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ATOMICS INTERNATIONAL A Division of North American Aviation, Inc.		NAA-SR TDR NO 9411	APPROVALS
TECHNICAL DATA RECORD		PAGE 1 OF 39	
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G. V. Alm M. H. Binstock S. M. Cobb W. L. Cockrell R. B. Gordon H. Pearlman A. W. Thiele A. Weitzberg		STATEMENT OF PROBLEM Cold Compacting of $UO_2 + ZrH_2$ Fuel Pellets for Critical Experiments	
		ABSTRACT A total of 22,284 fuel pellets were fabricated for the SNAP Critical Assembly. These pellets were cold pressed from granulated material consisting of 10 w/o highly enriched ceramic grade UO_2 and 90 w/o ZrH_2 . A portion of these pellets were made with an addition of 1.0 to 6.0 w/o HfH_2 , 0.1 to 0.6 w/o EU_2O_3 , (0.3 w/o EU_2O_3 - 3 w/o HfH_2), (0.6 w/o EU_2O_3 - 6.0 w/o HfH_2). The pellets were compacted on an automatic press (Stokes) @ 35 T.S.I. and yielded approximately 72% - 75% of the theoretical densities of the mixed powders. Difficulty was experienced in pelletizing the UO_2-ZrH_2 as blended. The material was, therefore, granulated, coated with stearic acid (0.5 w/o) to provide lubricant for the die during automatic compaction. Treatment of the UO_2-ZrH_2 mix for granulation consisted of compacting the mix @ 12 T.S.I. into briquettes. The pre-pressed compacts were broken into small bits and then fractioned to -16 + 50 mesh granules. An application of 0.4 w/o clear lacquer was applied to each pellet to increase their resistance to shock and chipping. The composition of each type pellet fabricated was identified by color coding using vertical lacquer stripes painted on each pellet.	

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I. INTRODUCTION

The SCA-V fuel pellet referred to in this report was fabricated by cold pressing a homogenized mixture of $\text{ZrH}_2\text{-UO}_2$. Every precaution was taken during manufacturing to meet the required specifications enumerated below:

Each pellet shall have a UO_2 content of 10 w/o. A portion of these pellets shall contain varying amounts of poison (HfH_2 , EU_2O_3). The allowable variation of UO_2 in each pellet shall be within $\pm 5\%$. The finished pellets shall be 0.410 ± 0.001 " in diameter, $0.410" \pm 0.025$ " in height and with a density of 72 - 75% theoretical. All pellets shall be spray coated with a film of Krylon lacquer to increase their resistance to shock during subsequent handling.

Tabulated below are the quantity of pellets made in the following ratios of UO_2 , HfH_2 and EU_2O_3 :

<u>No. of Pellets Made</u>	<u>UO_2</u>	<u>ZrH_2</u>	<u>HfH_2</u>	<u>EU_2O_3</u>
13,466	10 w/o	90 w/o		
4,984	10	89	1 w/o	.
492	10	88	2	
512	10	87	3	
517	10	84	6	
500	10	89.9		0.1 w/o
480	10	89.7		0.3
477	10	89.4		0.6
475	10	86.7	3	0.3
430	10	83.4	6	0.6

The procedures covering nuclear safety and criticality for this fabrication effort were in accordance with Atomics International Nuclear Safety Analysis C-140, entitled "Fuel Pellets for SCA-5 Critical Machine", January 29, 1963.

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II. MATERIALS AND EQUIPMENT

A. Material

1. UO_2 - Ceramic grade, 93.22 O/U enriched, -325 mesh. The material was purchased from United Nuclear Corp. and supplied by D/721-13.
2. Zirconium Hydride - The ZrH_2 powder was purchased from Metals Hydride, Inc., in -325 mesh size.
3. Hafnium Hydride - Purchased from A. D. Mackay, Inc., in -325 mesh size.
4. Europium Oxide - The as-received Eu_2O_3 was granular and required crushing to a fine powder prior to use. The material was 99.9% pure. It was purchased from Research Chemicals, Division of Nuclear Corp., of America.
5. Lacquer - Sinclair's protective plastic coating #935.

B. Equipment

1. Stokes automatic press, 12 tons capacity, Figure 1
2. Inert atmosphere glove box (3), Figure 2
3. Small hydraulic jack for ejection, Figure 3
4. Taylor screens for granulation
5. Five-hundred ton press for pre-pressing, Figure 4
6. PK blender - 4 quarts, Figure 5
7. Rectangular dies, $2\frac{1}{2}$ " x $3\frac{3}{4}$ " (3) (See Figure 4)
8. Small balance accurate to 0.001 gm
9. Metro-gram balance accurate 0.1 gram, Figure 6
10. Seco balance accurate to 0.01 gram
11. Vented hood for spraying, Figure 7
12. Assorted utensils for handling powder

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13. In-process storage cabinet "Lyons", Figure 8

14. Syntron vibrator

III. FABRICATION METHODS

A. Blend Record

Prior to blending, a batch record was established for each batch of "mix" to be prepared. This record contains information relating to the batch number of the "mix" and also, the lot numbers of both UO_2 and ZrH_2 . This record accompanied each batch of "mix" throughout each succeeding process steps to function as a process control card.

B. Weighing and Blending

Each lot of UO_2 and ZrH_2 to produce a batch of "mix" was weighed out in a ratio of one part UO_2 , to 9 parts ZrH_2 . Each constituent was weighed to 0.01 gram accuracy. In batches which contained poison, the Eu_2O_3 and HfH_2 weights were adjusted to this ratio and weighed to the same accuracy before adding to the $\text{UO}_2 + \text{ZrH}_2$ powders. The maximum batch size of all blends prepared were not greater than 2 kg.

