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PERFORMANCE OF UNENCAPSULATED (U, Pu)O₂ FUEL PINS (SERIES F3A) IRRADIATED IN EBR-II TO 50,000 MWd/Te

W. H. McCARTHY
J. W. BENNETT
G. R. HULL
K. J. PERRY

U. S. ATOMIC ENERGY COMMISSION
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W. H. McCarthy, J. W. Bennett, G. R. Hull,
and K. J. Perry

Approved:

J. H. Field
Principal Project Engineer

Approved:

K. M. Horst, Manager
Development Engineering

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BREEDER REACTOR DEPARTMENT • GENERAL ELECTRIC COMPANY
SUNNYVALE, CALIFORNIA 94086

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ABSTRACT

Sixteen unencapsulated mixed-oxide fuel pins were irradiated in EBR-II to approximately 5 atomic percent burnup at 16 kW/ft nominal peak linear power. The fuel fabrication parameters were varied within the ranges proposed for commercial liquid metal fast breeder reactors (LMFBR) except that pin diameter was approximately 15% larger than usually specified. No cladding failures occurred. Pin swelling was substantially greater in Type-304L stainless steel clad fuel pins than in Type-316 clad elements. Fission gas release to the internal void volume ranged from 73 to 97%. Experimental burnup values were 10 to 12% less than calculated values and varied across the subassembly in a manner that suggested some fission rate elevation from an adjacent extra-worth driver subassembly. Substantial attack was found in the cladding at its inside surface and the extent of this attack (up to 0.009 inch intergranular penetration at about 1158°F) correlated with temperature but not with any fuel fabrication parameter. The penetrating fission product material contained Cs, Mo, and Te. The unusually large amount of fuel/fission product/cladding reaction may be related to the high carbon content in the mixed oxides and/or to a short high temperature operating period.

1. INTRODUCTION

The demonstration of successful fuel performance to burnups of 50,000 to 100,000 MWd/Te over a broad range of power levels is necessary to prove that fast spectrum nuclear reactors will be economically attractive.¹ Toward this end, an in-pile test program was initiated involving the irradiation of encapsulated and unencapsulated fuel pins in the Experimental Breeder Reactor (EBR-II). Examination of some 25 encapsulated fuel pins, irradiated to exposures of 50,000, 70,000, and 118,000 MWd/Te, has now been completed.^{2,3,4} Much useful information has been obtained from these examinations; but because these fuel pins were not exposed to flowing sodium, applicability of the results is presently limited. In May 1970, achievement of burnup levels of 50,000 MWd/Te was accomplished on 16 unencapsulated fuel pins.* These pins were the first unencapsulated mixed-oxide fuel pins clad in Types-304L and -316 stainless steel tubing to be irradiated in flowing sodium under nearly prototypic LMFBR conditions. Presented in this report are the data and analyses obtained from irradiation of these 16 pins which constitute the F3A experiment.

Design parameters, including fuel density, fuel form, diametral gap, and cladding material were investigated. The combined effects of fast neutron flux and exposure to flowing sodium in combination with the above parameters were analyzed in an attempt to evaluate such performance characteristics as cladding integrity and distortion, fission gas release, fuel distribution and gross structure, fuel-cladding mechanical interaction, sodium-cladding compatibility, and fuel-cladding compatibility.

2. SUMMARY

2.1 IRRADIATION PARAMETERS

These are the first unencapsulated mixed-oxide fuel pins in the U.S. program that were successfully irradiated in a fast reactor to a significant burnup. These pins were irradiated in EBR-II Subassembly X040 at start-of-life peak linear powers ranging from 14.9 to 17.0 kW/ft. Total exposure in EBR-II was 12,884 MWd. An interim examination was performed on the fuel pins after an average burnup of 3.0 at.%. Following reinsertion as Subassembly X040A, irradiation was continued until the fuel pin nearest the reactor core center reached a calculated average burnup of 5.17 at.%, (46,600 MWd/Te). Maximum peak burnup was 5.77 at.% (52,000 MWd/Te). The peak fluence on the cladding was calculated to be approximately 3.65×10^{22} per cm² of neutrons with energies greater than 0.1 MeV. Total peak neutron fluence was 4.30×10^{22} cm⁻². The maximum calculated cladding temperature was 610°C (1130°F).**

* An additional 19 pins were irradiated by ANL⁵ in the same subassembly as the F3A pins.

**All power, burnup, and temperature values given in this report are based on EBR-II Experimenter's Guide⁶ physics calculations, at start of life where applicable, unless otherwise stated.

The range of the as-fabricated fuel pin parameters is as follows:

Fuel Composition: Mixed oxide -75 wt % UO_2 25 wt % PuO_2 (0.04 to 0.11% carbon)

Stoichiometry: O/M 1.98 and 2.00

Fuel Type: Solid and annular pellets

Fuel Pellet Density: 84.3 to 94.9% of theoretical

Fuel-Cladding Diametral Gap: 0.0036 to 0.0083 inch

Cladding Material: Types-316 and -304L stainless steel

Cladding Wall Thickness: 0.020 inch

Cladding Outside Diameter: 0.290 inch

Fuel pin performance was evaluated by an interim examination and by an extensive post-irradiation examination. No cladding failures occurred.

2.2 RESULTS

2.2.1 Swelling

Total fuel pin swelling was substantially greater in Type-304L clad pins than in Type-316 stainless steel clad elements. Diametral changes ranged from 0.37 to 0.49% in Type-316 clad pins and from 0.94 to 1.46% in Type 304L clad pins. Length increases were 0.10 to 0.27% with Type 316 and 0.67 to 0.78% with Type 304L. In addition, mechanical interactions (due to swelling) among adjacent pins, their wrapped spacer wires, and the hexagonal envelope tube caused the pins to take an oval cross-sectional shape. ** The degree of ovality was about 0.002 inch (maximum minus minimum diameter) at the peak flux region in Type-304L clad pins; substantially less than this amount was observed with Type 316. The ovality progressed helically along the pins with the same pitch as the wire wrap, as would be expected from the geometrical arrangement.

2.2.2 Fission Gas

Analysis of gas samples from six of the fuel pins showed that 73 to 97% of the fission gas produced during irradiation was released from the fuel, based on calculated burnup. Total gas pressure in the pins at 100°F ranged from 103 to 136 psi, postirradiation. The helium filling gas used in these pins appears to have contained as much as 12% argon or 1.3% nitrogen. Air permeability measurements on irradiated fuel pins indicated that the blanket section of the fuel element exhibits a significant resistance to gas flow from the plenum to a puncture in the fuel section. For example, flow rates of only 12 $\text{cm}^3/\text{minute}$ (S.T.P.) were observed for punctures near the top and near the bottom of the fuel section, with plenum pressure maintained at one atmosphere, and the puncture site evacuated to six microns.

2.2.3 Burnup

Burnup analyses on the irradiated F3A fuels showed substantially less fission in these pins than was calculated using EBR-II fission rate data.⁶ The peak measured burnup (F3B-3) was 5.16 atomic percent. This compares to 5.69% calculated for the same sample location. The computed values were always greater than the experimental values.

Calculated values ranged from 9.5 to 12.4% greater than the corresponding Nd fission product burnup results, except for one result with substantially greater discrepancy which was located at the upper end of pin F3B-3. (The low experimental value at the upper end of that pin can be accounted for on the basis of geometrical considerations during irradiation.) The burnup discrepancy varied with position in the subassembly in a consistent manner.

2.2.4 Metallographic Examination

Substantial chemical attack was observed at the inside surfaces of the claddings at the highest temperatures. Intergranular attack commenced at 527°C (980°F) and penetrated as far as 0.009 inch at the 610°C (1130°F) maximum cladding inside temperature.* The extent of this reaction did not correlate with any of the physical or chemical parameters of the fuel pins—i.e., no differences were observed in the chemical interaction with stoichiometry of 1.98 or 2.00 O/M, smear density of 82 or 88%, solid or annular pellets, or Type-316 or -304L stainless steel cladding. The extent of attack, however, did correlate with the cladding temperature regardless of the fuel pin parameters, and the neutron flux levels. Some general cladding attack (up to 0.003 inch) occurred at temperatures in the range of 525 to 600°C (977 to 1112°F). Where general reaction was found, very little intergranular attack was observed. Cladding

* An evaluation of all uncertainties associated with this value indicates that the maximum cladding temperature was between 1150 and 1200°F.

** Since irradiation induced metal swelling had not been observed when this subassembly was designed, additional clearances were not provided to accommodate the resultant increases in cladding and hexagonal wrapper dimensions.

attack was less in the cladding opposite fuel pellet-to-pellet interfaces. The high carbon content of the fuel (up to 0.1%) may be an important factor contributing to the unusually large amount of fuel/fission product/cladding reaction observed in this experiment.*

The cladding was sensitized (i.e., grain boundaries contained precipitated carbides) at all operating temperatures above about 427°C (800°F). Regions near grain boundaries were depleted in small spheroidal carbide precipitates. The carbide precipitation effects were more pronounced in Type 316 than in Type-304L cladding which is as expected with the higher carbon content in Type 316. No abnormalities were observed in the structure of the ceramic fuel

The observed diameters of equiaxed and columnar grain growth were, however, significantly larger than predicted. These results are consistent with the concept that the fuel was hotter than predicted. The predicted values would fall closer to the measured data if smaller values had been assumed for gap conductance, equiaxed grain growth temperature and/or columnar grain growth temperature. The values selected were 1500 Btu/ft²/h/°F, 1650°C and 2150°C, respectively.

2.2.5 Electron Microprobe Analysis

The chemical composition at selected regions of the fuel pins was assessed by electron microprobe analysis. Oxygen, cesium, tellurium, and molybdenum were found in the grain boundary regions of the cladding where attack occurred. The depth of penetration of the oxygen and molybdenum from the inside of the tubing was usually greater than that of the other elements mentioned, but cesium sometimes penetrated just as far. Cladding boundary regions were depleted in iron and usually depleted in chromium. Nickel distribution was fairly uniform.

2.2.6 Evaluation of Results

Various test results, aside from the unusually large amount of cladding attack, suggest that the F3A elements may have undergone a substantial overheating, for at least a short time. These include fission gas release, large equiaxed and columnar grain growth diameters, smaller absolute values of burnup discrepancy, greater burnup closer to location 4B1 (after corrections for distance from core centerline), and Kr-85 evolution from clad sections. On this basis, a diligent search was made for any external parameters which might have caused substantial overheating. The results of these studies indicate that maximum cladding temperatures experienced in this test were between 1150 to 1200°F. These values are between 30 to 80°F higher than those calculated using the EBR-II guide procedures.

3. EXPERIMENT DESIGN

3.1 FUEL PIN DESIGN

All the fuel pins were 60-5/8 inches long with the coprecipitated 25 wt % PuO₂—75 wt % UO₂ (mixed oxide) fuel contained in tubing with a nominal inside diameter of 0.250 inch and a nominal wall thickness of 0.020 inch. The 13.5-inch fuel column length corresponds with that of the EBR-II core. The upper and lower blanket sections and fission gas plenum were integral within the cladding. The pertinent fuel design parameters are summarized in Table 1 and Appendix A, and the fuel pin design is shown in Figure 1. Chemical and mechanical characteristics of the cladding are given in Tables B-1 and B-2 of Appendix B. The stainless steels conformed to the applicable materials specifications. Typical photomicrographs are shown in Figures B-7 through B-9.

To achieve the desired power in the EBR-II core, all pins contained oxide fuel that was fully enriched U and Pu—92.5% U-235/U and 91% Pu-239/Pu. As a consequence of the experimental requirements to use enriched uranium, the fast neutron exposure (>0.1 MeV) for the cladding is approximately one-third of that expected for fuel pins operating in a commercial breeder reactor at comparable burnups. In this regard, the tests do not simulate the level of irradiation damage to the cladding expected at high fuel burnups. However, the harder neutron spectrum of EBR-II offsets part of the factor of three in flux levels. Also, the tests are not a perfect chemical simulation of a commercial LMFBR since the amount of oxygen liberated during fission of U-235 is less than that liberated with Pu-239.

The ceramic grade mixed-oxide powder was prepared by the coprecipitation of plutonium hydroxide and ammonium diuranate from a solution of uranium and plutonium nitrate in nitric acid. The precipitated fuel was filtered, dried, and subsequently reduced at 750°C in an atmosphere of 6% hydrogen—94% helium to obtain a solid solution of (Pu_{0.25}U_{0.75})O₂.

The reduced powder was ball-milled, screened, prepressed at 50,000 to 100,000 psi for densification, and then granulated. Only material less than 200 mesh was used for pellet fabrication. Pellets were pressed in a double-action die at pressures from 20,000 to 40,000 psi, and then sintered in a 6% hydrogen—94% helium atmosphere for three hours at

*Current fuel specifications allow only 150 ppm carbon. At the time this fuel was prepared, the importance of low carbon content was not generally appreciated.

1500°C. Chemical analyses of the pellets are given in Appendix A, Tables A-24 through A-26. The only significant impurity determined by spectrochemical analysis was 150 ppm iron.

The oxygen-to-metal ratio (O/M) was adjusted during sintering by controlling the water vapor content of the helium, 6% hydrogen atmosphere. If this gas was saturated with water, stoichiometric fuel was produced (O/M = 2.000). Thoroughly dry sintering gas would produce ~1.96 O/M. The intermediate substoichiometric fuels that were used in the F3A series had O/M of 1.98; this was obtained by using an appropriate ratio of dry and saturated gas in the furnace stream. To assure adequate control, one pellet from each boat was analyzed for O/M by a standard thermogravimetric method.

Fabrication of the fuel pins consisted of loading five bottom UO₂ blanket pellets, the mixed-oxide fuel pellets and five upper UO₂ blanket pellets into the cladding, followed by the spring, spacer, and plenum tube. The pin was then evacuated and backfilled with helium, and the upper end plug was welded and inspected. Diameter measurements were made and recorded for each pellet making up the fuel column prior to loading so that the individual pellet-to-cladding gaps would be known. Fabrication parameters for each pin are given in Appendix A, Tables A-1 through A-8. Pellet-by-pellet dimension, density, O/M, and batch number are given in Tables A-9 through A-24. Pellet diameters and gaps are shown graphically in Appendix C, Figures C-1 through C-16.

The results of absorbed gas analysis for batch B237 are given in Appendix A, Table A-25. The total gas content (134 µl/gm) was fairly close to the acceptable limit of 150 µl/gm. Insignificant amounts of halogen were found but the carbon content of 420 and 1120 ppm for the two batches of fuel was substantially above the expected values, see Table A-26. Mixed-oxide fuel prepared at General Electric has usually contained only 20 to 200 ppm carbon. The current carbon specification is 150 ppm maximum and revision to an even lower limit is being considered.

Table 1
GROUP F3A AS-FABRICATED FUEL PIN PARAMETERS

Fuel Pin	Fuel Type	Average O/M Ratio	Average Fuel Density (% T.D.)	Smeared Density (%)	Fuel Column Length (in.)	Fuel-Cladding Diametral Gap Range (mils)	Type of Cladding
F3B-1	Annular Pellet	1.98	94.92	88.35	13.523	4.0–5.7	316
F3B-2	Solid Pellet	1.98	90.70	87.56	13.559	3.9–5.0	316
F3B-3	Annular Pellet	2.00	93.49	87.54	13.494	3.7–4.6	316
F3B-4	Solid Pellet	2.00	91.39	87.93	13.523	3.8–6.4	316
F3B-5	Solid Pellet	1.98	86.03	82.87	13.497	4.0–5.5	316
F3B-6	Solid Pellet	2.00	84.31	81.13	13.522	3.8–6.2	316
F3B-7	Annular Pellet	1.98	94.45	86.48	13.526	4.8–8.3	304L
F3B-8	Solid Pellet	1.98	90.21	86.08	13.522	4.4–6.5	304L
F3B-9	Annular Pellet	2.00	92.84	85.64	13.491	4.6–7.9	304L
F3B-10	Solid Pellet	2.00	90.21	86.19	13.526	4.3–7.9	304L
F3B-11	Solid Pellet	1.98	85.75	81.45	13.519	5.3–7.9	304L
F3B-12	Annular Pellet	1.98	94.43	87.88	13.487	4.0–5.7	316
F3B-13	Solid Pellet	1.98	90.22	87.26	13.510	3.6–4.6	316
F3B-14	Annular Pellet	2.00	93.32	87.26	13.526	3.8–5.1	316
F3B-15	Solid Pellet	2.00	89.42	86.25	13.521	3.9–5.4	316
F3B-16	Solid Pellet	1.98	85.61	82.65	13.469	3.9–5.4	316

Nominal Fuel Composition: 25 wt % Pu – 75% U mixed oxide

Nominal Cladding Inside Diameter: 0.250 inch

Nominal Uranium Enrichment: 92.5% U-235

Annular pellets had 0.044-inch inside diameters

Figure 1. F3A Fuel Pin Design

Final pre-irradiation examination and testing of each mixed-oxide fuel pin included the following:

- a. Helium leak-check of all welds
- b. Detailed visual examination
- c. Weight of the fuel pin
- d. Neutron radiograph of the fuel pin
- e. Dimension measurements, including overall length and diameter measurements (profilometry) at 0-degree and 90-degree orientations and while rotating
- f. X-rays of end plug welds.

