2	50	(f)	(f)	(f)	(f)
BD-4-2	0.42 Si	0.3	0.32	110	130	19.8	56	(f)	(f)	(f)	(f)
BD-2-2	0.42 Si	0.3	0.33	110	140	17.3	48	(f)	(f)	(f)	(f)
BD-7-1	0.42 Si	0.3	0.35	120	150	35.2	86	(f)	(f)	(f)	(f)
BD-3-2	0.42 Si	0.3	0.35	120	150	29.4	74	(f)	(f)	(f)	(f)
BD-8-1	0.42 Si	0.3	0.37	120	150	22.2	54	(f)	(f)	(f)	(f)

- (a) Specimens were pressed from -325 mesh elemental powders at 100,000 psi. The silicon alloy was sintered at 1050°C; the other alloys were sintered at 1100°C.
 (b) G_i = microin./in. per fission/ 10^6 total atoms.
 (c) Specimen surface was too rough for measurement.
 (d) Estimated to have been between 100 and 150°C.
 (e) Specimen fractured when load was applied to indenter.
 (f) Measurements could not be made because specimen was stuck in irradiation holder.

TABLE XIII

Effect of Irradiation on Hot-Worked Uranium-3.5 w/o Molybdenum Alloy Powder Compacts^(a)

Spec. No.	Type of Specimen	Porosity, %	Total Atom Burnup, a/o	Length Change, %	Growth Rate, G_i (b)	Diameter Change, %	Width Change, %	Thickness Change, %	Weight Change, mg	Hardness Change, R_A
CD-4-3	Rolled Plate	0	0.083	-3.89	-48	-	2.32	16.3	-28.4	12.8
CD-3-3	Rolled Plate	0	0.092	1.64	18	-	-3.16	7.84	2.2	(c)
CD-2-3	Rolled Plate	0	0.101	1.60	16	-	-5.06	7.73	3.8	(c)
CD-1-3	Rolled Plate	0	0.105	2.47	23	-	-5.20	6.29	9.1	10.4
CD-6-3	Rolled Plate	4.0	0.053	-0.060	- 1.1	-	0.72	3.99	2.9	13.0
CD-5-3	Rolled Plate	4.0	0.070	0.110	1.6	-	1.03	3.35	2.2	0.2
CD-6-1	Swaged Rod	0	0.053	2.52	47	-0.54	-	-	2.7	16.4
CD-5-1	Swaged Rod	0	0.070	1.79	25	-0.053	-	-	3.1	11.5
CD-4-1	Swaged Rod	0	0.083	1.85	22	-0.43	-	-	4.2	14.4
CD-3-1	Swaged Rod	0	0.092	2.65	28	-0.27	-	-	3.2	13.6
CD-2-1	Swaged Rod	0	0.101	1.81	18	-0.69	-	-	2.7	15.1
CD-1-1	Swaged Rod	0	0.105	1.61	15	-0.22	-	-	-97.1	11.7

- (a) Specimens were prepared by rolling or swaging pre-alloyed powder in steel sheaths at 600°C. After final machining to size, the specimens were held at 850°C for 15 minutes. Irradiation temperatures are estimated to be from 100 to 150°C, depending upon the burnup obtained.
 (b) G_i = microin./in. per fission/ 10^6 total atoms.
 (c) Specimens broke when load was applied to indenter.

Figure 1. Uranium Compact End-Pressed to Full Density.

Micro No. 20679

250X

Figure 2. Uranium Compact End-Pressed to 2 to 4% Porosity.

Micro No. 20681

250X

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Figure 3. Uranium Compact Side-Pressed to Full Density.

Micro No. 20762

250X

Figure 4. Uranium Compact Side-Pressed to 13.0% Porosity.

Micro No. 20760

250X

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Figure 5. Uranium Compact Hot-Rolled to 11.0% Porosity.

Micro No. 20758

250X

Figure 6. Uranium - 1.4 w/o Molybdenum Alloy Compact, Cold-Pressed and Sintered.

Micro No. 20683

250X

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Figure 7. Uranium - 2.0 w/o Molybdenum Alloy Compact, Cold-Pressed and Sintered.

Micro No. 20684

250X

Figure 8. Uranium - 2.5 w/o Molybdenum Alloy Compact, Cold-Pressed and Sintered.

Micro No. 20682

250X

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Figure 9. Uranium - 3.5 w/o Molybdenum Alloy Compact, Hot-Rolled to Theoretical Density.

Micro No. 20685

250X

Figure 10. Uranium - 3.5 w/o Molybdenum Alloy Compact, Hot-Rolled to 96% Theoretical Density. Typical Pores Are Shown.

Micro No. 20677

250X

Figure 11. Uranium - 3.5 w/o Molybdenum Alloy Compact, Hot-Rolled to 96% Theoretical Density. An Area Between Pores Is Shown.