The accurately weighed UO_2 and ZrH powder was screened through a 28-mesh sieve three times. This ensured the UO_2 was free of all spherical clumps. Also, reduced the possibility of the UO_2 appearing as conglomerates in the ZrH_2 powder. After screening, the $\text{UO}_2 + \text{ZrH}_2$ mix was then poured into a four-quart PK blender and intimately mixed for one hour. Upon completion of the blending cycle, eight grab samples were taken and submitted to chemistry for UO_2 determination and blending efficiency.

C. Prepressing and Granulation

The processed batch of mix was transferred from the blender to the atmosphere glove box attached to the compacting press. A

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2¼" x 3¼" rectangular, single action die was used to slug the mix.

The die was loaded to capacity with the mix, leveled with a leveling device and pressed to 12 T.S.I. Immediately after pressing, the die was returned to the controlled atmosphere glove box where the compact was ejected from the die. The resultant compact was 3/8" thick and with sufficient density suitable for granulation.

After slugging the entire batch of mix, the compacts were crushed into small pieces that would pass through a 16-mesh screen and be retained on a 50-mesh screen. All the fines generated from this operation were collected and recycled until the amount of fines remaining were minute. This amount was then added to the -16 +50 mesh fractions. The final step was a reblending of the granules for 15 minutes with an addition of 0.5 w/o stearic acid.

D. Automatic Compaction of Granules

Prior to operating under power, the "Stokes" press was adjusted for height and pressure. This was determined by operating the press manually, to compact several pellets for dimensional check and for sufficient density. After the necessary adjustments were made on the press, the hopper was filled with the granules and the automatic feed connected. The press speed was adjusted to produce 24 pellets per minute. The pellets were checked from time to time to make certain that they were uniform in height and density. Most of the material was pressed into pellets with a little variation in height. This occurred as a result of "fines" generated from constant agitation of the granules, caused by vibration set-up by the press while under power. Another factor that influenced the height of the pellets was the settling of the material in the hopper.

The height variation from pellet to pellet was minimized by adjusting the die cavity and pressure periodically. It should

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be mentioned that for each batch of granules compacted, a minor adjustment was required on the press. Approximately 450 pellets were produced from each batch of granules.

From each pellet batch, a total of nine samples were inspected for chemical composition and for dimensions. Every 50th pellet was the rate of sampling for each pellet batch. The results of the dimensional and density check are summarized in Appendix A. These results were determined prior to the chemical analysis as the latter was a destructive test.

E. Application of Lacquer to Pellets

The surfaces of the pressed pellets were very powdery. This required removal of all adhering powder particles from each pellet prior to lacquering. This was accomplished by holding each pellet with a pair of pharmaceutical tweezers and brushing the pellet off with a small brush. This operation was carried out in a glove box. Since the use of tweezers were a necessity to facilitate handling of the pellets with gloved hands, the time consumed for this operation was quite extensive. After the excess powder was removed, the powder free pellets were placed on trays for lacquering. These trays were fabricated from plexi-glass and so designed to accommodate 35 pellets. The outside dimensions of these trays were roughly 4" x 6" and ½" thick. They contained a 5" x 7" array of ½" diameter cavities 1/8" deep, spaced ¾" center-to-center. These trays were made in pairs to match-fit. (See Figure 7)

This provided a means to sandwich the pellets so they could be pancaked (turned over) back and forth during the spraying operation.

The spraying operation was conducted in a vented hood equipped with a tripod type turn table. This enabled rapid turning of the racked pellets while applying the lacquer. The absorption rate of lacquer into the pellets was great. As a result, it

required from 6 to 8 coats of lacquer to obtain a powder free surface pellet and sufficient thickness for protection. It was found that better results were obtained from slow spraying than rapid spraying. It appeared that slower spraying, light coats, closed the surface pores more readily and required less lacquer for each coat.

F. Color-Coding of Fuel Pellets

Each batch of fuel pellets were identified as to this composition in the form of colored, vertical strips painted on each pellet. Since a large quantity of pellets were involved, a spraying fixture was fashioned to facilitate rapid spraying of 45 pellets in one operation. The spraying fixture was fabricated from 0.020" wall x 0.5" I.D. x 23" long stainless steel tube. Three slots 0.053" wide and spaced 120° apart were machined length-wise in the tube. These slots equally spaced, allowed spraying of three different colors without having to blankout the other slots. Table II summarizes the color-coding of the pellets as to their composition.

G. Packaging of Pellets for Shipment

The pellets were assembled in 7/16" I.D. x 1/2" O.D. x 11" plastic tubes. Each tube was loaded with a maximum of 27 pellets (see Figure 7). The tubes were sealed by capping each end with friction fitting stoppers. The loaded tubes were then clustered in a bundle of 17. After clustering, the assembly was held together with plastic tape wrapped around the outside. No more than one batch of pellets were clustered in the assembly. The pellets were shipped to the Santa Susana Vault in a 6" diameter x 28" cask contained in a 55-gallon drum.

IV. DISCUSSION OF RESULTS

The variation in height of pressed pellets were within the allowable tolerances ($\pm 0.5\%$). The densities were geometrically determined @ 72% - 75% theoretical. All pellets were free of cracks and the use of a small amount of stearic acid made ejection from the die very easy.

The assure conformance to the density and dimensional requirements, the pellets were inspected intermittently during compaction, e.g., the first ten pellets were checked for the referenced characteristics and each 50th thereafter, were checked in the same manner.

Initially, the delivery weight of each batch of pellets were to be determined by weighing the pellets before and after lacquering. This method was found to be unsatisfactory and was discontinued for the following reasons: The as-pressed pellets surfaces were very powdery and subsequent handling caused this powder to become detached from the pellets. This resulted in an extra weighing of this detached material and subsequent adjustment of the pellets initial weight. This appeared to be no problem at this point, but during the spraying operation, it was necessary to reject a number of pellets which were accidentally chipped or broken and those that were damaged prior to packaging. Each time a pellet was rejected for any reason, an adjustment of the pellets original weight had to be made. Due to the large quantity of pellets involved and the time consumed in constantly balancing the starting weight of the pellets, it was deemed that the time spent did not justify this method of determining the delivery weight of the pellets, when an alternate method could be used to obtain the same weight accuracy.