3.2 SUBASSEMBLY DESIGN

The test vehicle was an EBR-II Mark B-37 experimental subassembly that accommodates 37 fuel pins, 0.290 inch in diameter by 60-5/8 inches long. The 37 fuel pins were positioned in a close-packed array within the hexagonal subassembly tube. The pins were spaced by 0.0565-inch Type-304 stainless steel wires that were helically wound around each pin and welded at the end plugs. The design details of the Mark B-37 subassembly are included in Reference 7.

The 16 fuel pins were contained in the experimental subassembly designated as X040 for the first 3 at.% of fuel burnup. Following the nondestructive interim examination, the pins were inserted in subassembly X040A for the balance of the irradiation. These subassemblies also contained nineteen ANL mixed-oxide fuel pins and two ANL stainless steel dummy rods.* The interim test results of the ANL fuel pins and dummy rods were reported elsewhere.⁵ The fueled length of the ANL pins was only 11.0 inches, but the F3A elements and the driver fuel rods contained 13.5 inches of fuel. The bottom of the ANL fuel was positioned 0.85 inch above the bottom of the core. Thus, the F3A pins operated at lower than nominal local power in the lower 0.85 and upper 1.65 inches of the fueled length. This effect should be particularly important for the central pin, F3B-3, which was surrounded by four immediately adjacent ANL pins and had only two F3A neighbors (see Figure 2).

4. OPERATIONAL HISTORY

4.1 FUEL PIN POSITIONS

The 16 fuel pins were positioned in subassemblies X040 and X040A as shown in Figure 2. These positions were selected in order to make the peak linear powers of all specimens as equal as possible.

4.2 REACTOR EXPOSURE

Subassembly X040 was loaded into position 5-B-2 in the EBR-II core on August 15, 1968, and the reactor went to full-power operation (50 MW) for run 30A on August 26, 1968. The subassembly was irradiated for runs 30 through 35 at which time it was removed for interim examination on July 14, 1969. This examination is discussed in detail in Subsection 4.3. Following this examination the fuel pins were inserted into subassembly X040A which was then placed into position 5-B-2** on September 30, 1969. Full power operation (50 MW) for run 38B began on October 4, 1969. The test was terminated on May 18, 1970 at the end of run 42. The power distribution for each F3A run in EBR-II is given in Table 2. The integrated reactor exposure was 12,884 MWd, which corresponds to 257.7 days of reactor operation at 50 MW full power. The subassembly received ~64 full-power cycles during this period. Figure 3 presents the Group F3A Power History. During run 39, the reactor power versus time plot indicated brief excursions to 54 to 55 MW on about December 25, 1969 and again on about January 19, 1970.

The peak fluence on the cladding was 3.65×10^{22} nvt of neutrons with energy greater than 0.1 MeV. The subassembly was discharged from the reactor core on May 18, 1970. Based on the midplane fission rate⁵ for position 5-B-2, estimates of the peak linear power for each pin are shown in Table 3. During normal reactor operation the sodium inlet temperature was maintained at 371°C (700°F). Under these conditions, the peak cladding temperatures at the fuel cladding interface ranged from 527°C (981°F) to 610°C (1130°F), as shown in Table 3. Figures A-1 to A-12 in Appendix A show the circumferentially averaged axial temperature profiles over the fueled region of typical pins.

*A third dummy rod was substituted for one of the ANL pins when the pins were reconstituted in subassembly X040A following the interim examination.

**The subassembly was placed in reactor position 5-B-4 during runs 39B and C. This position is symmetrically equivalent to 5-B-2.

DATE LOADED: 8/15/68
 DATE DISCHARGED FOR INTERIM EXAMINATION: 7/14/69
 DATE RELOADED: 10/4/69
 DATE DISCHARGED: 5/18/70
 ACCUMULATED REACTOR EXPOSURE: 12, 884 MWd

0XX PIN DESIGNATIONS WERE FROM
 ANL (11 INCH FUELED LENGTH)

*PIN 012 (LOCATION 22) WAS REPLACED
 WITH STAINLESS STEEL (SST) DUMMY
 WHEN X040A WAS PREPARED.

TO CORE CENTER

EBR-11 CORE LOCATION: 5-B-2
 SUBASSEMBLIES NO. X040
 X040A
 SUBASSEMBLY FLOW RATE: 68 gpm
 SUBASSEMBLY TYPE: MARK 37B

VIEW LOOKING DOWN ON T-BAR GRID

Figure 2. Fuel Pin Positions in EBR-II Subassemblies X040 and X040A

Table 2
REACTOR POWER DISTRIBUTION HISTORY FOR F3A SERIES^(a)

Run Number	THERMAL-MEGAWATT DAYS AT POWER INDICATED IN MWt						Total
	< 10 MWt	10-20 MWt	25-30 MWt	35-40 MWt	45-46 MWt	50 MWt	
30A	0.04	12	30	4	159	447	652
B	0.07	0.36	-	-	-	166	166
C	0.03	-	52	-	-	-	52
D	0.02	-	79	-	-	-	79
31A	0.03	-	89	-	-	-	89
B	0.09	-	159	-	-	-	159
C	0.01	-	84	-	-	-	84
D	0.01	-	80	-	3	289	372
E	-	-	-	-	-	-	0
F	0.01	-	-	-	-	413	413
G	0.02	-	-	-	-	111	111
32A	2.03	21.88	11	14	2	803	854
B	0.03	1.44	4	-	-	225	230
C	0.02	-	-	-	-	84	84
D	0.03	-	-	-	-	231	231
33A	0.74	16.67	55.46	22.50	1.88	502.08	599.33
B	0.59	3.34	8.13	4.17	-	560.42	576.65
34A	0.09	2.49	20.06	2.50	-	796.88	822.02
B	0	4.38	16.12	8.13	-	281.25	310.08
35	0.72	15.72	43.58	21.34	0.94	1118.87	1201.17
38B	0.18	5.73	7.19	5.73	0.94	580.20	599.97
39A	1.17	5.94	26.97	9.69	2.8	723.96	770.54
B	0.08	3.33	5.00	4.17	-	172.92	185.50
C	0.01	3.43	2.40	6.15	0.94	402.09	415.02
40A	0.17	1.24	4.37	1.66	-	435.42	442.86
B	0	1.68	0.63	1.67	-	919.79	923.77
41A	0.08	2.71	6.87	2.50	-	948.96	961.12
B	0.15	1.25	2.97	0.83	-	151.04	156.24
42	0.03	2.70	3.12	4.90	1.88	1331.25	1343.88
Total MWd	6.45	105.8	790.87	114	173	11694	12884
Percent of Total	0.05	0.82	6.14	0.89	1.35	90.76	100.01

(a) Data for Runs 30A-32D from "Operating History Data" Table III of EBR-II Run Reports. Where there was more than one power level any given day, the partition of total power was estimated from the power time curves.
 Data for runs 33A-42 taken from sections of EBR-II Run Reports entitled "Production Summary." In these, the power distribution was calculated by the EBR-II Project.

Figure 3. Calculated Linear Power During F3A Operation

Table 3
GROUP F3A NORMALLY CALCULATED IRRADIATION PARAMETERS

Fuel Pin	Start of Life Peak Linear Power (kw/ft)	Peak Burnup		Start of Life Peak Temperature °C ^(b)	
		at. %	kWd/gm ^(a)	Cladding	Fuel
F3B-1	15.89	5.36	48.4	534 (994)	2338
F3B-2	16.32	5.54	50.0	593 (1099)	2585
F3B-3	17.00	5.77	52.0	610 (1130)	2536
F3B-4	16.26	5.50	49.7	584 (1084)	2580
F3B-5	15.04	5.40	48.8	544 (1011)	2399
F3B-6	14.91	5.46	49.3	541 (1005)	2374
F3B-7	16.47	5.56	50.1	527 (981)	2405
F3B-8	16.55	5.60	50.6	585 (1085)	2598
F3B-9	16.59	5.64	50.9	602 (1116)	2480
F3B-10	16.84	5.70	51.4	589 (1092)	2632
F3B-11	15.62	5.59	50.4	542 (1008)	2449
F3B-12	16.14	5.46	49.2	537 (999)	2380
F3B-13	16.36	5.57	50.2	586 (1087)	2585
F3B-14	16.82	5.72	51.6	537 (998)	2476
F3B-15	16.47	5.67	51.1	607 (1125)	2597
F3B-16	15.04	5.43	49.0	544 (1012)	2396

(a) kWd/gm $\equiv$ GWd/Te $\equiv$ 1000 MWd/Te (MeV/Fission) 193 for U-235, 194 for U-238, 199 for Pu-239)

(b) °F in parentheses: Highest fuel temperature at an even-inch axial distance from bottom of core based on a gap conductance of 1500 btu/hr-ft²-°F

Sodium Inlet Temperature: 371°C (700°F), nominal

Peak Cladding Fluence ($E > 0.1$ MeV): 3.65×10^{22} nvt.

Burnup Calculated from EBR-II Guide (Revised 2/27/70), taking account of fuel depletion.

Mean Peak Burnup = 5.56 at.-%.

Unless otherwise specified, all temperatures, neutron exposures, and power levels given in this report are start-of-life calculated values based on EBR-II physics data⁶ which mainly considers a core fueled preponderantly with driver subassemblies. Throughout the irradiation of the F3A pins, the core contained a substantial fraction of experimental subassemblies including some unfueled ones. These low worth subassemblies may have caused some perturbation in the neutron flux distribution in the F3A subassembly. Experimental burnup measurements performed by General Electric and others show that the power generation of oxide elements in EBR-II is approximately 15% less than the calculated value.* Therefore, the true temperature, neutron exposure, and power levels during most of the irradiation were somewhat less than the calculated values. Use of the normally calculated values has the advantage that the results by different experimenters can be compared on a fairly consistent basis even though their accuracy may be questionable. Fluence and burnup data given in this report have been corrected for fuel depletion.

* The experimental values agree more closely with secondary sodium loop calorimetry than with the primary loop data which are the basis of the calculations.

During nine runs in which the F3A pins were in the reactor, a driver subassembly containing 70% enriched pins was inserted at position 4B1, immediately adjacent to the subassembly containing the F3A pins. This may have caused the F3A fuel elements to operate at higher than normal powers and temperatures during about 29% of the time-at-power. The usual driver fuel is 52% enriched, so that the 70% fuel contains about 35% more than the nominal U-235 content. (The object was to simulate EBR-II operation at 62.5 MW.) Physics calculations and analyses performed by ANL indicate that the maximum increase in power that would result from the high worth driver was 2%. Normal run-to-run power variations in EBR-II are about 6%.

4.3 INTERIM EXAMINATION AT EBR-II

Subassembly X040 was removed for interim examination at the EBR-II site on June 30, 1969 following irradiation to a peak calculated burnup of 36,000 MWd/Te (~ 3 at.%). After being cleaned in moist argon in the EBR-II fuel transfer coffin, the subassembly was disassembled and the following nondestructive tests were made

- a. Detailed visual examination and optical photography
- b. Weighing
- c. Neutron radiography of all fuel pins
- d. Temperature measurements
- e. Diameter measurements at 0-degree and 90-degree orientations at one- to two-inch intervals.

The cladding generally appeared similar to the pre-irradiation condition. Spiral spacer wires had loosened and were separated from the cladding in some areas. All welds appeared to be in excellent condition, and a slight bowing was observed on several of the pins.

Neutron radiographs showed the presence of center voids in all fuel pins. Pellet interfaces were still present in the pins loaded with pellets.

Measurements of diametral change at discrete axial locations at 0-degree and 90-degree orientations indicated that all fuel pins had increased in diameter. The greatest diametral increases occurred on four of the five Type-304L clad fuel pins.

The interim examination did not uncover any potential failures nor anomalous fuel pin behavior. The fuel pins were approved for reinsertion in the EBR-II core for further irradiation toward a target burnup of 50,000 MWd/Te. The fuel pins were loaded in EBR-II subassembly X040A and reinserted in the EBR II core on October 4, 1969.

4.4 DISCHARGE AND DISASSEMBLY

Subassembly X040A was discharged from the EBR II and transferred to the Fuel Cycle Facility (FCF) at the end of run 42. As was done in the interim examination, the subassembly was cleansed of sodium with moist argon followed by water flushing and argon drying. Disassembly was accomplished in the air cell of the FCF by cutting the hexagonal tube of the subassembly.

Visual observations indicated that all fuel pins were in good condition such that the pins appeared to be bright and clean. Most of the fuel pins had regions where the spiral wire stood away from the cladding approximately 5 to 10 mils.

Neutron radiography was performed on the fuel pins at EBR-II. These appeared similar to the neutrographs taken at 3 at.%.

Diameter measurements were performed on pins at EBR-II at discrete axial locations using the same 0-degree and 90-degree orientations as for the examination at 3 at.%. The differences in diameter change between the Type-304L and Type-316 clad fuel pins were dramatically evident again during this examination.

Following this preliminary examination at EBR-II, the fuel pins were loaded into the EBR II source coffins and transferred to Test Area North for subsequent shipment to the Radioactive Materials Laboratory at the Vallecitos Nuclear Center (VNC) for detailed examination. Photographs of the pins appear in Figure 4

5. POST-IRRADIATION EXAMINATION

5.1 NONDESTRUCTIVE EXAMINATION

All sixteen Group F3A fuel pins were nondestructively examined as follows.

5.1.1 Neutron Radiography

Neutron radiography was the initial operation in the post-irradiation examination of these fuel pins at VNC. Exposures were made at 0-degree and 90-degree orientations. Single exposure radiographs were obtained over the full length of the fuel. Prints of the neutrograph negatives were made to specifically delineate fuel characteristics such as the

Table 4
PERTURBED AND TOTAL EXPOSURE OF SERIES F3A PINS

Run Number	MWd	Number of High Worth Pins at 4B1	MWd Perturbed	Accumulated MWd Perturbed	Accumulated MWd Total
30A	652	0	0	0	652
B	166	91	166	166	818
C	52(a)	0	0	166	870
D	79(a)	0	0	166	949
31A	89(a)	91	89	255	1038
B	159(a)	0	0	255	1197
C	84(a)	0	0	255	1281
D	372	0	0	255	1653
E	0	91	0	255	1653
F	413	91	413	668	2066
G	111	91	111	779	2177
32A	852	91	852	1631	3029
B	249	91	249	1880	3278
C	72	0	0	1880	3350
D	224	0	0	1880	3574
33A	600	91	600	2480	4174
B	576	0	0	2480	4750
34A	822	83	750	3230	5572
B	310	0	0	3230	5882
35	1202	0	0	3230	7084
36A-38A	0	(X040 out of reactor)		3230	7084
38B	600	70	462	3692	7684
39A	771	0	0	3692	8455
B	186	0(b)	0(b)	3692	8641
C	415	0(b)	0(b)	3692	9056
40A	443	0	0	3692	9499
B	924	0	0	3692	10423
41A	961	0	0	3692	11384
B	156	0	0	3692	11540
42	1344	0	0	3692	12884

(a) 30 MW maximum

(b) 70 extra worth pins at 4B1 but X040A was at 5B4.

Figure 4. Photographs of Group F3A Fuel Pins Taken Through The Cell Window To Show Bowing

central void shown in Figure 5. All of the neutrographs show the typical center void formation and in all of them some pellet interfaces are still present. Fewer pellet interfaces were visible in the fuel pins which operated at the highest powers than in those which ran at lower powers. Neutrographs for all pins, except those shown in Figure 5, are given in Appendix C, Figures C-25 through C-29.

Full length measurements were made from the neutrograph negatives by comparison with a standard of known length which was neutrographed at the same time as the fuel pins. Pre-irradiation fuel column lengths were obtained by summing the micrometer measurements for every pellet. Fuel column length increases of 0.55% to 1.97% were found. These results are listed in Table 5.