Micro No. 20678

250X

Figure 12. Uranium - 3.5 w/o Molybdenum Alloy Compact, Hot-Swaged to Theoretical Density.

Micro No. 20676

250X

FIGURE 13
LENGTH SHORTENING UNDER IRRADIATION OF
END-PRESSED URANIUM POWDER COMPACTS

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Figure 14. Effect of 0.4 a/o Burnup at Differing Irradiation Temperatures on Uranium Compacts End-Pressed at 600°C. Magnification 2X.

Micro No. 15391

Micro No. 18214

Micro No. 17622

Micro No. 18699

Before

After

Specimen BD-3-1, Irradiated at 150°C

Before

After

Specimen G-19, Irradiated at 610°C

Figure 15. Effect of Irradiation on Hot-Pressed Uranium Powder Compacts with a 1/16 in. Dia. Axial Core Hole. Magnification 2X.

Micro No.	17622	17603	18710	18700

Burnup, a/o	0	0.28	0.43	0.48
Irrad. Temp., °C	-	660	670	770
Spec. No.	-	AB-50	G-22	G-20

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FIGURE 16

LOCATION AND IDENTIFICATION OF IRRADIATION SPECIMENS
MACHINED FROM HOT-PRESSED URANIUM HYDRIDE COMPACTS

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Figure 17. Effect of Irradiation on Unjacketed Specimens Machined from Compacts Made from Uranium Hydride End-Pressed at 600°C. Magnification 2X.

Micro No.	19118	19129	19113	19126

Burnup, a/o	0.087	0.27	0.40	0.70
Irrad. Temp., °C	100	180	250	540
Spec. No.	AE-9	AE-20	AE-3	AE-17

34

Figure 18. Effect of Irradiation on Stainless Steel-Jacketed Specimens Machined from Compacts Made from Uranium Hydride End-Pressed at 600°C. Magnification 2X.

Micro No.

19135

19151

19145

Jacket thickness, in.

0.005

0.010

0.020

Burnup, a/o

0.64

0.72

0.49

Irrad. Temp., °C

500

600

480

Spec. No.

AE-24

AE-37

AE-32

35

FIGURE 19
EFFECT OF IRRADIATION TEMPERATURE ON THE SWELLING
OF URANIUM HYDRIDE COMPACTS

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Figure 20. Effect of Irradiation on Uranium Compacts Side-Pressed at 600°C to Approximately 12.5% Porosity. Magnification 2X.

Micro No.	17622	17605	17607	18715

Burnup, a/o	0	0.080	0.24	0.46
Irrad. Temp., °C	-	250	580	730
Spec. No.	-	AB-51	AB-52	G-24

Figure 21. Effect of Irradiation on a Typical Uranium Compact Rolled at 600°C. The Specimen Shown below (No. CD-1-4) Contained 11.4% Porosity Prior to Irradiation. Magnification 2X.

Micro No. 17622
Before Irradiation

Micro No. 19917
After 0.11 a/o Burnup at an Estimated Temperature of 200°C.

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Figure 22. Effect of Irradiation on Cold-Pressed and Sintered Compacts of Uranium - 1 w/o Molybdenum Alloy.
Magnification 2X.

Micro No.	15391	18224	18221	18231

Burnup, a/o	0	0.17	0.26	0.38
Irrad. Temp., °C	-	90	120	150
Spec. No.	-	BD-6-2	BD-5-2	BD-8-2

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Figure 23. Effect of Irradiation at Approximately 150°C on Cold-Pressed and Sintered Uranium-Molybdenum Alloy Compacts. Magnification 2X.

Micro No.	19911	19919	19931

Burnup, a/o	0.11	0.095	0.055
Mo, w/o	1.4	2.0	2.5
Spec. No.	CD-1-2	CD-3-2	CD-6-2

Figure 24. Effect of Approximately 0.1 a/o Burnup on Hot-Worked Uranium - 3.5 w/o Molybdenum Alloy Compacts. Magnification 2X.

Micro No. 19912

Plate, 0.040 in. Thick, Rolled to Full Density at 600°C. (Specimen CD-1-3).

Micro No. 19928

Plate, 0.040 in. Thick, Rolled to 96% Full Density at 600°C. (Specimen CD-5-3).

Micro No. 19910

Rod, Swaged to Full Density at 600°C. (Specimen CD-1-1).

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Figure 25. Effect of Irradiation on Cold-Pressed and Sintered Compacts of Uranium - 1.6 w/o Niobium Alloy. Magnification 2X.

Micro No.	15391	18225	18219	18232

Burnup, a/o	0	0.19	0.32	0.37
Irrad. Temp., °C	-	95	130	150
Spec. No.	-	BD-6-3	BD-4-3	BD-8-3

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Figure 26. Typical Uranium - 0.42 w/o Silicon Alloy Compact, Specimen No. BD-3-2, after 0.35 a/o Burnup. The specimen is located in the upper mole in the aluminum holder, and is so distorted that it could not be removed.

18215

2X