The delivery weight for the production pellets were determined from the results of an experiment conducted as follows:

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A batch of 400 pellets were carefully weighed and lacquered with the following results:

Before Lacquering	1627.90 grams
After Lacquering	<u>1634.42</u> grams
Weight of Lacquer	6.52 grams or 0.4%

This operation was carefully conducted so there was no loss of material in handling or in the lacquering operation. Based upon the results obtained, it was assumed that all pellets sprayed contained 0.4% lacquer. On this assumption, the weight of the pellets before lacquering was eliminated. The weight obtained for the lacquered pellets were adjusted to this percentage regardless of how many pellets were rejected during the lacquering operation.

In order to maintain spraying consistency from batch to batch, it was decided to have the same person spray pellets.

V. EXPERIMENTAL METHODS

Prior to production of the enriched pellets, a blending experiment was performed, using depleted UO_2 , to determine the maximum batch size of $\text{UO}_2 + \text{ZrH}_2$ for blending efficiency, e.g., a batch size of 4000 grams of $\text{UO}_2 + \text{ZrH}_2$ was blended for one hour in a PK blender. Eight grab samples were taken and analyzed for UO_2 content. Chemical results indicated that the UO_2 determinations were not within the tolerances specified ($\pm 5\%$). Also, a 15 power microscopic examination of the blend showed large conglomerates of UO_2 powder which had not mixed intimately with the ZrH_2 .

In the following batch of "mix" prepared, the total batch size was reduced to 2000 grams. Prior to blending this mixture, it was vibrated three times through a 28-mesh screen as a means to ensure that the UO_2 and ZrH_2 were free of all spherical clumps. Samples tested for UO_2 content from this blend

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indicated that this type of blending presented a uniform distribution of UO_2 . Based on these results, this method of blending was adopted for the production batches.

Initially, the $\text{UO}_2 + \text{ZrH}_2$ blends were granulated for compression by the following recommended procedures. A prepared batch of $\text{ZrH}_2 + \text{UO}_2$ powder was pre-pressed @ 25 T.S.I. into compacts. These were broken into small bits and subsequently screened through a 16-mesh sieve. It was estimated that 40% "fines" were generated from this operation. These "fines" were not eliminated prior to compression. Also, no lubricant was added at this time. Difficulties experienced in pelletizing this batch were; (1) ~~seizing~~ of the die on the compression stroke; (2) Pellet binding in die; (3) All pellets produced were either chipped or laminated.

It was found that greater clearance between die and upper punch, and lower compacting pressure minimized these difficulties, but an insufficient density resulted from the reduced pressure.

Although the die was provided with a greater clearance, lamination and ~~seizing~~ of the die re-occurred when compression was carried out at the original pressure. Both principles of pressing (single and double action) were tried. Each method proved unsatisfactory. The single action pressing, resulted in top of pellet very dense and hard, bottom very soft, also, lamination occurred on top of pellet. The double action (pressure applied from top and bottom) resulted in a sufficient density, but lamination continued to occur. Since these difficulties were not completely eliminated, it was reason to assume that the granules were not properly prepared for automatic compaction.

Subsequent batches of granules for trial compression were prepared as follows: A pressure of 12 T.S.I. was used to pre-press the "mix" into compacts. These also, were broken

into small bits and crushed into granules that would pass through a 16-mesh screen and be retained on a 50-mesh screen. After seizing, the granulation was collected and rebled (15 minutes) with an addition of 5% stearic acid to reduce die friction during compression. This blend was compacted (under the same conditions) without any difficulty as the preceding blend. All pellets fabricated from this blend were of uniform height and sufficient density (Table I).

VI. RESULTS

- A. Satisfactory blend uniformity was accomplished by blending each batch of "mix" in quantities not greater than 2000 grams batch size.
- B. It was found from chemical analyses that each blend of mix was within the allowable ($\pm 0.5\%$) variation of UO_2 .
- C. Automatic compaction at 35 T.S.I. produced densification of 72 - 75% of the theoretical densities of the mixed powder.
- D. The densities of the pellets were determined geometrically. An expansion of 0.4% takes place on ejection from the die. Lamination and cracks which occur with this condition were avoided by a proper die taper.
- E. Each finished pellet was spray coated with approximately 0.4 w/o clear lacquer to increase this resistance to shock. No breakage was incurred while handling them, once the lacquer was applied.

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PAGE 14 OF 39TABLE IPROPERTIES OF $\text{UO}_2 + \text{ZrH}_2$ PRESSED PELLETS

PELLET NO. <u>FIRST 14</u>	HEIGHT <u>INCHES</u>	WEIGHT <u>GRAMS</u>	VOL. <u>CC</u>	PRESSED DENSITIES	
				<u>g/cc</u>	<u>% THEOR.</u>
1	.428	4.10	.93	4.41	75.00
2	.427	4.08	.89	4.58	77.90
3	.421	3.97	.87	4.56	77.60
4	.432	4.14	.90	4.60	78.20
5	.430	4.18	.91	4.59	78.06
6	.429	4.13	.90	4.59	78.11
7	.430	4.15	.90	4.61	78.40
8	.429	4.11	.90	4.57	78.70
9	.427	4.09	.89	4.60	78.20
10	.429	4.14	.90	4.60	78.20
11	.430	4.15	.90	4.61	78.40
12	.427	4.12	.90	4.58	77.90
13	.430	4.16	.91	4.57	77.70
14	.427	4.12	.90	4.57	77.70