5.1.2 Gamma Activity of Fuel Pins

Precision scans of the axial distribution of the total gamma activity were obtained on all 16 fuel pins. These scans covered all of the insulator and fuel regions and continued well into the plenum region. Because of varying background conditions in cell and instrument settings, it was not possible to obtain a measurement of relative gamma activity between fuel pins from these results, but internal variations of gamma activity for each fuel pin were determined. The gamma activity scans of all the pins can be found in Appendix C, Figures C-17 through C-24. The gamma activity distribution of the fuel sections generally conforms to a chopped cosine curve with its maximum displaced slightly below the centerline of the core. Some fuel produced sharp peaks of gamma activity superimposed on the chopped cosine curve. These peaks show that axial redistribution of the fission products has occurred. In most cases the highest gamma activity, except for the sharp peaks, occurred about six inches above the bottom of the core.

Spectral scans of the gamma activity were obtained on selected local areas of each fuel pin; regions of peak gross gamma activity were emphasized, but off-peak positions were also scanned. Each spectral scan is identified by its position number on the gross gamma scan of the individual fuel pin. The observed gamma-emitting isotopes are reported in Appendix C, Table C-1. These peak heights can be validly used for comparing a certain isotope at various positions on a given pin. They should not, however, be used for quantitative intercomparisons among different isotopes, nor for comparisons among pins. Large concentrations of Nb-95 were observed in the peak regions of the gross gamma scans. Cs-137 was most heavily concentrated in the upper, hotter regions of the fuel pins. The balance of the isotopes roughly followed the chopped cosine axial distribution of gamma activity.

5.1.3 Dimensional Measurements

Continuous diameter profile scans were made along the length of each fuel pin at four orientations 45 degrees apart. The results of these scans on each fuel pin as compared to the pre-irradiation fuel pellet lengths and diameters are included in Appendix C, Figures C-1 through C-16. These profiles indicate maximum diameter increases of about 0.4% in fuel pins clad in Type 316 and about 1.2% in the Type-304L stainless steel clad fuel pins. Peak diameter increases in all of the fuel pins occurred above the peak linear power and burnup region at approximately 8 to 11 inches above the bottom of the fuel column. The upper plenum regions of the fuel pins, which were above the reactor core, generally were uniform except for the slight diametral variations typical of as-fabricated tubing. These sections were used as the baselines to determine relative changes in the diameter of the cladding of each pin. The plenum diameter is also shown for each fuel pin on the profiles. The reproducibility of the profilometer system is 0.0001 inch as established by successive profile measurements on the same pin at the same orientation. Local pin thickness changes were determined by measuring the distance between the reference line and the profilometer trace for each orientation. In general, these thicknesses at any given axial location were not equal and the pins were oval in cross section. This ovality was especially apparent in the profiles of the Type-304L clad fuel pins but it was also observed with Type-316 cladding. Figures C-4 and C-8 illustrate this effect by indicating the locations on each pin where the wire wrap crossed each orientation. Each distinct peak has a valley 90 degrees away from it, and these valleys vary along the length of the pin in accordance with the position of the wire wrap, i.e., valleys occur on a given trace at 3-inch intervals. This effect is displayed by the slanted lines across Figures C-4 and C-8. The maximum diameter increase for all of the orientations was determined for each fuel pin. Additionally, an equivalent diameter was calculated from the average of the 0-degree, 45-degree, 90-degree, and 135-degree values. All of these diameter increases are reported in Table 6 for each fuel pin. No diameter changes due to pellet interface ridging effects were observed.

Overall length measurements were made on each pin and compared with pre-irradiation lengths. Increases in length were observed in all pins and are listed in Table 6. Type-304L clad fuel pins increased approximately three times as much as did the fuel pins clad in Type-316 stainless steel. In all cases, overall length increases were less than 0.8%.

Figure 5. Neutron Radiographs of Group F3A Fuel Pins F3B-1, 2, and 3

Table 5
F3A FUEL PIN DIMENSION CHANGES

Fuel Pin	Cladding Alloy	Interim Examination			Post-Irradiation Examination			ΔD Interim (in.)	ΔD Total (%)
		Maximum Diameter Increase	Length Increase	ΔL (in.)	Maximum Diameter Increase	Length Increase	ΔL (in.)		
		ΔD (in.)	ΔL (in.)	ΔL (%)	ΔD (in.)	ΔL (in.)	ΔL (%)		
F3B-1	316	0.34	1.0	0.34	0.37	1.1	0.37	82	
F3B-2	316	0.34	1.0	0.34	0.34	1.0	0.34	82	
F3B-3	316	0.34	1.0	0.34	0.48	1.3	0.48	78	
F3B-4	316	0.31	0.9	0.31	0.48	1.3	0.48	69	
F3B-5	316	0.17	0.6	0.17	0.48	1.3	0.48	68	
F3B-6	316	0.38	1.1	0.38	0.48	1.3	0.48	78	
F3B-7	304L	0.125	0.52	0.125	13.606	0.7	0.7	47	
F3B-8	304L	0.136	0.59	0.136	13.667	0.9	0.9	58	
F3B-9	304L	0.127	0.58	0.127	13.604	0.9	0.9	80	
F3B-10	304L	0.168	0.68	0.168	13.683	1.2	1.2	48	
F3B-11	304L	0.090	0.31	0.090	13.568	0.7	0.7	33	
F3B-12	316	0.238	0.48	0.238	13.740	1.3	1.3	107	
F3B-13	316	0.179	0.34	0.179	13.687	1.3	1.3	92	
F3B-14	316	0.070	0.28	0.070	13.581	1.2	1.2	100	
F3B-15	316	0.137	0.34	0.137	13.616	1.3	1.3	93	
F3B-16	316	0.266	0.52	0.266	13.777	1.3	1.3	83	
F3B-11	316	0.171	0.34	0.171	13.671	1.3	1.3		
F3B-12	316	0.087	0.31	0.087	13.564	1.2	1.2		
F3B-13	316	0.094	0.31	0.094	13.584	1.2	1.2		
F3B-14	316	0.106	0.34	0.106	13.602	1.2	1.2		
F3B-15	316	0.196	0.38	0.196	13.699	1.3	1.3		
F3B-16	316	0.094	0.34	0.094	13.563	1.2	1.2		

Table 5
SUMMARY OF F3A FUEL LENGTH CHANGES

2.1.1 Fission Gas Collection and Analysis

Six fuel pins were punctured and their gases expanded into an evacuated system of known volume to measure the total volume of fission gas. The analytical results of these gas samples are tabulated in Tables 7 and 8. The He filling gas in pins F3B-1, -2, -4, and -7 apparently contained about ten percent argon. F3B-2 contained some nitrogen. A sample of the gas from F3B-1 was analyzed for tritium; the concentration was less than four parts per billion. Fuel and cladding from F3B-10 at 8.9 inches from the core bottom were also analyzed for tritium. The results were 1.19 and 0.06 ppb, respectively. The former represents a retention of about 0.72% in the fuel.

In an attempt to determine the effect of puncture location on the rate of fission gas release, the initial punctures were made in four different axial locations; i.e., plenum region, upper insulator, ~2.6 inches from top of fuel column, and bottom insulator. Pins F3B-1 and F3B-2 were punctured in the bottom insulator ~0.5 inch below the bottom of the fuel column. Pins F3B-3 and F3B-4 were punctured ~2.8 inches below the top of the fuel column. Pin F3B-5 was punctured in the upper insulator ~1 inch above the top of the fuel column. Pin F3B-7 was punctured in the plenum region.

Punctures were made using a 0.125-inch diameter self-centering drill. Prior to puncturing, the collection system was evacuated to a pressure of ~8 microns of mercury. As the drill bit pierced the cladding of each pin, a rapid rise in pressure was indicated and drilling was immediately stopped. From this point on the pressure in the collection pump was measured periodically until it stabilized.

Table 6
F3A FUEL PIN DIMENSION CHANGES

Fuel Pin	Cladding Alloy	Interim Examination		Post-Irradiation Examination				ΔD Interim ^(b)
		Maximum Diametral Increase		Length Increase		Maximum Diametral Increase		ΔD Total
		ΔD (mils)	ΔD (%)	ΔL (mils)	ΔL (%) ^(a)	ΔD (mils)	ΔD (%)	(%)
F3B-1	316	1.0	0.34	31	0.23	1.1	0.37	92
F3B-2	316	0.8	0.28	27	0.20	1.0	0.34	82
F3B-3	316	1.0	0.34	30	0.22	1.3	0.45	76
F3B-4	316	0.9	0.31	35	0.26	1.3	0.45	69
F3B-5	316	0.5	0.17	27	0.20	1.3	0.45	38
F3B-6	316	1.1	0.38	23	0.17	1.4	0.49	78
F3B-7	304L	1.5	0.52	86	0.67	3.1	1.10	47
F3B-8	304L	1.7	0.59	93	0.69	2.9	1.02	58
F3B-9	304L	1.9	0.66	93	0.69	3.1	1.10	60
F3B-10	304L	1.9	0.66	105	0.78	4.0	1.46	45
F3B-11	304L	0.9	0.31	92	0.68	2.7	0.94	33
F3B-12	316	1.4	0.48	26	0.10	1.3	0.45	107
F3B-13	316	1.0	0.34	32	0.24	1.1	0.37	92
F3B-14	316	1.3	0.45	32	0.24	1.3	0.45	100
F3B-15	316	1.1	0.38	36	0.27	1.2	0.41	93
F3B-16	316	0.7	0.24	32	0.24	1.3	0.45	53

(a) Based on all the length increase occurring over the fuel column length (~ 13.5 inches).

(b) The proportion of total diametral increase which occurred before the interim examination at 3.10 at.% mean peak burnup. This was 56% of total mean peak burnup.

5.2 DESTRUCTIVE EXAMINATION

5.2.1 Fission Gas Collection and Analysis

Six fuel pins were punctured and their gases expanded into an evacuated system of known volume to measure the total volume of free gas in each pin. Aliquots of the gas were taken for gas chromatographic, and mass spectrometric analysis. The analytical results of these gas samples are tabulated in Tables 7 and 8. The He filling gas in pins F3B-1, -2, -4, and -7 apparently contained about ten percent argon. F3B-2 contained some nitrogen. A sample of the gas from F3B-1 was analyzed for tritium; the concentration was less than four parts per billion. Fuel and cladding from F3B-10 at 6.9 inches from the core bottom were also analyzed for tritium. The results were 1.19 and 0.06 ppb, respectively. The former represents a retention of about 0.75% in the fuel.

In an attempt to determine the effect of puncture location on the rate of fission gas release, the initial punctures were made in four different axial locations; i.e., plenum region, upper insulator, ~ 2.6 inches from top of fuel column, and bottom insulator. Pins F3B-1 and F3B-2 were punctured in the bottom insulator ~ 0.5 inch below the bottom of the fuel column. Pins F3B-3 and F3B-4 were punctured ~ 2.6 inches below the top of the fuel column. Pin F3B-5 was punctured in the upper insulator ~ 1 inch above the top pellet of the fuel column. Pin F3B-7 was punctured in the plenum region.

Punctures were made using a 0.125-inch diameter self-centering drill. Prior to puncturing, the collection system was evacuated to a pressure of ~ 6 microns of mercury. As the drill bit pierced the cladding of each pin, a rapid rise in pressure was indicated and drilling was immediately stopped. From this point on the pressure in the collection bomb was measured periodically until it stabilized.

Table 7
GAS CHROMATOGRAPHIC ANALYSIS OF F3A FUEL PIN GAS

Pin F3B	-1	-2(a)	-3	-4	-5	-7(a)
N ₂ Vol %	0.05	0.205	<0.003	0.08	0.04	0.04
CO ₂ Vol %	0.02	0.050	<0.003	<0.003	0.03	<0.002
H ₂ Vol %	0.19	<0.002	0.08	0.19	0.19	<0.001
Ar Vol %	2.27	1.41	<0.004	2.31	0.03	1.50
He Vol %	16.37	13.64	16.85	16.94	17.41	14.89
Kr Vol %	10.45	10.84	10.72	10.61	10.19	10.70
Xe Vol %	70.74	76.87	72.40	70.86	70.97	75.34
Xe/Ke	6.77	7.09	6.75	6.68	6.96	7.04
Total Fission Gas (Kr + Xe)	81.19	87.71	83.12	81.47	81.16	86.04
N ₂ + H ₂ + Ar, Vol %	2.51	1.62	0.08	2.58	0.26	1.54
% Ar in Fill Gas ^(b) $\left(\frac{\text{Ar}}{\text{N}_2 + \text{H}_2 + \text{Ar} + \text{He}} \right)$	12.0	9.2	0.0	11.8	0.2	9.1
% N ₂ in Fill Gas $\left(\frac{\text{N}_2}{\text{N}_2 + \text{H}_2 + \text{Ar} + \text{He}} \right)$	0.3	1.3	0.0	0.4	0.2	0.2
% He in Fill Gas ^(b) $\left(\frac{\text{He}}{\text{N}_2 + \text{H}_2 + \text{Ar} + \text{He}} \right)$	86.7	89.4	99.5	86.8	98.5	90.6

(a) Average of duplicate aliquots for F3B-2 and F3B-7, others are single values.

(b) He produced by (n,α) reactions or from tertiary fission during irradiation was ignored in fill-gas computations.

Table 8
MASS SPECTROGRAPHIC ANALYSIS OF FISSION GAS

Fuel Pin	F3B-1	F3B-2	F3B-3	F3B-4	F3B-5	F3B-7
Kr-83/Kr	15.85	15.77	15.95	15.91	15.77	15.78
Kr-84/Kr	27.84	27.79	27.77	27.71	27.54	27.74
Kr-85/Kr	6.84	6.83	6.90	6.93	6.71	6.92
Kr-86/Kr	49.46	49.61	49.38	49.45	49.98	49.56
Xe-131/Xe	15.51	15.49	15.58	15.54	15.34	15.49
Xe-132/Xe	22.43	22.27	22.37	22.29	22.35	22.24
Xe-134/Xe	33.81	33.77	33.77	33.79	33.77	33.83
Xe-136/Xe	28.25	28.47	28.29	28.38	28.54	28.44
Xe/(Xe + Kr)	85.7	85.4	85.4	85.8	87.0	85.4
Xe/Kr	5.99	5.85	5.85	6.04	6.69	5.85

Figure 6 shows the volume of gas at STP in pins F3B-1, -2, -3, and -4 as a function of time following puncture. Gas releases from pins F3B-5 and -7 (punctured above fuel column) were very rapid. When the first pressure reading was made one minute after puncture, all of the gas from pin F3B-7 and 95% of the gas from pin F3B-5 had been released.

A general observation from these results is that the rate of gas release decreases as the distance of the puncture from the plenum increases. Half lives for gas release (i.e., the time required for one-half of the gas to escape) are as follows:

Table 9
GAS RELEASE HALF-LIVES

Pin Number	Location of Puncture	Gas Release Half-Life
F3B-1	Bottom insulator	~ 1.2 minutes
F3B-2	Bottom insulator	~ 15.0 minutes
F3B-3	Top portion of fuel column	~ 25 seconds
F3B-4	Top portion of fuel column	~ 40 seconds
F3B-5	Upper insulator	≤ 25 seconds
F3B-7	Plenum	≤ 25 seconds

In order to further determine the effect of the puncture location on the rate of gas release, an additional experiment was performed on pin F3B-3. Punctures were made at the four locations shown in Figure 7. The rate of air flow between the plenum hole and each of the other three holes was determined. With the plenum region at approximately one atmosphere, a vacuum of ~6 microns was attained in the rest of the system. The pin was then punctured and the rate of air flow over each path was determined with a constant pressure drop between the holes of about one atmosphere. These results are shown in Figure 8. Paths 1 and 2 resulted in approximately the same flow rates, while path 3 was much slower. This result indicates that the specific location of a puncture in the fuel column does not have much effect on the flow rate. It does show, however, that the insulator pellets significantly reduce the rate of gas flow from the plenum to the fueled region, even in a cold fuel rod.