EVERY 10th
PELLET

1	.430	4.13	.90	4.59	78.10
10	.431	4.20	.92	4.57	77.70
20	.429	4.17	.91	4.58	77.90
30	.428	4.15	.90	4.61	78.40
40	.428	4.17	.91	4.58	77.90
50	.426	4.07	.93	4.37	74.10
60	.428	4.16	.93	4.47	76.02
70	.429	4.19	.94	4.46	75.90
80	.430	4.20	.94	4.47	76.02
90	.430	4.23	.94	4.50	76.65
100	.431	4.27	.94	4.54	77.20
110	.429	4.23	.94	4.50	76.50
120	.430	4.21	.94	4.48	76.19
130	.432	4.26	.94	4.53	77.04
140	.429	4.22	.93	4.54	77.21
150	.429	4.21	.94	4.48	76.19
160	.430	4.19	.94	4.46	75.85
180	.427	4.05	.93	4.35	73.97
190	.420	4.01	.92	4.36	74.14

THEORETICAL DENSITY

5.88 g/cc

10 w/o UO_2 (Depleted)

TABLE II

SUMMARY OF COLOR-CODING OF SCA-5 FUEL PELLETS FOR CHEMICAL COMPOSITION

BATCH NO.	COMPOSITION	COLOR	NO. OF STRIPES
1; 27	10 w/o UO_2 +90 w/o ZrH_2	R	1
28; 37; 38; 39; 41; 42; 43; 44; 45; 46; 47	10 w/o UO_2 +89 w/o ZrH_2 +1 w/o HfH_2	R	3
29	10 w/o UO_2 +88 w/o ZrH_2 +2 w/o HfH_2	W-Y	2
30	10 w/o UO_2 +87 w/o ZrH_2 +3 w/o HfH_2	R-Y	2
31	10 w/o UO_2 +84 w/o ZrH_2 +6 w/o HfH_2	R-W-Y	3
32	10 w/o UO_2 +89.9 w/o ZrH_2 +0.1 w/o Eu_2O_3	Y	1
33	10 w/o UO_2 +89.7 w/o ZrH_2 +0.3 w/o Eu_2O_3	Y	2
34	10 w/o UO_2 +89.4 w/o ZrH_2 +0.6 w/o Eu_2O_3	Y	3
35	10 w/o UO_2 +86.7 w/o ZrH_2 +0.3 w/o Eu_2O_3 +3 w/o HfH_2	W	2
36	10 w/o UO_2 +83.4 w/o ZrH_2 +0.6 w/o Eu_2O_3 +6 w/o HfH_2	R-W	2

CODE:

W = White

R = Red

Y = Yellow

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FIGURE 1
STOKES AUTOMATIC PRESS - 12-TON CAPACITY

FIGURE 2
INERT ATMOSPHERE GLOVE BOX

FIGURE 3
SMALL HYDRAULIC JACK FOR EJECTION

FIGURE 4
500-TON PRESS FOR PRE-PRESSING

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FIGURE 5
PK BLENDER - 4 QUART CAPACITY

FIGURE 6
METRO-GRAM BALANCE - ACCURATE TO 0.1 GRAM

FIGURE 7
VENTED HOOD FOR SPRAYING

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FIGURE 8

INPROCESS STORAGE CABINET "LYONS"

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PRESSED SCA-5 FUEL PELLETSPROPERTIES OF $UO_2 + ZrH_2$ PRESSED PELLETS

<u>EVERY 50th PELLET</u>	<u>HEIGHT INCHES</u>	<u>WEIGHT GRAMS</u>	<u>PRESSED DENSITIES g/cc</u>	<u>% THEOR.</u>
<u>BATCH #1</u>				
50	.439	4.33	4.51	76.70
100	.440	4.33	4.51	76.70
150	.435	4.25	4.47	76.02
200	.423	4.04	4.34	73.81
250	.423	4.01	4.31	73.30
300	.436	4.26	4.48	76.19
350	.433	4.22	4.44	75.51
400	.438	4.31	4.49	76.36
450	.440	4.33	4.51	76.70
<u>BATCH #2</u>				
50	.440	4.32	4.50	76.53
100	.427	4.10	4.36	74.15
150	.429	4.19	4.46	75.85
200	.431	4.17	4.44	75.51
250	.430	4.17	4.44	75.51
300	.411	3.78	4.20	71.43
350	.437	4.30	4.48	76.19
400	.434	4.22	4.44	75.51
450	.428	4.13	4.39	74.66
<u>BATCH #3</u>				
50	.427	4.10	4.36	74.15
100	.429	4.08	4.34	73.81
150	.432	4.14	4.36	74.15
200	.434	4.28	4.51	76.70
250	.431	4.09	4.35	73.98
300	.436	4.09	4.31	73.30
350	.438	4.27	4.45	75.68
400	.428	4.05	4.31	73.30
450	.415	3.81	4.19	71.26

Pellet composition - 10 w/o UO_2 and 90 w/o ZrH_2

Theoretical density - 5.88 g/cc.

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<u>EVERY 50th</u> <u>PELLET</u>	<u>HEIGHT</u> <u>INCHES</u>	<u>WEIGHT</u> <u>GRAMS</u>	<u>PRESSED DENSITIES</u> <u>g/cc</u>	<u>% THEOR.</u>
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BATCH #4

50	.440	4.43	4.61	78.40
100	.429	4.08	4.34	73.81
150	.420	3.88	4.22	71.77
200	.431	4.14	4.40	74.83
250	.436	4.22	4.44	75.51
300	.433	4.19	4.41	75.00
350	.432	4.17	4.39	74.66
400	.430	4.11	4.37	74.32
450	.423	3.96	4.26	72.45

BATCH #5

50	.424	4.01	4.31	73.30
100	.441	4.39	4.53	77.04
150	.433	4.20	4.52	76.87
200	.420	3.86	4.20	71.43
250	.439	4.34	4.52	76.87
300	.432	4.20	4.42	75.17
350	.440	4.29	4.47	76.02
400	.419	3.82	4.15	70.58
450	.439	4.30	4.48	76.19

BATCH #6

50	.442	4.37	4.55	77.38
100	.432	4.15	4.37	74.31
150	.437	4.28	4.46	75.85
200	.422	3.94	4.28	72.78
250	.436	4.29	4.52	76.87
300	.435	4.28	4.51	76.70
350	.436	4.28	4.51	76.70
400	.431	3.14	3.34	56.80

Pellet composition - 10 w/o UO_2 and 90 w/o ZrH_2

Theoretical density - 5.88 g/cc.

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<u>EVERY 50th</u> <u>PELLET</u>	<u>HEIGHT</u> <u>INCHES</u>	<u>WEIGHT</u> <u>GRAMS</u>	<u>PRESSED DENSITIES</u> <u>g/cc</u>	<u>% THEOR.</u>
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BATCH #7

50	.422	4.00	4.35	73.98
100	.428	4.11	4.37	74.32
150	.431	4.17	4.44	75.51
200	.439	4.36	4.54	77.21
250	.432	4.17	4.39	74.66
300	.433	4.21	4.43	75.34
350	.435	4.24	4.46	75.85
400	.432	4.18	4.40	74.83
450	.432	4.20	4.42	75.17

<u>EVERY 100th</u> <u>PELLET</u>
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BATCH #8

100	.424	4.08	4.39	74.66
200	.418	3.99	4.34	73.81
300	.421	4.00	4.35	73.98
400	.416	3.95	4.34	73.81

<u>EVERY 50th</u> <u>PELLET</u>

BATCH #9

50	.427	4.08	4.34	73.81
100	.440	4.34	4.52	76.87
150	.438	4.30	4.48	76.19
200	.435	4.28	4.51	76.70
250	.436	4.32	4.55	77.38
300	.439	4.32	4.50	76.53
350	.437	4.31	4.49	76.36
400	.439	4.32	4.50	76.53

Pellet composition - 10 w/o UO_2 and 90 w/o ZrH_2

Theoretical density - 5.88 g/cc.

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<u>EVERY 100th</u> <u>PELLET</u>	<u>HEIGHT</u> <u>INCHES</u>	<u>WEIGHT</u> <u>GRAMS</u>	<u>PRESSED DENSITIES</u> <u>g/cc</u>	<u>% THEOR.</u>
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BATCH #10

100	.423	4.06	4.37	74.32
200	.415	3.93	4.32	73.47
300	.428	4.19	4.46	75.85
400	.422	4.08	4.43	75.34

BATCH #11

100	.413	3.86	4.29	72.96
200	.412	3.83	4.26	72.45
300	.417	3.95	4.34	73.81
400	.418	3.99	4.34	73.81

BATCH #12

100	.419	4.08	4.43	75.34
200	.423	4.15	4.46	75.85
300	.417	4.04	4.40	74.83
400	.420	4.09	4.45	75.68

EVERY 50th
PELLETBATCH #13

50	.428	4.18	4.45	75.68
100	.429	4.20	4.47	76.02
150	.432	4.30	4.53	77.04
200	.430	4.27	4.54	77.21
250	.435	4.34	4.57	77.72
300	.422	4.05	4.40	74.83
350	.428	4.18	4.45	75.68
400	.429	4.20	4.47	76.02
450	.418	4.00	4.35	73.98

Pellet composition - 10 w/o UO_2 and 90 w/o ZrH_2

Theoretical density - 5.88 g/cc.

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<u>EVERY 50th</u> <u>PELLET</u>	<u>HEIGHT</u> <u>INCHES</u>	<u>WEIGHT</u> <u>GRAMS</u>	<u>PRESSED DENSITIES</u> <u>g/cc</u>	<u>% THEOR.</u>
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BATCH #14

50	.423	4.04	4.34	73.81
100	.418	3.95	4.29	72.96
150	.422	4.02	4.37	74.32
200	.426	4.10	4.41	75.00
250	.429	4.15	4.41	75.00
300	.438	4.35	4.53	77.04
350	.428	4.18	4.45	75.68
400	.422	4.03	4.38	74.49
450	.419	3.97	4.32	73.47

BATCH #15

50	.424	4.12	4.43	75.34
100	.412	3.85	4.28	72.79
150	.425	4.20	4.52	76.87
200	.420	4.06	4.41	75.00
250	.411	3.85	4.28	72.79
300	.426	4.21	4.53	77.04
350	.425	4.19	4.51	76.70
400	.426	4.21	4.53	77.04
450	.417	4.00	4.40	74.83

BATCH #16

50	.437	4.41	4.59	78.06
100	.432	4.26	4.48	76.19
150	.433	4.28	4.51	76.70
200	.436	4.38	4.61	78.40
250	.423	4.20	4.52	76.87
300	.424	4.12	4.43	75.34
350	.422	4.05	4.40	74.83
400	.424	4.09	4.40	74.83
450	.423	4.05	4.35	74.98

Pellet composition - 10 w/o UO_2 and 90 w/o ZrH_2

Theoretical density - 5.88 g/cc.

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<u>EVERY 50th</u> <u>PELLET</u>	<u>HEIGHT</u> <u>INCHES</u>	<u>WEIGHT</u> <u>GRAMS</u>	<u>PRESSED DENSITIES</u> <u>g/cc</u>	<u>% THEOR.</u>
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BATCH #17

50	.424	4.13	4.44	75.51
100	.423	4.08	4.39	74.66
150	.414	3.88	4.26	72.45
200	.427	4.16	4.42	75.17
250	.429	4.22	4.49	76.36
300	.422	4.05	4.40	74.83
350	.419	4.01	4.36	74.15
400	.426	4.11	4.42	75.17
450	.422	4.05	4.40	74.83

EVERY 100th
PELLETBATCH #18

100	.420	4.04	4.39	74.66
200	.422	4.10	4.46	75.85
300	.425	4.20	4.52	76.87
400	.422	4.11	4.47	76.02

EVERY 50th
PELLETBATCH #19

50	.417	3.93	4.32	73.47
100	.418	3.95	4.29	72.96
150	.420	3.99	4.34	73.81
200	.424	4.05	4.35	73.98
250	.423	4.00	4.30	73.13
300	.418	3.96	4.30	73.13
350	.419	3.97	4.32	73.47
400	.425	4.09	4.40	74.83
450	.419	3.97	4.32	73.47

Pellet composition - 10 w/o UO_2 and 90 w/o ZrH_2

Theoretical density - 5.88 g/cc.