Gas release and void volume data are given in Table 10. At the approximate maximum released volume of 100 cm³, STP, the end-of-life plenum pressure at 477°C (900°F), would have been 254 psi. Fission gas release fractions for

Figure 6. Rate of Fission Gas Release from F3A Fuel Pins

Figure 7. Location of Puncture Holes in Pin F3B-3

Figure 8. Flow Rates Through Fuel Pin F3B-3

Table 10
FISSION GAS — SERIES F3A

Pin Number	Total Gas Released (cm ³ at STP)	Total (Xe + Kr) Released ^(a) (cm ³ at STP)	Total (Xe + Kr) Produced ^(b) (cm ³ at STP)	% (Xe + Kr) Released		Total Pin Void Volume (cm ³)	
				Calculated Burnup ^(b)	Experimental Burnup ^(c)	Measured Postirradiation	As Fabricated
F3B-1	92.5	75.1	102.5	73.3	83.1	15.9	16.2
F3B-2	116.7	102.4	105.6	96.9	107.8	16.0	16.2
F3B-3	99.1	82.4	109.5	75.2	83.4	16.3	16.2
F3B-4	93.7	76.3	105.2	72.6	81.2	16.5	16.2
F3B-5	101.1	82.0	97.1	84.5	94.7	17.0	16.2
F3B-7	111.5	95.9	106.5	90.1	103.1	14.7 ^(d)	16.5

(a) Based on gas chromatographic results, Table 7.

(b) Based on calculated average burnup per Reference 6 assuming all U which is not U-235 to be U-238 and using 0.246 rare gas fission product atoms per fission.

(c) Using the average Nd burnup values of Table 11.

(d) The 14.7 cm³ value is doubtful.

these six pins were calculated from the results and are summarized in Table 10. The fission gas production calculations were based on a total Xe + Kr yield of 0.246 rare gas atoms per fission. The fission gas release for individual fuel pins was determined from total gas volume measurements, and the fraction of Xe and Kr in the gas was obtained by gas chromatographic analysis. The fraction of Xe plus Kr released did not correlate well with any fuel or irradiation parameter. These fractions were somewhat greater than those of the 50,000 MWd/Te F2 fuel pins.²

5.2.2 Sectioning of Fuel Pins

All fuel surfaces were visually examined and photographs of the surfaces are included in the sectioning diagrams in Appendix B, Figures B-1 through B-6. Three longitudinal and two transverse metallographic specimens were obtained from each pin following sectioning. The specific locations of these specimens were selected to study effects in the peak flux and peak temperature regions of each pin.

A section for burnup analysis was obtained from each fuel pin in the region of peak power adjacent to the metallography section. The gross gamma activity scan of the fuel pin was used to detect any local perturbations in the gamma activity of the fission products. These regions were avoided in the selection of the fuel section for burnup analysis. Five burnup specimens were taken from pin F3B-3 in order to obtain an axial burnup profile of the fuel pin.

5.2.3 Fuel Burnup

Sections 1/4 inch long, including fuel and cladding, were cut for burnup analysis from the peak burnup region of each fuel pin. The entire cross section of the fuel was dissolved, the cladding leached of fission products, and the solutions prepared for analysis with a triple spike of U-233, Pu-242, and Nd-150. The isotopic ratios of uranium, plutonium, and neodymium were then determined with a mass spectrometer. The analytical procedure used for the burnup determination was ASTM Specification E-267 (GEAP-5354)⁸ and a FORTRAN IV Code.⁹ These results are shown in Table 11.

The fission burnup based on the neodymium and heavy element analyses are reported. The uncertainty in these values is no more than 3%. The local burnup for each sample was calculated based on EBR-II physics data for the normalized axial fission rate distribution. These are also shown in Table 11 as burnups derived from EBR-II guide fission rates and include depletion corrections. Comparison of Nd and heavy element results with burnups based on EBR-II guide calculations shows the analytical results to be consistently lower. The differences range from 9.5 to 12.4% of the Nd* values except for sample F3B-3N which had a difference of 22.8%. Results from sample F3B-3N should have been substantially lower than nominal because it was taken from the upper end of the fuel column of the central pin. The fuel in this pin was 2.5 inches longer than that in four of the six adjacent pins in the subassembly. (These four were ANL pins and the geometry is described in Subsection 3.2 of this report and some discussion is given in Section 6.)

The discrepancy in burnup between the calculated and the measured values was less in the F3A pins than the 13 to 20% discrepancies found earlier in 19 pin subassemblies. The X040 and X040A subassemblies contained 37 pins of 0.25-inch nominal fuel diameter. Because these pins were not encapsulated, substantially more fuel could be placed in these pins than in the 0.22-inch inside diameter pins usually used. In fact, subassembly X040 contained more fissionable material than did any other EBR-II experimental subassembly yet examined. Thus, it is possible that a smaller neutron flux depression was present in the F3A series than in previous irradiations.

On the other hand, the burnup discrepancy varied within the subassembly in a regular manner with the experimental burnup increasing (relative to the calculated value) towards reactor location 4B1. This was the position of the extra-worth driver subassemblies which were inserted during approximately 29% of the exposure. The decreased burnup discrepancy may have been caused by the extra-worth drivers rather than the greater fissile content of this experiment relative to other experiments. The distribution of burnup (normalized for distance from the center of the core) is shown in Figure 9. As indicated, there is a statistically significant (95% confidence) slope with greater fission rates at locations closer to the high-worth driver. The lower 95% confidence limit on this slope was -0.01367 in $(\text{Nd}^{148}/\text{calculated burnup})$ per inch of distance from the high-worth driver. This corresponds to an approximately 5% increase in power, due to the 70% driver, across the 1.2 inches over which the burnup measurements were made (using a factor of $\sim 3:1$ for the ratio of total to perturbed exposure). The power increase corresponding to the upper 95% confidence limit was about 8%.

The measured burnup axial profile for F3B-3 matches that expected from EBR-II physics calculations except for the uppermost sample. This is shown in Figure 10.

* The Nd-148 values are quoted here.

Table 11
BURNUP COMPARISON – SERIES F3A

Sample	Distance from Bottom of Fuel (inches)	Calculated Local Burnup (C) (at.%) ^(a)	Measured Burnup (at.%)			Discrepancy (%)	
			Nd-148	Average Nd ^(b)	HM ^(c)	$\frac{[(C) - (Nd-148)]}{Nd-148}$	$\frac{Nd-148}{(C)}$
F3B-1H	6.6	5.34	4.70	4.71	4.65	12.0	87.96
F3B-2E	4.6	5.46	4.88	4.90	4.85	10.5	89.50
F3B-3C	0.5	4.67	4.21	4.23	4.18	9.7	90.25
F3B-3E	3.7	5.54	4.98	4.96	4.90	10.1	89.94
F3B-3H	7.4	5.69	5.14	5.16	5.10	9.7	90.29
F3B-3J	10.6	5.02	4.51	4.52	4.47	10.3	89.75
F3B-3N	12.8	4.92	3.80	3.83	3.79	22.8	77.21
F3B-4D	6.6	5.48	4.90	4.90	4.84	10.5	89.45
F3B-5D	6.6	5.38	4.77	4.80	4.74	11.4	88.65
F3B-7E	7.2	5.50	4.82	4.81	4.76	12.4	87.61
F3B-10E	6.9	5.66	5.12	5.06		9.5	90.47
Average						10.61 ^(d)	89.39 ^(d)

(a) $(C) = (EBR-II \text{ Calculated Peak}) \times \left[\frac{(\text{Local/Average}) \text{ Ratio per EBR-II Guide}}{1.12} \right] \div 1.12$
(1.12 = Peak/Average for U-235 and Pu-239 per Guide).

(b) Average Nd = Average burnup values from Nd-148, Nd-146, and Nd-145 isotopes.

(c) HM = Heavy Metal (U + Pu Depletion) burnup measurements.

(d) F3B-3N Value omitted (low burnup because 4 of 6 adjacent pins unfueled).

Figure 9. Burnup Discrepancy in X040A Fuel Pins as a Function of Distance From Center of High-Worth Subassembly at 4B1

Figure 10. Axial Fission Rate Profile—Comparison of Calculated and Experimental Values

5.2.4 Cladding Analyses

5.2.4.1 Temperature Measurement by Kr-85 Evolution

Pieces of cladding from pins F3B-2 and F3B-7 were heated and the evolution of Kr-85 was monitored as a function of temperature. The maximum, late-in-life temperature of a sample can be determined from an analysis of a plot of Kr-85 evolution rate versus temperature.¹⁰ The results obtained by this method are given in Table 12. These data indicate that the F3A pins may have operated with cladding temperatures that were at least 100°F above the calculated temperatures. The development of this method is still proceeding, but the results appear to be accurate within 40 to 50°F, or better. It should be noted that the results from some F3B (E1H) series samples, tested concurrently with the F3A specimens described in Table 12, agreed satisfactorily with the calculated temperatures that were based upon measured burnup.

5.2.4.2 Carbon Redistribution

Several one-eighth-inch-thick ring sections of cladding from pin F3B-2 were alpha decontaminated* and subjected to carbon analysis by combustion. The objective was to determine whether any gross carbon redistribution occurred during irradiation. The results are shown in Table 13. It appears that, within the precision of the method (about ±50 ppm), there was no decarburization and no carbon redistribution in the cladding.

* This decontamination procedure typically removes up to 0.002 inch of metal from the inside of the cladding.

Table 12

CLADDING TEMPERATURE MEASUREMENT BY KR-85 EVOLUTION (Reference 10)

Pin Number	Axial Location, Inches Above Bottom of Core	Kr-85 Temperature (°F)	Normally Calculated Local Temperature (°F) (Start of Life)
F3B-2 ^(a)	11.3 to 12.3	1166	1078
F3B-2	11.3 to 12.3	1175	1078
F3B-7	11.4 to 12.4	1132	970
F3B-7	11.4 to 12.4	1196 ^(b)	970

(a) Samples from the plenum region of F3B-2 were also tested: but insufficient Kr-85 was released to obtain a temperature measurement.

(b) This sample also produced a temperature indication of 930°F which may have been an artifact of the method, i.e., possible inclusion of fuel.

Table 13

CARBON ANALYSES FROM TYPE 316 CLADDING OF PIN F3B-2

Sample	Axial Location, Inches Above Bottom of Core	Normally Calculated Temperature (°F)		Carbon Content (ppm)		
		At Outside Diameter	At Inside Diameter	Sample	Mean Value	Range
D2-2	4.1	818	930	801	710	183
D2-3	4.2	820	933	618		
G-2	5.9	862	977	534	576	84
G-3	6.0	865	980	618		
K1-2	11.9	990	1079	553	572	39
K1-3	12.0	992	1080	592		
Five Irradiated Samples ^(a)					583 ^(a)	84
Seven Unirradiated Controls (Analyzed at GE)					584	128
Five Unirradiated Controls (Analyzed by Independent Laboratory)					614	60
Two Supplier's Certification Values					650	100

(a) Excluding Sample D2-2 which appears to be anomalous.

5.3 METALLOGRAPHIC EXAMINATION

5.3.1 Optical Metallography

Metallographic examination was performed on a one-inch longitudinal section from the top of the fuel column and a transverse section from near the peak power region of each of the six fuel pins. Additional longitudinal and transverse specimens were examined from each pin to investigate selected areas of interest. The location of each metallography specimen is designated on the fuel pin sectioning diagrams in Appendix B, Figures B-1 through B-6.

All specimens were taken from regions where the initial pellet-cladding gap was known. This is important because the local heat transfer conditions directly affect the temperature distribution and the corresponding microstructural changes observed in the fuel. The specimens from the top of the fuel pins were taken to include the areas of highest cladding temperatures and areas where fission products such as Cs were found to be concentrated in the gamma scans.

Metallographic examination involved the following procedure. Initially, all specimens were vacuum impregnated with hysol resin mounting material to achieve good fuel and edge retention during preparation. After grinding, the final polishing operation was done with 0.5 micron diamond paste. Each specimen was then examined and photographed in the as-polished condition. A montage of the cross section of each transverse specimen was prepared at a magnification of 50X to record the overall microstructure of the section. A composite of a diametral section showing typical microstructure at 100X was made on each of the transverse specimens. Montages of the fuel-cladding interface and pellet interfaces were also made on selected longitudinal specimens. Photomicrographs of selected areas of interest were obtained from all specimens at higher magnifications.

The fuel and cladding microstructures of selected specimens were then developed by etching. Electrolytic etching at 6 volts for ten seconds in 10% oxalic acid was the usual practice for developing cladding microstructure. Photomicrographs were taken of the same areas photographed in the as-polished phase of the examination. In addition, the microstructure of some of the cladding was examined in detail using Vilella's or Murakami's etchants, to reveal sigma phase. No sigma phase was found.

Normal structure changes were observed in the fuel in all of the transverse sections from the peak power region of each fuel pin. There was a central void surrounded by a zone of long columnar grains. The columnar grains were surrounded by large equiaxed grains and the outermost ring of fuel was fine grained, typical of the as-fabricated fuel. Figure 11 shows each of these peak power microstructures. The fuel pin design parameters and in-pile operating conditions corresponding to these specimens are presented in Table 14. The extent of the microstructural changes observed in each section are also tabulated. These measurements were made from the diametral composites at 100X magnification. The calculated and measured fuel structural parameters are plotted in Figures 12 and 13. The fact that the calculations predict substantially smaller equiaxed and columnar grain regions than observed is obvious from these figures and Table 14. This implies that the pins operated at higher powers than calculated. The void diameters, however, are fairly well predicted.

The apparent fuel-clad gaps seen in F3B-2, F3B-5, and F3B-7 are believed to be the result of material being removed from the sample during metallographic preparation. If a gap had actually existed between the fuel and the cladding at the time of metallographic preparation, it should have been filled with the hysol resin with which all specimens are vacuum-impregnated. No hysol is present in these gaps and it is therefore concluded that these gaps probably do not represent actual end-of-life fuel-cladding gaps.

Examination of the outside surface of the cladding in all metallographic specimens was performed in order to study the effect of exposure to high temperature flowing sodium. No deterioration or attack of the cladding was observed in any of the specimens examined and all surfaces were found to be in good condition. Figure 14 shows a representative region of the cladding outside surface taken from Type-316 clad pin, F3B-2. This sensitized, but unattacked, microstructure is typical of the outside surface regions which were examined.

The inside cladding surface of the fuel pins examined showed cladding deterioration due to intergranular attack in 12 of the 26 metallographic samples. This attack was visible in the as-polished condition in five of the six pins examined: F3B-2, F3B-3, F3B-5, F3B-7, and F3B-10. F3B-1 samples did not reveal any attack. With the exception of F3B-1, and one each from F3B-2 and F3B-5, all specimens which operated at average beginning-of-life clad inside surface temperatures greater than 525°C (977°F)* exhibited intergranular penetration. All those specimens which operated at cladding inside temperatures of less than 525°C were not attacked.

Figures 15 through 20 show the effect of temperature on the presence and degree of intergranular attack. They exhibit typical cladding areas which operated at inside surface temperatures from 434 to 588°C (813 to 1127°F). Figure 15 shows such 250X views of cladding in the etched** condition from a Type-304L clad pin, F3B-10, and a Type-316 clad pin, F3B-2, which operated at 435°C (815°F). These microstructures and their as-polished counterparts show no evidence of intergranular attack. They exhibit typical Type-304L and Type-316 etched microstructures, including twinning and carbide precipitation within the grain matrix and at the grain boundaries. No sensitization occurred on the cold side of the Type-304L specimen, which operated at 383°C (722°F). This is probably due to the lower carbon content of Type-304L compared with Type 316.

Figure 16 shows similar views of cladding microstructures from Types-304L and -316 fuel pins taken from locations where cladding inside surface temperatures were ~500°C (932°F). These specimens from Type-304L clad

* These cladding temperatures are based on unperturbed calculations using EBR-II experimenter's guide fission rate data and assuming that the ANL pins were fully fueled for 13.5 inches instead of 11.0 inches.

** 10% oxalic acid electrolytic etching was used unless otherwise stated.

A601-04

(a) F3B-1

A616-04

(d) F3B-5

A586-04

(b) F3B-2

A575-04

(e) F3B-7

A596-04

(c) F3B-3

A628-04

(f) F3B-10

Figure 11. Transverse Sections from Near the Peak Flux Regions of the F3A Fuel Pins Examined, 9X

Table 14
 MICROSTRUCTURAL PARAMETERS—POSTIRRADIATION EXAMINATION OF X040 and X040A PINS
 (SERIES F3A)

Pin Number	Specimen	Distance from Core Bottom (inches)	Cladding i.d. Temperature Start of Life		Maximum Cladding Penetration 0.001-inch	Fuel Structural Diameters, 0.001-inch					
			(°C)	(°F)		EGG ^(a)		CGG ^(b)		Void	
						Obs ^(c)	Pred ^(d)	Obs	Pred	Obs	Pred
F3B-1	A603	13.0–14.0	533	991	0	NM	126	NM ^(e)	^(e)	NM	47
F3B-1	A602	6.7	501	934	0	200	170	153	111	39	52
F3B-1	A601	6.0	496	924	0	200	170	147	112	40	52
F3B-1	A600	–0.5–+0.5	434	813	0	NM		NM		NM	
F3B-2	A589	13.1–14.1	591	1095	7.5	202	164	187	75	–	42
F3B-2	A588	13.1	589	1093	4.6	198	164	146	77	46	43
F3B-2	A587	6.3–7.3	537	999	0	NM	188	NM	141	NM	52
F3B-2	A586	5.2	516	960	0	202	187	182	140	55	51
F3B-2	A604	–0.5–+0.5	438	820	0	215	148	178		52	38
F3B-3	A599 ⁽ⁱ⁾	13.1–14.1	608	1127	9.0	206	162	162	–	49	53
F3B-3	A598	12.9	605	1121	7.0	192	162	170		25	53
F3B-3	A597 ⁽ⁱ⁾	11.2–12.2	596	1104	3.0 ^(f)	196	171	157	97	32	55
F3B-3	A596	6.8	545	1013	1.5	198	188	158	142	56	59
F3B-3	A595	–0.6–+0.4	434	823	0	NM	140	NM	–	NM	51
F3B-5	A617	12.9–13.9	542	1007	2.7	190	156	147		50	52
F3B-5	A616	12.9	541	1005	3.0	200	157	174	–	42	53
F3B-5	A615	11.4–12.4	536	997	0	200	163	143	56	48	55
F3B-5	A614	7.2	508	947	0	200	184	165	130	57	64
F3B-7	A622	13.4	526	979	3.5 ^(f)	190	135	150		37	49
F3B-7	A575	7.0	497	926	0	190	175	174	121	55	55
F3B-7	A576	4.5–5.5	481	897	0	210	173	170	118	54	54
F3B-7	A577	4.5	476	888	0	202	171	162	114	38	53
F3B-10	A630	12.9–13.9	586	1087	7.0	212	169	166	91	48	46
F3B-10	A629	12.9	584	1084	5.0	215	170	170	93	44	46
F3B-10	A628	6.3	526	979	3.6	206	192	172	149	75	55
F3B-10	A627	–0.3–+0.7	434	813	0	NM	155	NM		NM	41
ANL007		11.85 ^(h)	583	1081	5.0	236	183 ^(d)	172	95 ^(d)	108	78 ^(d)
ANL012 ^(g)		11.85 ^(h)	528	983	2.0	234	181 ^(d)	174	106 ^(d)	102	72 ^(d)

(a) Equiaxed Grain Growth Diameter, or inside limit of unrestructured region.

(b) Columnar Grain Growth Diameter.

(c) Observed by measurement on micrograph (mean of several observations).

(d) Calculated values.

(e) Not Measured, Dash (—) indicates that calculation predicts that the parameter is not present.

(f) General attack also observed.

(g) ANL 012 was sectioned at 3.0 a/o burnup (Exposed in S/A X040 only).

(h) Total fuel length = 11.0 inches in ANL Pins. (Bottom of ANL fuel was 0.85-inch above bottom of core).

(i) Specimens A597 and A599 were remounted in A682 for electron microprobe examination.

Figure 12. Microstructural Parameters for Pins F3B-1, F3B-2 and F3B-5—Normal Calculations

Figure 13. Microstructural Parameters for Pins F3B-3, F3B-7 and F3B-10—Normal Calculations

A589-18,19

ETCHED

250X

Figure 14. Cladding Outside Surface on Fuel Pin F3B-2

a. 304L CLAD F3B-10, AT BOTTOM OF FUEL COLUMN

b. 316 CLAD F3B-2, AT BOTTOM OF FUEL COLUMN

Figure 15. Cladding Microstructures from Group F3A Pins F3B-10 and F3B-2 Typical for Cladding Inside Temperatures of $\sim 815^{\circ}\text{F}$

a. F3B-7, 304L CLAD

b. F3B-5, 316 CLAD

Figure 16. Cladding Microstructures from Group F3A Pins F3B-7 and F3B-5 Typical for Cladding Inside Temperatures of $\sim 930^{\circ}\text{F}$

F3B-7 and Type-316 clad F3B-5 are typical of the microstructures from the other F3A pins which operated at approximately this same temperature. No intergranular attack was seen in the as-polished condition and none is visible in these etched specimens. Both Types-316 and -304L specimens showed sensitized structures across the entire wall thickness.

Figure 17 shows as-polished and etched photomicrographs from Type-304L clad F3B-10 and Type-316 clad F3B-5 which exhibit the lowest temperature occurrences of intergranular attack observed in the F3A fuel pins. These sections operated at cladding inside surface temperatures of 526 and 541°C (979 and 1005°F), respectively. It is readily apparent in the as-polished microstructures that intergranular attack extending as much as 0.003 inch into the cladding wall occurred in this temperature range. These areas of attack were found in only a few isolated locations of each specimen examined in this range. The remainder of the cladding on each specimen was unattacked and appeared to be in excellent condition. The etched structure from F3B-5 reveals areas depleted in carbides adjacent to the attacked grain boundaries. The Type-304L microstructure from F3B-10 does not show this depletion in the etched condition which is due most likely to its lower carbon content and/or different etching characteristics. Boundaries of two of the smaller Type-304L grains in Figure 17 were attacked to such an extent by the etchant that the grains fell out. Note that the grain closest to the surface was surrounded by the intergranular phase, in the as-polished condition (A628-20-21).

Figure 18 shows similar views of Type-304L and Type-316 cladding which has undergone intergranular attack of about 0.002–0.005 inch. Cladding inside surface temperature was 526°C (979°F) for the Type-304L specimen and 589°C (1093°F) for the Type 316. Again, the attack was limited to discrete regions of these specimens. Close examination of the etched Type-316 microstructure again revealed the presence of areas depleted in carbide.

Figure 19 shows as-polished and etched microstructures from Type-304L clad F3B-10 and Type-316 clad F3B-2 which operated at cladding inside surface temperatures of 588°C (1090°F). This is the highest temperature at which both Type-304L and Type-316 specimens are available. Intergranular attack extending 0.005–0.006 inch into the cladding wall is readily noted in the as-polished structure. In the etched condition, both specimens exhibit interesting characteristics. The Type-316 specimen from F3B-2 shows the previously observed depleted zones adjacent to the attacked grain boundaries. It also shows a metallic-appearing phase in the attacked grain boundaries. Since cesium and its oxides should have been readily attacked by the etchant, this phase is probably not cesium. The Type-304L specimen from F3B-10 exhibits a microstructure which shows neither depleted zones nor any visible material in the attacked grain boundaries. Unlike the Type-316 specimens, the attacked areas of the Type-304L specimen were not appreciably delineated by the etchant. Again, this is probably due to the lower carbon content in the Type-304L compared with the Type-316 cladding.

The peak power fuel pin, F3B-3, provided the hottest [608°C (1127°F) cladding inside temperature] and most extensively attacked cladding specimen examined. Figure 20 shows the two most heavily attacked regions of the F3B-3 specimen. Intergranular attack is seen in the ~100X as-polished micrographs extending 0.008 to 0.009 inch into the cladding wall. This was the deepest intergranular penetration observed in the Group F3A fuel pins. Etching served to further delineate the attacked grain boundaries and the depleted regions (which appear to be typical of this type of intergranular attack). Although no material was visible in the attacked grain boundaries near the cladding surface, a careful examination of these boundaries several mils from the inside surface revealed a brownish looking phase which suggests the presence of Cs₂O.

Figure 21 summarizes the temperature dependence of the intergranular attack shown by the group F3A specimens. At beginning-of-life average inside cladding temperatures below 516°C (960°F), no intergranular attack was seen. Above this temperature, the depth of penetration increased continuously to a maximum penetration of 0.009 inch at a temperature of 609°C (1127°F). Most of the attack occurred in the uppermost regions of the fuel pins, and it is apparent that temperature determines the amount of attack. In fact, intergranular attack was observed as much as seven inches below the top of the fuel column in two of the pins, F3B-10 and F3B-3.

No correlation was apparent between the presence or degree of intergranular attack and any fuel parameters such as: pellet type, fuel density, oxygen-to-metal ratio, or cladding material. Intergranular attack was noted in each of the following types of fuel pins: annular pellet and solid pellet fuel pins, ~88% and ~83% smear density fuel pins, 1.98 and 2.00 initial O/M ratios, and Types-316 and -304L claddings. The amount of data obtained in this analysis is not sufficient to completely assess the possible role which each of these parameters plays in the intergranular attack of the cladding; it is clear, however, that such effects must be secondary to the effect of temperature.

In addition to the intergranular type of attack which was observed, two specimens, one from Type-304L clad fuel pin F3B-7, and one from Type-316 clad fuel pin F3B-3, exhibited general attack at the inside surface of the cladding. This attack, which extended up to 0.003 inch into the clad wall in one of the specimens, is shown in Figure 22. A metallic looking phase was seen in the fuel-clad gap in each of these specimens. The initial cladding inside temperatures at these locations were 596°C (1104°F) in the Type-316 clad F3B-3 and 526°C (979°F) in the Type-304L clad F3B-7.

A628-20-21

AS-POLISHED

250X

A628-34-35

ETCHED

250X

a. F3B-10, 304L CLAD $\sim 980^{\circ}\text{F}$ CLAD INSIDE TEMPERATURE

A616-13-14

AS-POLISHED

250X

A616-27-28

ETCHED

250X

b. F3B-5, 316 CLAD $\sim 1005^{\circ}\text{F}$ CLAD INSIDE TEMPERATURE

Figure 17. Cladding Microstructures from Group F3A Pins F3B-10 and F3B-5 which Operated at Cladding Inside Temperatures of $\sim 1000^{\circ}\text{F}$

A622-20-21

AS-POLISHED

250X

a. F3B-7, 304L CLAD $\sim 980^{\circ}\text{F}$ CLAD INSIDE TEMPERATURE

A588-15-24

AS-POLISHED

250X

A588-37-42

ETCHED

250X

b. F3B-2, 316 CLAD $\sim 1090^{\circ}\text{F}$ CLAD INSIDE TEMPERATURE

Figure 18. Cladding Microstructures from Group F3A Pins F3B-7 and F3B-2 which Operated at Cladding Inside Temperatures of ~ 980 – 1090°F

A589-04-05

AS-POLISHED

250X

A589-12-13

ETCHED

250X

a. F3B-2, 316 CLAD

A630-22-23

AS-POLISHED

250X

A630-34-35

ETCHED

250X

b. F3B-10, 304L CLAD

Figure 19. Cladding Microstructures from Group F3A Pins F3B-2 and F3B-10 which Operated at Cladding Inside Temperatures of $\sim 1090^{\circ}\text{F}$

Figure 20. As-Polished and Etched Cladding Microstructures from Type-316 Clad Group F3A Pin F3B-3 which Operated at Cladding Inside Temperatures of $\sim 1130^{\circ}\text{F}$

Figure 21. Cladding Penetration in EBR-II Subassemblies X040 and X040A—Normally Calculated Temperatures

A597-13

AS-POLISHED

100X

(a) F3B-3, 316 CLAD $\sim 1080^{\circ}\text{F}$ CLAD INSIDE TEMPERATURE

A622-16

AS-POLISHED

100X

(b) F3B-7, 304L CLAD $\sim 1040^{\circ}\text{F}$ CLAD INSIDE TEMPERATURE

Figure 22. Areas of General Cladding Attack Observed in Two Pins

These temperatures are above the 516°C (960°F) level at which intergranular attack was first seen to occur; but not much intergranular attack was found in these regions of general attack. The approximate position of the original cladding inside surface on Type-316 clad F3B-3 corresponds to a discontinuity in the reaction product as indicated on the specimen shown in Figure 22a. Because of the relatively small amount of attack in the Type-304L clad F3B-7 sample, the original interface could not be associated with any microstructural feature.

Figure 23 exhibits a 10X montage of the entire F3B-3 specimen which was generally attacked and from which Figure 20 was prepared. Cladding thickness measurements using a filar eyepiece showed that the cladding thickness at positions more than ~0.020 inch from a pellet-to-pellet interface are ~0.002 inch less than the essentially unattacked cladding immediately opposite the pellet interface. Some cladding thickness measurements are given in Table 15, and some of these are shown in Figure 23. Although no metallic phase is present in the fuel-cladding gap at these locations, the apparent loss of cladding material indicates that general attack has occurred, and that less material is lost immediately adjacent to the pellet interfaces than at other locations on the specimen.

Some microhardness surveys were made across the Type-316 cladding from the peak flux pin, F3B-3. The purpose was to detect possible signs of carbon or oxygen removal by the flowing sodium. (It was expected that any transport of these elements through the cladding would be greater in the unencapsulated pins because the continuously purified flowing sodium in contact with the pins would be a more effective impurity sink than the static sodium in a capsule.) The microhardness results are plotted in Figure 24. Surprisingly, the cladding was harder toward the outside. This is in contrast to what would be expected for carbon or oxygen removal from the outside, with a concentration gradient driving the impurity to the surface. The hardness was somewhat greater in the higher flux, lower temperature section which was closer to the reactor midplane. No significant difference was observed between indentations placed across a grain boundary and those entirely within a grain.

Table 15
POST-IRRADIATION CLADDING THICKNESS—PIN F3B-3^(a)

F3B-3 (A597, 599) Type 316		F3B-7 (A622) Type 304L		F3B-10 (A630) Type 304L	
Distance ^(b)	Cladding Thickness (mils)	Distance ^(b)	Cladding Thickness (mils)	Distance ^(b)	Cladding Thickness (mils)
13.67 ^(c)	21.0	13.44 ^(d)	19.7	13.56 ^(c)	19.7
13.40	20.3	13.29	20.0	13.35	19.6
13.25	20.9	13.06	19.6	13.22	19.4
12.99	20.5	12.72	19.6	13.21 ^(d)	19.5
12.03 ^(d)	21.1 ^(e)	12.62	19.2	12.91	19.1
11.82	19.5 ^(e)				
11.81 ^(d)	21.1 ^(e)				
11.65	19.4 ^(e)				
11.60 ^(d)	21.1 ^(e)				
11.46	20.1 ^(e)				
11.18	19.6 ^(e)				
11.15	18.3 ^(e)				

(a) From metallographic specimens. Sections may not be exactly diametral, resulting in slightly overestimated cladding thickness values.

(b) Distance from bottom of fuel in inches (assuming 13.50-inch fuel column).

(c) Adjacent to blanket pellet.

(d) At pellet-to-pellet interface.

(e) Locations shown on Figure 23.

Figure 23. Longitudinal Section From F3B-3 (11.2-12.2 Inches from Bottom of Fuel) Showing Variations in Cladding Thickness

Figure 24. Microhardness Traverses of F3B-3 Cladding

5.3.2 Electron Microprobe Examination

Pin F3B-3 which exhibited the most extensive intergranular and matrix penetration (0.003 to 0.009 inch) in the F3A series was given a detailed examination with the shielded electron microprobe. The area examined was the upper 2.3 inches of the fuel column. Other pins are presently being examined by the microprobe and will be reported in the PA-10 Quarterlies. The results of the examination of pin F3B-3 are summarized in Table 16. In all of this work, the $K\alpha$ spectral lines were used for O, Cr, Fe, and Ni. $L\alpha$ was used for Mo, Tc, Ru, Pd, Te, Xe, and Cs. For U, $M\alpha$ was used for Pu, $M\beta$.