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<u>EVERY 50th</u> <u>PELLET</u>	<u>HEIGHT</u> <u>INCHES</u>	<u>WEIGHT</u> <u>GRAMS</u>	<u>PRESSED DENSITIES</u> <u>g/cc</u>	<u>% THEOR.</u>
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BATCH #20

50	.417	3.96	4.35	73.98
100	.413	3.86	4.29	72.96
150	.418	3.98	4.33	73.64
200	.418	4.00	4.35	73.98
250	.417	3.96	4.35	73.98
300	.413	3.88	4.31	73.30
350	.417	3.98	4.37	74.32
400	.418	3.99	4.34	73.81
450	.419	4.00	4.34	73.81

BATCH #21

50	.420	3.98	4.33	73.64
100	.430	4.15	4.41	75.00
150	.438	4.28	4.46	75.85
200	.431	4.22	4.49	76.36
250	.430	4.23	4.50	76.53
300	.429	4.21	4.48	76.19
350	.421	4.03	4.38	74.90
400	.418	3.96	4.30	73.13
450	.418	3.96	4.30	73.13

BATCH #22

50	.414	3.90	4.29	72.96
100	.420	4.02	4.37	74.32
150	.409	3.79	4.21	71.60
200	.414	3.86	4.24	72.11
250	.413	3.84	4.27	72.62
300	.412	3.82	4.24	72.11
350	.425	4.05	4.35	73.98
400	.429	4.13	4.39	74.66
450	.433	4.24	4.46	75.85

Pellet composition - 10 w/o UO_2 and 90 w/o ZrH_2

Theoretical density - 5.88 g/cc.

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<u>EVERY 50th PELLET</u>	<u>HEIGHT INCHES</u>	<u>WEIGHT GRAMS</u>	<u>PRESSED DENSITIES g/cc</u>	<u>% THEOR.</u>
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BATCH #23

50	.425	3.95	4.25	
100	.422	3.92	4.26	
150	.421	3.97	4.32	
200	.434	4.20	4.42	
250	.430	4.01	4.27	
300	.430	3.99	4.24	
350	.432	4.04	4.25	
400	.420	3.85	4.18	
450	.433	4.10	4.32	

BATCH #24

50	.429	4.06	4.32	73.47
100	.433	4.23	4.45	75.68
150	.432	4.13	4.35	73.98
200	.435	4.16	4.38	74.49
250	.426	3.99	4.29	72.96
300	.431	4.13	4.39	74.66
350	.430	4.06	4.32	73.47
400	.428	4.03	4.29	72.96
450	.429	4.06	4.32	73.47

BATCH #25

50	.435	4.15	4.37	74.32
100	.434	4.12	4.34	73.81
150	.433	4.13	4.35	73.98
200	.434	4.14	4.36	74.15
250	.424	3.96	4.26	72.45
300	.427	4.00	4.26	72.45
350	.433	4.14	4.36	74.15
400	.427	4.03	4.29	72.96
450	.424	3.98	4.28	72.79

Pellet composition - 10 w/o UO_2 and 90 w/o ZrH_2

Theoretical density - 5.88 g/cc.

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<u>EVERY 50th</u> <u>PELLET</u>	<u>HEIGHT</u> <u>INCHES</u>	<u>WEIGHT</u> <u>GRAMS</u>	<u>PRESSED DENSITIES</u> <u>g/cc</u>	<u>% THEOR.</u>
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BATCH #26

50	.435	4.30	4.53	77.04
100	.430	4.12	4.38	74.49
150	.417	3.95	4.34	73.81
200	.435	4.24	4.46	75.85
250	.419	3.99	4.34	73.80
300	.431	4.20	4.47	76.02
350	.423	4.04	4.34	73.80
400	.427	4.08	4.34	73.80
450	.432	4.21	4.43	75.34

BATCH #27

50	.419	3.94	4.28	72.79
100	.427	4.10	4.36	74.15
150	.425	4.08	4.39	74.66
200	.429	4.14	4.40	74.83
250	.425	4.07	4.38	74.49
300	.425	4.04	4.34	73.81
350	.419	3.94	4.28	72.79
400	.419	3.92	4.26	72.45
450	.430	4.12	4.38	74.49

Pellet composition - 10 w/o UO_2 and 90 w/o ZrH_2

Theoretical density - 5.88 g/cc.

BATCH #28

250	.403	3.85	4.38	73.99
300	.428	4.15	4.41	74.49
350	.429	4.30	4.57	77.20
400	.436	4.45	4.68	79.05
450	.413	3.99	4.38	73.99

Pellet composition - 10 w/o UO_2 - 89 w/o ZrH_2 - 1 w/o HfH_2

Theoretical density - 5.92 g/cc

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<u>EVERY 50th</u> <u>PELLET</u>	<u>HEIGHT</u> <u>INCHES</u>	<u>WEIGHT</u> <u>GRAMS</u>	<u>PRESSED DENSITIES</u> <u>g/cc</u>	<u>% THEOR.</u>
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BATCH #29

50	.410	4.01	4.46	74.96
100	.421	4.18	4.54	76.30
150	.421	4.09	4.46	74.46
200	.415	4.08	4.48	75.29
250	.415	4.08	4.48	75.29
300	.415	4.09	4.49	75.46
350	.415	4.06	4.46	74.46
400	.416	4.12	4.53	76.13
450	.412	4.07	4.52	75.97

Pellet composition - 10 w/o UO_2 - 88 w/o ZrH_2 - 2 w/o HfH_2

Theoretical density - 5.95 g/cc

BATCH #30

50	.420	4.20	4.57	76.42
100	.419	4.19	4.55	76.09
150	.417	4.13	4.54	75.92
200	.414	4.13	4.54	75.92
250	.417	4.17	4.58	76.59
300	.418	4.21	4.58	76.59
350	.423	4.26	4.58	76.59
400	.418	4.17	4.53	75.75
450	.401	3.80	4.32	72.24