Table 16
SUMMARY OF ELECTRON MICROPROBE EXAMINATION OF PIN F3B-3

Location	Axial Position Below Top of Fuel (inch)	Element	Results	Figure
Fuel	0.6	O	Inconclusive	25
	0.6	Xe	Concentrated in EGG	25
	0.6	Pu	Concentrated toward void, 40% maximum	25
Metallic Ingot In Central Void	0.6	Ru	Major constituent	26
	0.6	Mo	Major constituent	26
	0.6	Tc	Major constituent	26
	0.6	Pd	Inconclusive	None
	0.6	U	Absent except for fuel inclusions	26
	0.6	Pu	Absent except for fuel inclusions	26
	0.6	O	Absent except for fuel inclusions	26
Blanket	Above fuel	U, Cs	Second phase particles contain Cs, depleted in U (cesium, uranium plutonate), matrix contains less Cs	27
Cladding ^(a) Grain Boundaries	0.27	Fe	Depleted intergranularly	28
	0.27	Cr	Less depleted than Fe	28
	0.27	Ni	Approximately level	28
	0.27	Mo	Penetrated to full depth of attack	28
	0.27	Cs	Probably somewhat less penetration than Mo	28
	0.27	Te	Restricted to ~1 grain from surface	28
	0.27	O	Extensive penetration	28
Fuel/Cladding Reaction Zone	0.27	Fe	Probable absence	28
	0.27	Cr	Inconclusive	28
	0.27	Ni	Present	28
	0.27	Cs, Te, Mo, O	Strong presence	28
Cladding Grain Boundaries ^(b)	0.37	Fe	Substantially depleted	29, 30
	0.37	Cr	~40% enhancement	29, 30
	0.37	Ni	Slight depletion	30
	0.37	Mo	Very little penetration	29, 30
	0.37	Cs	Complete penetration	29,
	0.37	Te	Complete penetration	29
	0.37	O	Extensive penetration	29

Table 16 (Continued)

Location	Axial Position Below Top of Fuel (inch)	Elements	Results	Figure
Fuel/Cladding Reaction Zone	{ 0.37	Fe	Comparable to Cladding matrix	29
	{ 0.37	Cr	Not found	29
	{ 0.37	Cs, Mo, Te, O	Strong presence	29
Cladding ^(a)	{ 0.6	Fe, Cr, Ni	Similar to 0.27-inch location	None
	{ 0.6	Mo, Cs, Te	Similar to 0.27-inch location	None
	{ 0.6	O	Concentrated at grain boundaries and near inside surface	31 32
Cladding Grain Boundaries ^(b)	{ 1.38	Fe, Cr, Ni	Depleted ~ to 0.27-inch location	33
	{ 1.38	Mo, Cs, Te, O	Present	33
Fuel/Cladding Reaction Zone	1.38	Fe, Ni	Present	33
		Cr	Inconclusive	33
		Mo, Cs, Te, O	Present	33
Cladding Grain Boundaries ^(c)	{ 1.61	Fe	Depleted ~ to 1.38-inch location	33
	{ 1.61	Cr, Ni	Less depletion than at 1.38-inch	33
	{ 1.61	Mo	Discontinuous	33
	{ 1.61	O	Less evident than at 1.38-inch	33
	{ 1.61	Te	Probable absence	33
Fuel/Cladding Reaction Zone	{ 1.61	Fe	Present	33
	{ 1.61	Cr, Ni	Less obvious than at 1.38-inch	33
	{ 1.61	Mo, Cs, O	Present	33
	{ 1.61	Te	Probable absence	33

(a) Principally intergranular attack.

(b) Substantial matrix attack, some intergranular penetration.

(c) This location had two-phase penetration according to light microscopy.

5.3.2.1 Fuel in F3B-3 at 12.9 Inches Above Core Bottom

Figure 25 shows a cross-sectional optical montage at 12.9 inches above the bottom of the fuel in pin F3B-3, together with electron-microprobe analysis data for plutonium, oxygen, and xenon across the section. The oxygen distribution was essentially flat, but the method was not sensitive enough to differentiate between the small O/M differences expected. The oxygen situation is complicated by the state of oxidation of the various fission products, which may be responsible for the somewhat greater apparent scatter in oxygen intensity for the columnar grain growth region. Substantially all of the retained xenon was found in the outer 0.020-inch-thick ring of fuel.

Substantial plutonium redistribution occurred with as much as 40% Pu being found at the edge of the central void. This redistribution was complicated by the fact that this section was one inch above the top of the eleven-inch ANL fuel in four of the surrounding six pins. Thus, substantial shifts in the fission rate and neutron energy spectrum were expected at this point. There was, in fact, a decrease in the void diameter to 0.025 inch from the 0.044-inch as-fabricated hole in the annular pellets. It appeared that Pu-rich oxide had been vapor deposited in the upper fuel column region of F3B-3. This is consistent with the theory that the central void tends to adjust its size and shape so that its surface is an isotherm. Deposition of plutonia-rich vapor, however, is contrary to thermodynamic expectations unless the fuel is substoichiometric.^{1,2} The F3B-3 fuel was originally stoichiometric.

✓

Figure 25. Photomicrograph of Specimen F3B-3 and Corresponding Radial Distributions of Pu/(Pu+U), Oxygen, and Xenon

Figure 26 illustrates the results of electron microprobe study of fuel adjacent to the central void at 12.9 inches above the bottom of the core and containing a metallic fission product ingot in the center void. This ingot was found to contain substantial concentrations of ruthenium, molybdenum, and technetium. There were also indications of palladium (these could have been fluorescence of the other elements). Except for a few islands of fuel within the ingot, there was no evidence of oxygen. Some of the uranium-rich islands showed plutonium; most did not.

5.3.2.2 Blanket

That portion of the blanket, or upper insulator pellet, in contact with the fuel exhibited a two-phase structure. This was examined with the electron microprobe and the results are illustrated in Figure 27. The matrix contains cesium and tends to be depleted in uranium compared to the islands of UO_2 imbedded in it. It appears that a substituted oxide phase, very possibly cesium uranate, has penetrated intergranularly into the blanket.

5.3.2.3 Cladding

Electron microprobe examination of the cladding and the fuel-cladding reaction product always showed cesium, molybdenum, and tellurium. Oxygen was observed in the cladding with the highest concentrations at the grain boundaries. Spectral scans were made in the cladding for all fission products. Only cesium, molybdenum, and tellurium were found except for the rare appearance of iodine or rubidium.

Figure 28 shows an area of cladding approximately 0.27 inch below the top of the fuel. Based on optical metallography, the maximum depth of intergranular penetration was 0.0076 inch at this point.* The X-ray images for the cladding constituents in Figure 28 indicate that the grain boundary regions are substantially depleted in iron, less so in chromium and contain roughly the same nickel content as the matrix. The substantial iron depletion extends to the full depth of the intergranular penetration found by light microscopy. Corresponding X-ray images for fission products are also given in Figure 28. Molybdenum penetrated to the full depth of the intergranular attack shown by optical metallography. Cesium may have penetrated this far, but it seems to be more concentrated in the material between the fuel and cladding and in the grossly enlarged cladding grain-boundary regions. The small discontinuity in the top center of the optical photomicrograph gives an intense cesium and a pronounced molybdenum X-ray image. Oxygen penetrates the grain boundaries whether or not they are grossly enlarged. Because the oxygen X-ray has low energy, it is difficult to image, and this element may have penetrated substantially further than is apparent in Figure 28.

Figure 29 shows an area of cladding approximately 0.37 inch below the top of the fuel in pin F3B-3. This region had intergranular penetration to a depth of about 0.0015 inch which affected the first layer of cladding grains but did not penetrate far between the second layer of grains. There was an extensive layer of fission product/cladding reaction phase; general (or matrix) attack of the cladding occurred at this location. The grain boundary regions were depleted in iron to the farthest depth of penetration as revealed in the light optical micrograph. In contrast to the results at 0.27 inch below the top of the fuel, sections of the cladding boundaries were enhanced in chromium. This is shown both in the Cr X-ray image and in the reversed contrast specimen current image which has a superimposed Cr X-ray intensity trace. Scaling this trace indicates that the Cr content of the boundary region may be 36 relative percent greater than the matrix concentration which is 17.2 wt %, absolute. But the fuel-cladding reaction layer probably contains no more than 23 relative percent of the cladding matrix chromium content. No Cr signal was displayed on the X-ray image from the fuel-cladding reaction product. However, a substantial signal (comparable in strength to that from the cladding matrix) was displayed from the reaction layer in the iron X-ray images, even though iron was not unambiguously present in the reaction layer at 0.27 inch below the top of the fuel. Oxygen penetrated well into the cladding boundaries and was present in the fuel-cladding reaction layer. Substantial oxygen concentration at the grain boundary triple point is just visible in the upper right-hand corner of the optical micrograph in Figure 29. No Fe, Cr, nor fission product concentrations were found at this point. Cesium and tellurium were found in abundant concentration in the reaction product layer and these elements also penetrated substantially to the limit of intergranular attack exposed in the light optical metallography. Molybdenum, however, was restricted to the reaction product layer and it did not penetrate the cladding grain boundaries.

* The depth of penetration in Figure 28 appears to be about twice the 0.0076 inch actually present because an off-diameter longitudinal section was taken. A grazing section was used to minimize the amount of fuel in the specimen so that the radiation limit of the shielded electron microprobe was not exceeded. The ratio of apparent cladding thickness in this specimen to the known preirradiation thickness is 1.6 to 2.0.

Figure 26. Electron Microprobe Study of Fission Product Ingot and Fuel at Edge of Central Void in Pin F3B-3

REVERSED CONTRAST SPECIMEN
CURRENT IMAGE, APPROXIMATELY 600X

REVERSED CONTRAST SPECIMEN CURRENT
IMAGE, APPROXIMATELY 200X

Cs INTENSITY TRACE, APPROXIMATELY 600X

Cs IMAGE, APPROXIMATELY 600X

U INTENSITY TRACE SUPERIMPOSED ON SPECIMEN
CURRENT IMAGE, APPROXIMATELY 600X

OPTICAL PHOTOMICROGRAPH, 120X A682/A599

Figure 27. Electron Microprobe Study of Blanket Pellet in Fuel Pin F3B-3

Figure 28. Electron Microprobe Study at Approximately 200X of Pin F3B-3 at 0.27 Inch Below Top of Fuel

Figure 29. Electron Microprobe Study at Approximately 500 X (Except as Noted) of Pin F3B-3 at 0.37 Inch Below Top of Fuel

X-ray intensities from Fe, Cr, Ni, Mo, and Cs were measured near the inside surface at 0.37 inch below the top of the fuel, and traversing across a cladding grain boundary which appeared to be enhanced in chromium. The results are given in Figure 30. These data have been corrected for background and counting system dead time. They were standardized against readings on the matrix at cladding mid-thickness and normalized to 100%. The point at 7.7 microns was obtained by maximizing the Cr and Cs signals for very slight beam deflections across the boundary. Normalization factors* were in the range of 1.00 to 1.02 except for the points at 6.6 and 7.7 microns. Normalization factors at these two points were 0.86 and 0.80, respectively. This is probably due to the tellurium content at the grain boundary which was not measured. The data, when standardized with pure Fe, Cr, and Ni, indicate significantly larger chromium and smaller nickel concentrations than the plotted values standardized against the matrix intensities, or when compared with the wet chemistry analysis. Therefore, there is some excitation of at least the Cr X-ray from the slightly shorter wavelength Fe and Ni X-rays. For this reason, the data in Figure 30 should not be considered absolute, but the relative proportions are valid. The indicated molybdenum concentrations corresponded well with the wet chemistry mean value of 2.84 wt % (1.67 at.%). The plotted data show the substantial decrease in iron content at the attacked grain boundary and an approximate fifty relative percent increase in the chromium concentration there. The molybdenum content increased only slightly at the boundary.

It appears then that there are differences between the general attack observed at 0.37 and the preponderantly intergranular attack at 0.27 inch below the top of the fuel. At 0.27 inch, cladding constituents were not found in the fission product layer near the inside of the cladding; chromium was depleted in the cladding boundaries and molybdenum penetrated the stainless steel to the limit of intergranular attack. At 0.37 inch, however, iron and nickel (but not chromium) were found in the fuel-cladding reaction layer; chromium was enhanced at certain grain boundary locations and molybdenum was restricted to the reaction layer. At 0.27 inch, tellurium was limited to the fission product layer and the grossly enlarged boundary regions but this element penetrated to the limit of attack at the 0.37 inch section.

A transverse section of pin F3B-3 at 0.6 inch below the top of the fuel was examined with the electron microprobe. Maximum intergranular penetration was 0.007 inch and the fission product and cladding constituent distributions were quite similar to those at 0.27 inch below the top of the fuel. That is, Mo was the farthest penetrating fission product, Cs extended well into the grain boundary regions, and Te remained at the interface and in the grossly enlarged boundaries. Iron, chromium, and nickel were depleted in the boundary regions. Oxygen was concentrated at the inside surface of the cladding and in the grain boundaries. This is illustrated by the oxygen X-ray intensity traces superimposed on reversed contrast specimen current images in Figure 31 and, more quantitatively, by point counting at five locations across the cladding, Figure 32. Data in Figure 32 are averages of three readings at each location and they have been corrected for background.

Pin F3B-3 was examined with the electron microprobe at points 1.38 and 1.61 inches below the top of the fuel. As shown in Figures 22(a) and 23, this was the region which experienced about 0.001 to 0.002 inch of general cladding recession. This was also the region where the attack was mitigated at pellet-to-pellet interfaces. The 1.38-inch location was 0.030 inch from a pellet interface where the reaction phase was about 0.002 inch thick. The 1.61-inch location involved more intergranular attack at 0.020 inch from a pellet interface. Optical photomicrographs, reversed contrast specimen current images, and X-ray images for the principal fission products and cladding constituents are shown in Figure 33.

The attack at 1.38 inches below the top of the fuel involved substantial grain boundary depletion of iron, chromium, and nickel; cesium, and especially molybdenum, penetrated the grain boundaries; tellurium did not penetrate as far as the other fission products and the boundary phase was oxidized. The fuel-cladding reaction phase had high, fairly uniform, concentrations of iron, cesium, molybdenum, and tellurium. The nickel in the reaction phase, however, was concentrated close to the fuel and was depleted adjacent to the cladding. Chromium was present only in a few spots about 0.0002 inch in diameter.

* The normalization factor is defined here as the total for all elements of the ratios of intensity from the unknown point to that of the standard (matrix).

Figure 30. Electron Microprobe Traverse Across Attacked, Chromium Rich, Cladding Grain Boundary at 0.37 Inch Below the Top of the Fuel in Pin F3B-3

Figure 31. Oxygen as Oxide Concentrated in Grain Boundaries of Fuel Pin F3B-3

Figure 32. Oxygen Intensity Across Cladding of Sample F3B, with Higher Concentrations on Fuel Side

The intergranular penetration at 1.61 inches below the top of the fuel appeared, in the optical metallography, to be two-phase with one phase taking the form of a central spine in the attacked cladding grain boundaries. This structure is also suggested in the reversed contrast specimen current image where a central core, lighter than the matrix, is surrounded by a darker outline. This indicates, not unambiguously, that the central material has a higher mean atomic number than the matrix while the outlining material has a lower atomic number. As at 1.38 inch, the attacked boundaries were depleted in iron. The depletion of chromium and nickel, however, is much less obvious. The molybdenum grain boundary concentration appeared to be discontinuous and the oxygen penetration was less complete than at 1.38 inches. It may be that the less obvious depletion of chromium at 1.61 inches is due to the two-phase penetration. That is, one of the phases may be chromium carbide and the other a mixture of fission product oxides containing little or no chromium. The net effect, at the limit of spacial resolution of the Cr X-ray image, is a signal equivalent to the matrix Cr content. Definite conclusions, however, must await the results of the continuing investigation.

Figure 33. Electron Microprobe Study of Pin F3B-3 at Approximately 200 X at 1.38 and 1.61 Inch Below Top of Fuel (A628/A597)

6. DISCUSSION OF RESULTS

6.1 DIAMETER AND LENGTH CHANGES

Diameter measurements which were made from the continuous profilometer traces of the F3A fuel pins indicated ~ 2 to 3 times greater diameter increase (Table 6) in the Type-304L clad fuel pins than in the Type-316 clad fuel pins of similar design and operation history. Considering that the Type-304L clad fuel pins also exhibited ~ 2 to 3 times greater length increases, it appears that the major factor in this difference in diameter increase is a larger amount of irradiation induced metal swelling in the Type-304L cladding. Differences in the high temperature creep strengths of the two materials should not be an important reason for the difference in diameter increase since fuel swelling induced stresses have not been found to be very large at the F3A burnups.² Short-time high temperature strength may have some influence on pin swelling during startup, however. An average of 80% of the total pin diametral increase with Type 316 occurred before the interim examination at 3.1% burnup. With Type 304L, however, the average proportion of pin swelling taking place before interim examination was only 47%. This corresponds fairly well with the fraction of burnup, which occurred before interim examination (56%). The best explanation for this difference in diameter increase is that the Type 304L underwent substantially more irradiation induced metal swelling than did the Type 316. This is illustrated schematically in Figure 34. It is difficult to rationalize the much greater swelling rate of Type 304L in terms of creep since relaxation would be expected to unload the system substantially.