Pellet composition - 10 w/o UO_2 - 87 w/o ZrH_2 - 3 w/o HfH_2

Theoretical density - 5.98 g/cc

BATCH #31

50	.411	4.12	4.58	75.33
100	.413	4.16	4.62	75.99
150	.410	4.10	4.56	75.00
200	.409	4.08	4.53	74.51
250	.408	4.05	4.55	74.84
300	.415	4.18	4.59	75.49
350	.405	4.00	4.49	73.85
400	.412	4.12	4.58	75.33
450	.414	4.19	4.60	75.66

Pellet composition - 10 w/o UO_2 - 84 w/o ZrH_2 - 6 w/o HfH_2

Theoretical density - 6.08 g/cc

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<u>EVERY 50th PELLET</u>	<u>HEIGHT INCHES</u>	<u>WEIGHT GRAMS</u>	<u>PRESSED DENSITIES g/cc</u>	<u>% THEOR.</u>
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BATCH #32

50	.408	3.99	4.48	76.06
100	.413	4.10	4.56	77.42
150	.413	4.15	4.61	78.27
200	.415	4.17	4.58	77.76
250	.413	4.10	4.56	77.42
300	.417	4.16	4.57	77.59
350	.416	4.16	4.57	77.59
400	.416	4.16	4.57	77.59
450	.413	4.09	4.54	77.08

Pellet composition - 10 w/o UO_2 - 89.9 w/o ZrH_2 - 0.1 w/o Eu_2O_3

Theoretical density - 5.89 g/cc

BATCH #33

50	.417	4.13	4.53	77.30
100	.414	4.07	4.47	76.28
150	.413	4.05	4.50	76.79
200	.413	4.06	4.51	76.96
250	.418	4.14	4.50	76.79
300	.416	4.13	4.54	77.47
350	.415	4.08	4.48	76.45
400	.417	4.12	4.53	77.30
450	.416	4.12	4.53	77.30

Pellet composition - 10 w/o UO_2 - 89.7 w/o ZrH_2 - 0.3 w/o Eu_2O_3

Theoretical density - 5.86 g/cc

BATCH #34

50	.418	4.21	4.58	77.63
100	.420	4.23	4.60	77.97
150	.416	4.19	4.60	77.97
200	.415	4.18	4.59	77.80
250	.420	4.29	4.66	78.98
300	.415	4.21	4.63	78.47
350	.412	4.16	4.62	78.31
400	.422	4.35	4.73	80.17
450	.409	4.12	4.58	77.63

Pellet composition - 10 w/o UO_2 - 89.4 w/o ZrH_2 - 0.6 w/o Eu_2O_3

Theoretical density - 5.90 g/cc

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<u>EVERY 50th</u> <u>PELLET</u>	<u>HEIGHT</u> <u>INCHES</u>	<u>WEIGHT</u> <u>GRAMS</u>	<u>PRESSED DENSITIES</u> <u>g/cc</u>	<u>% THEOR.</u>
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BATCH #35

50	.422	4.37	4.75	78.13
100	.411	4.15	4.61	75.82
150	.420	4.32	4.70	77.30
200	.418	4.29	4.66	76.64
250	.420	4.32	4.70	77.30
300	.423	4.41	4.74	77.96
350	.413	4.22	4.69	77.14
400	.418	4.30	4.67	76.81
450	.413	4.20	4.67	76.81

Pellet composition - 10 w/o UO_2 - 86.7 ZrH_2 - 0.3 w/o Eu_2O_3 -
3 w/o HfH_2

Theoretical density - 6.08 g/cc

BATCH #36

50	.419	4.29	4.66	74.32
100	.413	4.22	4.69	74.80
150	.410	4.14	4.60	73.37
200	.410	4.08	4.53	72.25
250	.408	4.08	4.58	73.05
300	.409	4.15	4.61	73.52
350	.406	4.03	4.53	72.25
400	.414	4.14	4.55	72.57
450	.406	3.95	4.44	70.81

Pellet composition - 10 w/o UO_2 - 83.4 w/o ZrH_2 - 0.6 w/o Eu_2O_3 -
6 w/o HfH_2

Theoretical density - 6.27 g/cc

BATCH #37

50	.409	3.94	4.38	73.99
100	.412	3.97	4.41	74.49
150	.414	4.03	4.43	74.83
200	.414	4.05	4.45	75.17
250	.413	4.04	4.49	75.84
300	.413	4.07	4.52	76.35
350	.412	4.01	4.46	75.34
400	.410	3.97	4.41	74.49
450	.406	3.90	4.38	73.99

Pellet composition - 10 w/o UO_2 - 89 w/o ZrH_2 - 1 w/o HfH_2

Theoretical density - 5.92 g/cc

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NO. NAA-SR-TDR 9411DATE 1/13/64PAGE 36 OF 39APPENDIXPROPERTIES OF $\text{UO}_2 + \text{ZrH}_2$ PRESSED PELLETS

<u>EVERY 50th PELLET</u>	<u>HEIGHT INCHES</u>	<u>WEIGHT GRAMS</u>	<u>PRESSED DENSITIES g/cc</u>	<u>% THEOR.</u>
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BATCH #38

50	.404	3.84	4.36	73.65
100	.404	3.86	4.39	74.16
150	.402	3.80	4.32	72.97
200	.404	3.84	4.36	73.65
250	.402	3.80	4.32	72.79
300	.412	3.00	3.33	73.14
350	.409	3.94	4.37	73.82
400	.408	3.93	4.42	74.66
450	.408	3.93	4.42	74.66

Pellet composition - 10 w/o UO_2 - 89 w/o ZrH_2 - 1 w/o HfH_2

Theoretical density - 5.92 g/cc

BATCH #39

50	.418	4.12	4.48	75.68
100	.410	3.99	4.43	74.83
150	.419	4.16	4.52	76.35
200	.418	4.12	4.48	75.68
250	.416	4.07	4.47	75.51
300	.416	4.08	4.48	75.68
350	.418	4.13	4.49	75.84
400	.411	4.00	4.44	75.00
450	.408	3.90	4.38	73.99

Pellet composition - 10 w/o UO_2 - 89 w/o ZrH_2 - 1 w/o HfH_2

Theoretical density - 5.92 g/cc

BATCH #41

50	.412	4.01	4.46	75.34
100	.408	3.95	4.44	75.00
150	.404	3.89	4.42	74.66
200	.409	4.00	4.44	75.00
250	.411	3.98	4.42	74.66
300	.408	3.94	4.43	74.83
350	.410	3.98	4.42	74.66
400	.417	4.08	4.48	75.68
450	.401	3.80	4.32	72.97

Pellet composition - 10 w/o UO_2 - 89 w/o ZrH_2 - 1 w/o HfH_2

Theoretical density - 5.92 g/cc

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NO. NAA-SR-TDR 9411DATE 1/13/64PAGE 37 OF 39APPENDIXPROPERTIES OF $\text{UO}_2 + \text{ZrH}_2$ PRESSED PELLETS

<u>EVERY 50th</u> <u>PELLET</u>	<u>HEIGHT</u> <u>INCHES</u>	<u>WEIGHT</u> <u>GRAMS</u>	<u>PRESSED DENSITIES</u> <u>g/cc</u>	<u>% THEOR.</u>
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BATCH #42

50	.416	4.09	4.49	75.84
100	.416	4.10	4.51	76.18
150	.421	4.19	4.55	76.87
200	.413	4.02	4.47	75.51
250	.416	4.03	4.43	74.83
300	.416	4.08	4.48	75.68
350	.414	4.06	4.46	75.34
400	.422	4.22	4.59	77.53
450	.414	4.05	4.45	75.17

Pellet composition - 10 w/o UO_2 - 89 w/o ZrH_2 - 1 w/o HfH_2

Theoretical density - 5.92 g/cc

BATCH #43

50	.415	4.05	4.45	75.17
100	.413	4.06	4.51	76.18
150	.415	4.09	4.49	75.84
200	.405	3.91	4.39	74.16
250	.415	4.10	4.51	76.18
300	.417	4.13	4.54	76.69
350	.416	4.10	4.51	76.18
400	.414	4.09	4.49	75.84
450	.413	4.04	4.49	75.84

Pellet composition - 10 w/o UO_2 - 89 w/o ZrH_2 - 1 w/o HfH_2

Theoretical density - 5.92 g/cc

BATCH #44

50	.405	3.87	4.35	73.48
100	.402	3.81	4.33	73.14
150	.412	3.99	4.43	74.83
200	.415	4.03	4.43	74.83
250	.405	3.85	4.33	73.14
300	.413	4.02	4.47	75.51
350	.402	3.81	4.33	73.14
400	.406	3.89	4.37	73.82
450	.407	3.90	4.38	73.99

Pellet composition - 10 w/o UO_2 - 89 w/o ZrH_2 - 1 w/o HfH_2

Theoretical density - 5.92 g/cc

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<u>EVERY 50th PELLET</u>	<u>HEIGHT INCHES</u>	<u>WEIGHT GRAMS</u>	<u>PRESSED DENSITIES g/cc</u>	<u>% THEOR.</u>
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BATCH #45

50	.419	4.11	4.47	75.51
100	.408	3.88	4.36	73.65
150	.412	3.98	4.42	74.66
200	.412	3.98	4.42	74.66
250	.420	4.11	4.47	75.51
300	.412	3.97	4.41	74.49
350	.411	3.90	4.33	73.14
400	.412	3.96	4.40	74.32
450	.418	4.06	4.42	74.66

Pellet composition - 10 w/o UO_2 - 89 w/o ZrH_2 - 1 w/o HfH_2

Theoretical density - 5.92 g/cc

BATCH #46

50	.405	3.84	4.31	72.80
100	.413	4.00	4.44	75.00
150	.410	3.92	4.36	73.65
200	.410	3.92	4.36	73.65
250	.405	3.83	4.30	72.64
300	.411	3.97	4.41	74.49
350	.406	3.86	4.34	73.31
400	.408	3.89	4.37	73.82
450	.405	3.83	4.30	72.64

Pellet composition - 10 w/o UO_2 - 89 w/o ZrH_2 - 1 w/o HfH_2

Theoretical density - 5.92 g/cc

BATCH #47

50	.409	3.91	4.34	73.81
100	.413	4.03	4.37	74.32
150	.410	3.94	4.38	74.49
200	.412	3.99	4.43	75.34
250	.412	4.00	4.44	75.51
300	.410	3.95	4.39	74.66
350	.412	4.01	4.46	75.85
400	.413	4.00	4.44	75.51
450	.403	3.82	4.34	73.81

Pellet composition - 10 w/o UO_2 - 90 w/o ZrH_2

Theoretical density - 5.88 g/cc

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APPENDIX

PROPERTIES OF UO_2 + ZrH_2 PRESSED PELLETS

EVERY 50# <u>PELLET</u>	HEIGHT <u>INCHES</u>	WEIGHT <u>GRAMS</u>	PRESSED DENSITIES	
			<u>g/cc</u>	<u>% THEOR.</u>
<u>BATCH #48</u>				
50	.413	4.04	4.49	76.36
100	.406	3.88	4.37	74.32
150	.413	4.02	4.47	76.02
200	.411	3.99	4.43	75.34
250	.407	3.95	4.44	75.51
300	.408	3.92	4.40	74.83
350	.414	4.06	4.46	75.85
400	.410	3.98	4.42	75.17
450	.414	4.04	4.44	75.51

Pellet composition - 10 w/o UO_2 - 90 w/o ZrH_2

Theoretical density - 5.88 g/cc