Diameter variations of about 0.002 inch between adjacent peaks and valleys were usual in the profilometer traces of the Type-304L clad fuel pins, but these variations were substantially less than 0.001 inch in the Type-316 clad fuel pins. Figure 35 illustrates these differences for Type-304L clad F3B-9 and Type-316 clad F3B-3. The peaks and valleys are most apparent in the Type-304L clad pins, but they are also visible in those pins clad in Type 316. The proposed explanation is that these variations result when the cladding moves outward by irradiation induced metal swelling and thermal expansion to interact with its own wire wrap and the wire wrap of an adjacent pin. Figure 36 schematically illustrates this mechanism by showing an unencapsulated wire wrapped fuel pin which is being deformed into oval-shaped cross sections by wire-wrap-clad interactions. As was the case in the F3A fuel pins, this pin is wrapped with a six-inch pitch. The location of the wire wrap attached to the illustrated pin is shown on the cross sections at each axial location as an open circle. The black circles represent wire wraps belonging to the six surrounding pins which make contact with the subject pin at the given axial locations. When each fuel pin is wrapped on a six-inch pitch, point contacts between the wires of adjacent pins and the subject pin occur every inch axially along the pin. It is at each of these locations that the pin is deformed into an oval cross-section when the uniform diametral expansion of the pin is restricted by the two wire wraps, which are in turn restricted by the fuel pins to which they are attached.

The resultant axial diametral profile produced by this mechanism is shown schematically in Figure 36. Diameter measurements along two planes which are at relative 90-degree orientations yield sinusoidal-type waves which are 90 degrees out of phase. The diametral increase which is measured at a valley indicates approximately the amount of diametral increase which occurred before the wire wrap's resistance to further expansion became appreciable. Further deformation beyond this point is indicated by the diameter increase measured at the peak on the plane which is 90 degrees from the valley. It is important not to confuse these diameter increases measured at peaks and valleys on the profilometer trace with uniform diametral increases of the entire pin cross section, since the former represent localized deformations along specific directions.

The actual profilometer traces, two of which are shown in Figure 35, show the largest diameter increases and most pronounced occurrences of oval cross sections at fuel pin axial locations of about six to nine inches above the bottom of the core. These locations correspond with the regions of highest metal swelling contributions to the pin diameter increases.

Because it was shown that Type-304L clad fuel pins underwent more swelling than the Type-316 clad fuel pins, it is reasonable to expect greater local ovality in Type 304L by the operation of this proposed mechanism for wire-wrap fuel pin interactions. These larger overall circumferential diametral increases of the Type-304L clad pins (due to swelling) yield additionally larger peak diametral increases when the restraint of the wire wraps leads to oval-shaped cross sections. Since the Type-316 clad fuel pins underwent less metal swelling, as deduced from the length increases, they undergo less ovality due to wire wrap-clad interactions.

The occurrence of oval cross sections has not been observed in previously examined encapsulated wire-wrapped fuel pins, even though they operated to comparable^{2,3,4} and, in many cases, much higher burnups than the subject F3A fuel pins. Wire wrap-clad interactions which were similar to those observed in the F3A fuel pins, however, have been seen in the ANL unencapsulated fuel pins which operated to comparable burnups⁵ in the same EBR-II

Figure 34. Schematic Reconstruction of Various Pin-Swelling Components Consistent with F3-A Series Observations and Assuming Type 316 to be Always Stronger than Type 304L.

Figure 35. Diameter Changes for a 304L and a 316 Clad Fuel Pin

Figure 36. Schematic Reproduction of Effects of Wire Wrap on Pin Ovality

subassembly as the F3A pins. Oval-shaped cross sections have not been found in encapsulated pins. This behavior can be predicted from the mechanism of wire wrap fuel pin interactions which has been proposed for the F3A fuel pins. The type of interaction between two wires and a fuel pin, as is shown in Figure 36, cannot occur in an encapsulated fuel pin which has no section with more than one wire between any pin and its capsule. It might be instructive, however, to examine some irradiated encapsulated pins for helical distributions of ovality and bow since, by the mechanism outlined for ovality, interaction between pin, wire and capsule would be expected to bow the pin away from the wire and to bow the capsule in the opposite direction. These effects could well be too small to measure, however, since the encapsulated system is elastically more flexible than an unencapsulated array.

6.2 FUEL-CLADDING GAP

The microsections taken near the peak flux regions in pins F3B-2, -5, and -7 showed some separation between the fuel and the cladding (Figure 11). No such space was observed in pins F3B-1, -3, and -10. (F3B-3 and -10 operated at higher linear powers than any of the other pins, and F3B-1 had the greatest fuel density.) All six of the sectioned pins exhibited some separation between the fuel and the cladding near the top of the fuel column as shown in Figure 37. It is very doubtful, however, that there was any void space between the fuel and cladding before sectioning. If such void space had existed, it would be expected to have been filled with the hysol mounting resin used to vacuum impregnate the specimens. Since there was, in general, no hysol at this location, it is probable that the space between fuel and cladding contained either very soft or very reactive fission product material, which was lost during specimen preparation. The fact that central sections of the two highest power and the highest fuel density pins had fuel pressed against the cladding, with no intermediate fission product layers, indicates that the combination of thermal expansion and fuel and cladding swelling may have been sufficient to force these fission product layers in axial directions away from the peak flux region. The indication that the other pins contained fission product layers between the cladding and fuel, in all axial locations, suggests that the fuel cladding mechanical interaction for these irradiations involved interfacial pressures comparable to the flow stresses for the fission product phases. These phases apparently contain mostly Cs, Te, Mo, and their oxides which are expected to be very weak at the 700 to 1100°F nominal operating temperatures. Thus, only minimum fuel-cladding mechanical interaction seems to have occurred. Further evidence suggesting only minor interaction is the much greater pin swelling with Type 304L than with Type-316 stainless which implies an effect due to cladding rather than one caused by the fuel.

6.3 FUEL CONTAMINATION

Because of the excessive amount of intergranular attack observed in these pins, a review of the fuel impurities was undertaken to establish whether any specific impurity would be related to the cladding attack.

Fluorine and chlorine analyses were performed on one batch (B233) of the F3A fuel. Results were two and less than one ppm, respectively, Table A-26. A few (e.g., 5 out of 50-65) pellets in F3B-1, -3, -7, and -10 were suspected of having been contaminated with oil. These were cleaned in acetone and thoroughly dried before loading. It is conceivable, however, that traces of carbon, silicon or halogen containing compounds could have been introduced in this manner. It is not obvious what effect, if any, such contamination could have on the cladding performance. In pin F3B-2, it was suspected that "traces of argon" were present in the helium atmosphere used during final closure by welding. In fact, gas chromatographic analyses for pins F3B-2 and -7 suggested a nine percent argon content in the fill gas and twelve percent for F3B-1 and -4 (Table 7). No argon was found, however, in the most seriously attacked pin: F3B-3. Argon can be converted to Cl^{37} by an n, α reaction of Ar^{40} followed by β decay of the resulting S^{37} to stable Cl^{37} . If the argon contamination amounted to ten percent (0.1 atmosphere partial pressure) in the helium-filled space of the pin, and if it were completely converted to chlorine which was entirely taken up by the fueled length of the cladding, then the resulting chlorine concentration in the cladding would be 82 ppm. Chlorine can be extremely potent in promoting stress corrosion cracking (which often is intergranular in nature), and such a level could possibly account for the observed corrosion. Given the facts, however, that much of the argon would not be converted, and that a significant porportion of the resulting chlorine should be absorbed in the fuel or combined with cesium, then the possibility of chlorine induced stress corrosion resulting from argon contamination seems somewhat remote, especially since the most seriously corroded pin was not contaminated with argon.

The high carbon content of the fuel (430 and 1120 ppm in the two batches used) may have had an effect on the fuel-cladding chemical interaction. An historical study of the effect of carbon in the fuel is now underway. Preliminary results are not inconsistent with the possibility that high carbon in the fuel may contribute to cladding attack. If carbon is important, then some rethinking of the theory for chemical attack by mixed oxide fuel will be required. The

Figure 37. Fuel Pin Structure Near Tops of Fuel Columns - 8X

usually accepted theory holds that in low carbon fuel there is sufficient carbon available (10 to 20 ppm) to provide effectively unlimited oxygen transport via the CO/CO₂ cycle.^{1,2} Substantially greater carbon content should not, by theory, enhance oxygen transport and thereby contribute further to cladding attack. Thus, the role of carbon is probably not limited to its effect on the radial distribution of oxygen. The interaction between the oxides of carbon and the cladding and fission products is a more likely possibility.

7. CONCLUSIONS

This investigation of unencapsulated pins irradiated to about five atomic percent burnup at 16 kW/ft revealed anomalously large amounts of fuel-fission product-cladding chemical interaction. Intergranular penetration of as much as 0.009 inch was observed at a calculated temperature of 1127°F. Experimental burnup measurements and Kr⁸⁵ analysis suggest that cladding temperatures may have been as high as 1175°F for part of the irradiation. The high carbon content of the fuel (420 to 1120 ppm) is considered to be a likely contributor (other than the high temperature) to the excessive cladding deterioration in this experiment. The larger than usual pin diameter (0.290 inch) may also have been a factor.

Fuel fabrication parameters did not obviously affect the degree of cladding attack. The variables studied included cladding type (Types-304L and -316 stainless steel), fuel O/M (1.98 and 2.00), and fuel density (84 to 95% pellets, 81 to 88% smear).

Fission product constituents involved in the cladding deterioration included cesium, molybdenum, and possibly tellurium. Substantial oxygen concentrations were found in the fuel-cladding reaction layer and in penetrated grain boundary regions of the cladding.

The Type-304L clad pins exhibited about three times as much diametral swelling as did Type-316 clad pins. Most of the swelling in Type-316 pins occurred early in life. The maximum total diametral increase was 1.5%.

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Manager—Advanced Development Activity General Electric Company Knolls Atomic Power Laboratory P. O. Box 1072 Schenectady, New York 12301	1	Irradiation Coordinator EBR-II Project Argonne National Laboratory P. O. Box 2528 Idaho Falls, Idaho 83401	1
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Laboratory Assistant Director Gulf General Atomic Incorporated P. O. Box 608 San Diego, California 92112	1	Technical Director, FFTF Project Hanford Engineering Development Laboratory P. O. Box 1970 Richland, Washington 99352	1

U.S. Atomic Energy Commission
Region II - Division of Compliance
Suite 818
230 Peach Tree Street, N. W.
Atlanta, Georgia 30303

Dr. Knox M. Broom, Jr.
Nuclear Specialist
Middle South Services, Inc.
P.O. Box 61000
New Orleans, La.

1 Assistant Director of Pacific Northwest Programs, RDT 1
U.S. Atomic Energy Commission
P.O. Box 550
Richland, Washington 99352

1 Technical Director, FFTF Project 1
Hanford Engineering Development Laboratory
P.O. Box 1970
Richland, Washington 99352

APPENDIX A

**DATA RETRIEVAL SYSTEM (BROADLOG) PRINTOUT FOR PIN PARAMETERS,
PELLET-BY-PELLET FUEL LINEUP, FUEL CHEMICAL ANALYSIS DATA
AND COMPUTED TEMPERATURE DISTRIBUTIONS**

TABLE A-1

TEST DESCRIPTION

THE PURPOSE OF THE GROUP F3A EXPERIMENT IS TO ESTABLISH THE BEHAVIOR OF PURE MIXED OXIDE FUEL PINS CLAD IN 304L AND 316 STAINLESS STEEL TUBING IN FLOWING SODIUM. THE IRRADIATION COMPARES THE ABILITY OF SOLID AND ANNULAR PELLETS OF TWO STOICHIOMETRIES TO ACCOMMODATE BURNUP INDUCED FUEL VOLUME INCREASES. IN ADDITION, VARIATIONS IN THE FUEL-CLAD GAP SIZES WILL PROVIDE INFORMATION ON THE EFFECT OF VOID VOLUME WITHIN THE PIN TO ACCOMMODATE FUEL SWELLING. THE DIAMETER OF THE FUEL PINS IN THIS TEST IS .290 INCHES. THIS IS A HIGH POWER TEST (15-18 KW/FT) WITH A TARGET BURNUP OF 100,000 MWD/TE.

GROUP F3A WAS REMOVED FROM EBR-II AND GIVEN AN INTERIM EXAMINATION AT 31,500 MWD/TE BURNUP.

NOTE:

THE HOLE SIZE FOR THE ANNULAR PELLETS WAS APPROXIMATELY 44 MILS.

FUEL PINS F3B-1 THRU F3B-16 WERE MADE BY FUEL PIN DRAWING NO. 886D598, REV.2.

TABLE A-2
FUEL PARAMETERS

P I J	TYPE	FORM	FUEL WEIGHT GRAMS	FUEL LENGTH CMES	COMPOSITIO. %PuO ₂	ENRICHMENT %U235	THEORETICAL %U235	SMOOTHED %U235	O/M	DIAMETER (PELLET) INCHES	CENTER HOLE INCHES	DIAMETRAL GAP MILS
F3B1	AP	CPT	104.28	13.481	24.90=24.90	92.40=92.40	93.19=96.25	88.35	1.966-1.980	.2427-.2442	.044-.044	4.2=5.7
F3B2	SP	CPT	103.59	13.531	24.50=24.50	92.60=92.60	88.96=91.84	87.56	1.976-1.981	.2435-.2443	.044	3.9=4.9
F3B3	AP	CPT	103.02	13.477	24.90=24.90	92.40=92.40	93.10=93.96	87.54	1.999-2.001	.2437-.2444	.044-.044	3.7=4.6
F3B4	SP	CPT	103.74	13.515	24.50=24.50	92.60=92.60	89.02=92.61	87.93	1.999-2.000	.2420-.2444	.044	3.8=6.4
F3B5	SP	CPT	97.58	13.479	24.50=24.50	92.60=92.60	84.44=87.10	82.87	1.977-1.983	.2429-.2442	.	4.0=5.5
F3B6	SP	CPT	95.72	13.502	24.50=24.50	92.60=92.60	83.25=84.84	81.13	1.999-1.999	.2422-.2444	.	3.8=6.2
F3B7	AP	CPT	103.99	13.508	24.90=24.90	92.40=92.40	92.79=96.94	86.48	1.966-1.980	.2428-.2454	.044-.044	4.8=8.3
F3B8	SP	CPT	103.60	13.506	24.50=24.50	92.60=92.60	88.38=91.88	86.08	1.979-1.983	.2440-.2459	.044	4.6=7.2
F3B9	AP	CPT	102.96	13.479	24.90=24.90	92.40=92.40	91.53=94.35	85.64	1.999-2.000	.2434-.2460	.044-.044	4.6=7.9
F3B10	SP	CPT	103.61	13.511	24.50=24.90	92.40=92.50	88.81=92.68	86.10	1.999-2.000	.2430-.2460	.044	4.4=7.9
F3B11	SP	CPT	97.94	13.500	24.50=24.50	92.60=92.60	84.69=86.97	81.45	1.976-1.979	.2432-.2451	.	5.3=7.9
F3B12	AP	CPT	103.85	13.477	24.90=24.90	92.40=92.40	93.32=95.52	87.88	1.975-1.980	.2430-.2448	.044-.044	4.0=5.7
F3B13	SP	CPT	102.85	13.491	24.50=24.50	92.60=92.60	89.03=91.20	87.26	1.980-1.983	.2438-.2444	.	3.6=4.7
F3B14	AP	CPT	103.81	13.496	24.90=24.90	92.40=92.40	91.64=93.98	87.26	1.999-2.000	.2433-.2444	.044-.044	3.8=5.1
F3B15	SP	CPT	101.78	13.503	24.90=24.90	92.40=92.40	88.50=91.58	86.25	1.999-2.000	.2430-.2443	.044	3.9=5.3
F3B16	SP	CPT	99.18	13.469	24.50=24.50	92.60=92.60	83.50=86.72	82.65	1.977-1.983	.2430-.2444	.	3.9=5.4

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TABLE A-3
BLANKET AND INSULATOR PARAMETERS

P I N	TYPE	B L A N K E T					I N S U L A T O R						
		ENRICHMENT % U235	O/M	DENSITY % TD	DIAMETER INCHES	LENGTH INCHES	WEIGHT GRAMS	ENRICHMENT % U235	O/M	DENSITY % TD	DIAMETER INCHES	LENGTH INCHES	WEIGHT GRAMS
*****	****	*****	*****	*****	*****	*****	*****	****	*****	*****	*****	*****	*****
F3B1	SP	0.77=0.77	2.000	95.7=96.1 95.91 .2459	.2458=.2460	2.489	20.343	SP	0.77=0.77	95.4=96.7 96.09 .2459	.2458=.2460	2.487	20.372
F3B2	SP	0.77=0.77	2.000	95.3=96.7 96.04 .2458	.2456=.2460	2.485	20.327	SP	0.77=0.77	95.0=96.9 95.96 .2458	.2454=.2459	2.480	20.263
F3B3	SP	0.77=0.77	2.000	95.9=96.2 96.04 .2457	.2455=.2459	2.484	20.299	SP	0.77=0.77	95.9=96.2 96.10 .2456	.2454=.2458	2.493	20.378
F3B4	SP	0.77=0.77	2.000	95.9=96.7 96.14 .2457	.2455=.2459	2.490	20.380	SP	0.77=0.77	94.8=96.6 96.04 .2458	.2455=.2460	2.476	20.251
F3B5	SP	0.77=0.77	2.000	95.6=97.0 96.04 .2457	.2456=.2458	2.488	20.336	SP	0.77=0.77	94.7=96.7 96.12 .2457	.2455=.2459	2.490	20.370
F3B6	SP	0.77=0.77	2.000	95.7=96.4 96.10 .2458	.2455=.2460	2.481	20.310	SP	0.77=0.77	95.1=96.6 95.94 .2458	.2456=.2460	2.485	20.306
F3B7	SP	0.77=0.77	2.000	95.1=97.2 96.11 .2457	.2454=.2459	2.478	20.273	SP	0.77=0.77	95.4=96.5 95.94 .2458	.2457=.2460	2.494	20.389
F3B8	SP	0.77=0.77	2.000	93.9=96.9 95.94 .2458	.2457=.2460	2.479	20.263	SP	0.77=0.77	94.0=96.8 95.93 .2458	.2457=.2459	2.483	20.291
F3B9	SP	0.77=0.77	2.000	95.2=97.0 96.11 .2457	.2455=.2459	2.485	20.327	SP	0.77=0.77	95.2=96.8 96.11 .2457	.2455=.2460	2.481	20.290
F3B10	SP	0.77=0.77	2.000	95.4=96.8 95.99 .2458	.2456=.2459	2.486	20.326	SP	0.77=0.77	94.9=97.2 96.01 .2457	.2454=.2459	2.479	20.250
F3B11	SP	0.77=0.77	2.000	95.9=96.7 96.09 .2458	.2456=.2459	2.490	20.376	SP	0.77=0.77	95.5=96.9 95.96 .2458	.2455=.2459	2.484	20.296
F3B12	SP	0.77=0.77	2.000	96.0=96.1 96.09 .2457	.2454=.2459	2.489	20.353	SP	0.77=0.77	96.0=96.1 96.09 .2458	.2456=.2460	2.497	20.432
F3B13	SP	0.77=0.77	2.000	95.8=96.2 96.05 .2457	.2456=.2459	2.492	20.377	SP	0.77=0.77	96.1=96.3 96.19 .2457	.2455=.2459	2.491	20.381
F3B14	SP	0.77=0.77	2.000	95.2=96.6 96.11 .2458	.2455=.2460	2.487	20.359	SP	0.77=0.77	94.7=96.7 96.08 .2457	.2454=.2460	2.489	20.359
F3B15	SP	0.77=0.77	2.000	93.3=97.2 95.89 .2459	.2457=.2460	2.471	20.198	SP	0.77=0.77	95.2=96.2 95.79 .2459	.2458=.2459	2.481	20.255
F3B16	SP	0.77=0.77	2.000	96.0=96.1 96.05 .2459	.2457=.2460	2.497	20.459	SP	0.77=0.77	95.9=96.1 96.04 .2458	.2456=.2460	2.491	20.380

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TABLE A-4
CLADDING

P I N	TYPE	ID INCHES	WALL THICKNESS INCHES	ID INCHES	CLAD COND.	TURE NUMBER	P.O. NUMBER	HEAT NUMBER	CERT. NUMBER	FAB. TECH	ASTM GRAIN SIZE	O/A PIN LENGTH INCHES
*****	****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****
F3B1	316	.2483-.2484	.0208-.0212	.2899-.2907	ANNB	D070	M0358G	46533	133776	WD	5	60.6204
F3B2	316	.2482-.2484	.0209-.0213	.2901-.2908	ANNB	D064	M0358G	46533	133776	WD	5	60.6224
F3B3	316	.2481-.2483	.0210-.0214	.2903-.2908	ANNB	D069	M0358G	46533	133776	WD	5	60.6244
F3B4	316	.2482-.2484	.0210-.0214	.2903-.2909	ANNB	D066	M0358G	46533	133776	WD	5	60.6174
F3B5	316	.2482-.2484	.0209-.0214	.2901-.2910	ANNB	D075	M0358G	46533	133776	WD	5	60.6224
F3B6	316	.2482-.2484	.0203-.0208	.2890-.2897	ANNB	D076	M0358G	46533	133776	WD		60.6164
F3B7	304L	.2502-.2511	.0192-.0199	.2895-.2899	ANN	J001	NAVAL	84n505	16282	WD		60.6104
F3B8	304L	.2503-.2522	.0192-.0199	.2895-.2900	ANN	J002	NAVAL	84n505	16282	WD		60.6134
F3B9	304L	.2506-.2513	.0193-.0198	.2898-.2902	ANN	J005	NAVAL	84n505	16282	WD		60.6164
F3B10	304L	.2504-.2509	.0195-.0199	.2896-.2902	ANN	J004	NAVAL	84n505	16282	WD		60.6254
F3B11	304L	.2504-.2511	.0197-.0202	.2904-.2908	ANN	J006	NAVAL	84n505	16282	WD		60.6164
F3B12	316	.2483-.2487	.0207-.0215	.2900-.2913	ANNB	D057	M0358G	46533	133776	WD	5	60.6134
F3B13	316	.2483-.2485	.0206-.0214	.2896-.2907	ANNB	D074	M0358G	46533	133776	WD	5	60.6154
F3B14	316	.2482-.2484	.0208-.0213	.2900-.2908	ANNB	D077	M0358G	46533	133776	WD	5	60.6184
F3B15	316	.2482-.2483	.0209-.0213	.2900-.2908	ANNB	D079	M0358G	46533	133776	WD	5	60.6214
F3B16	316	.2483-.2484	.0209-.0213	.2902-.2908	ANNB	D058	M0358G	46533	133776	WD	5	60.6144

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TABLE A-5
END PLUGS

***** BOTTOM END PLUG *****						***** TOP END PLUG *****					
P.O. NUMBER	TYPE	P.O. NUMBER	HEAT NUMBER	DIA IN.	INSERT LGTH	P.O. NUMBER	TYPE	P.O. NUMBER	HEAT NUMBER	DIA IN.	INSERT LGTH
F3B1	304L	W9555	69844			304L	W9555	69844	.2470	17.000	
F3B2	304L	W9555	69844			304L	W9555	69844	.2470	17.000	
F3B3	304L	W9555	69844			304L	W9555	69844	.2470	17.000	
F3B4	304L	W9555	69844			304L	W9555	69844	.2470	17.000	
F3B5	304L	W9555	69844			304L	W9555	69844	.2470	17.000	
F3B6	304L	W9555	69844			304L	W9555	69844	.2470	17.000	
F3B7	304L	W9555	69844			304L	W9555	69844	.2487	17.000	
F3B8	304L	W9555	69844			304L	W9555	69844	.2485	16.500	
F3B9	304L	W9555	69844			304L	W9555	69844	.2482	17.000	
F3B10	304L	W9555	69844			304L	W9555	69844	.2488	16.495	
F3B11	304L	W9555	69844			304L	W9555	69844	.2485	16.492	
F3B12	304L	71464	035015			304L	71464	035015	.2460	17.027	
F3B13	304L	71464	035015			304L	71464	035015	.2470	17.001	
F3B14	304L	71464	035015			304L	71464	035015	.2465	17.011	
F3B15	304L	71464	035015			304L	71464	035015	.2460	17.017	
F3B16	304L	71464	035015			304L	71464	035015	.2460	17.015	

TABLE A-6
PIN SPACING

P I N	SPACER TYPE	MATERIAL	HEAT NUMBER	OD INCHES	PITCH	TENSION
*****	*****	*****	*****	*****	*****	*****
F3B1	WIRE	314		.0565	6.00	
F3B2	WIRE	314		.0565	6.00	
F3B3	WIRE	314		.0565	6.00	
F3B4	WIRE	314		.0565	6.00	
F3B5	WIRE	314		.0565	6.00	
F3B6	WIRE	314		.0565	6.00	
F3B7	WIRE	314		.0565	6.00	
F3B8	WIRE	314		.0565	6.00	
F3B9	WIRE	314		.0565	6.00	
F3B10	WIRE	314		.0565	6.00	
F3B11	WIRE	314		.0565	6.00	
F3B12	WIRE	314		.0565	6.00	
F3B13	WIRE	314		.0565	6.00	
F3B14	WIRE	314		.0565	6.00	
F3B15	WIRE	314		.0565	6.00	
F3B16	WIRE	314		.0565	6.00	

TABLE A-7
MISCELLANEOUS

P I N	TYPE OF AXIAL RESTRAINT	BURST SAMPLE NUMBER	AIR GAUGE NUMBER	PROFILE TRACE NUMBER	MET, NUMBER	***** FUEL BATCH NUMBERS UTILIZED *****
*****	*****	*****	*****	*****	*****	*****
F3B1	SPRING	NAVAIL	D070	F3B1	D070	B237
F3B2	SPRING	NAVAIL	D064	F3B2	D064	B233
F3B3	SPRING	NAVAIL	D069	F3B3	D069	B237
F3B4	SPRING	NAVAIL	D066	F3B4	D066	B233
F3B5	SPRING	NAVAIL	D075	F3B5	D075	B233
F3B6	SPRING	NAVAIL	D076	F3B6	D076	B233
F3B7	SPRING	NAVAIL	J001	F3B7	J001	B237
F3B8	SPRING	NAVAIL	J002	F3B8	J002	B233
F3B9	SPRING	NAVAIL	J005	F3B9	J005	B237
F3B10	SPRING	NAVAIL	J004	F3B10	J004	B233
F3B11	SPRING	NAVAIL	J006	F3B11	J006	B233
F3B12	SPRING	NAVAIL	D057	F3B12	D057	B237
F3B13	SPRING	NAVAIL	D074	F3B13	D074	B233
F3B14	SPRING	NAVAIL	D077	F3B14	D077	B237
F3B15	SPRING	NAVAIL	D079	F3B15	D079	B237
F3B16	SPRING	NAVAIL	D058	F3B16	D058	B233

B237

TABLE A-8
 PELLET LINEUP FOR PIN F3B-1

PELLET NO.	DIST. FROM BOTTOM OF PIN TO TOP OF THIS PELLET (INCHES)	DIST. FROM BOTTOM OF FUEL TO TOP OF THIS PELLET (INCHES)	PELLET DIAMETER (INCHES)	PELLET LENGTH (INCHES)	PELLET WEIGHT (GRAMS)	PELLET DENSITY (GMS/CC)	PELLET DENSITY (X.T.D.)	PELLET DENSITY SMEARED	PELLET O/M	BATCH NO.	PELLET NUMBER IN BATCH
*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****
1	1.1374		.2458	0.4974	4.0990	10.6033	96.75	94.81	2.000	U51	
2	1.6348		.2460	0.4974	4.0650	10.4982	95.79	94.03	2.000	U51	
3	2.1322		.2458	0.4974	4.0820	10.5593	96.35	94.42	2.000	U51	
4	2.6296		.2460	0.4974	4.0810	10.5395	96.17	94.40	2.000	U51	
5	3.1270		.2459	0.4974	4.0450	10.4551	95.40	90.57	2.000	U51	
6	3.3435	0.2165	.2435	0.2165	1.6920	10.5924	96.25	89.54	1.980	8237	89
7	3.5610	0.4340	.2438	0.2175	1.6680	10.3677	94.21	87.87	1.980	8237	90
8	3.7782	0.6512	.2438	0.2172	1.6830	10.4754	95.19	88.78	1.980	8237	91
9	4.0004	0.8734	.2431	0.2222	1.7070	10.4476	94.94	88.02	1.980	8237	92
10	4.2163	1.0893	.2438	0.2159	1.6670	10.4382	94.85	88.47	1.980	8237	93
11	4.4343	1.3073	.2439	0.2180	1.6830	10.4281	94.76	88.46	1.980	8237	94
12	4.6521	1.5251	.2434	0.2178	1.6880	10.5132	95.53	89.80	1.980	8237	95
13	4.8797	1.7527	.2438	0.2276	1.7540	10.4184	94.67	88.30	1.980	8237	96
14	5.1029	1.9759	.2439	0.2232	1.7240	10.4332	94.81	88.50	1.980	8237	97
15	5.3291	2.2021	.2432	0.2262	1.7400	10.4523	94.98	88.14	1.980	8237	98
16	5.5506	2.4236	.2441	0.2215	1.7180	10.4590	95.04	88.87	1.980	8237	99
17	5.7760	2.6490	.2442	0.2254	1.7420	10.4128	94.62	88.55	1.980	8237	100
18	5.9961	2.8691	.2441	0.2201	1.6950	10.3846	94.36	88.24	1.980	8237	101
19	6.2186	3.0916	.2440	0.2225	1.7250	10.4633	95.08	88.63	1.980	8237	102
20	6.4405	3.3135	.2436	0.2219	1.7150	10.4662	95.11	88.55	1.980	8237	103
21	6.6630	3.5360	.2438	0.2225	1.7180	10.4385	94.85	88.47	1.980	8237	104
22	6.8814	3.7544	.2432	0.2184	1.6850	10.4835	95.26	88.40	1.980	8237	105
23	7.0943	3.9673	.2438	0.2129	1.6450	10.4456	94.92	88.53	1.980	8237	106
24	7.3151	4.1881	.2439	0.2208	1.7100	10.4610	95.06	88.73	1.980	8237	107
25	7.5391	4.4081	.2434	0.2200	1.6950	10.4512	94.97	88.28	1.980	8237	108
26	7.7545	4.6275	.2435	0.2194	1.6900	10.4400	94.87	88.26	1.980	8237	109
27	7.9746	4.8476	.2436	0.2201	1.7000	10.4595	95.04	88.50	1.980	8237	110
28	8.1941	5.0671	.2433	0.2195	1.6920	10.4654	95.10	88.32	1.980	8237	111
29	8.4114	5.2844	.2434	0.2173	1.6840	10.5124	95.53	88.79	1.980	8237	112
30	8.6304	5.5034	.2434	0.2190	1.6880	10.4556	95.01	88.31	1.980	8237	113
31	8.8523	5.7253	.2434	0.2219	1.7050	10.4228	94.71	88.04	1.980	8237	114
32	9.0722	5.9452	.2435	0.2159	1.7010	10.4241	95.27	88.63	1.979	8237	115
33	9.2912	6.1642	.2435	0.2190	1.6920	10.4714	95.15	88.52	1.979	8237	116
34	9.5108	6.3838	.2436	0.2156	1.6960	10.4586	95.04	88.49	1.979	8237	117
35	9.7322	6.6052	.2436	0.2214	1.7110	10.4654	95.10	88.55	1.979	8237	118
36	9.9506	6.8236	.2435	0.2184	1.6860	10.4630	95.06	88.45	1.979	8237	119
37	10.1696	7.0426	.2438	0.2190	1.6950	10.4633	95.08	88.66	1.979	8237	120
38	10.3890	7.2620	.2434	0.2194	1.6930	10.4674	95.12	88.41	1.979	8237	121
39	10.6073	7.4803	.2433	0.2183	1.6830	10.4669	95.11	88.33	1.979	8237	122
40	10.8283	7.7013	.2432	0.2210	1.7040	10.4769	95.20	88.34	1.979	8237	123

TABLE A-8 continued (F3B-1)

PELLET NO.	DIST. FROM BOTTOM OF PIN TO TOP OF THIS PELLET (INCHES)	DIST. FROM BOTTOM OF FUEL TO TOP OF THIS PELLET (INCHES)	PELLET DIAMETER (INCHES)	PELLET LENGTH (INCHES)	PELLET WEIGHT (GRAMS)	PELLET DENSITY (GMS/CC)	PELLET DENSITY (X7, L.)	PELLET DENSITY SMEARED	PELLET O/M	BATCH NO.	PELLET NUMBER IN BATCH
*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****
41	11.0493	7.9223	.2438	0.2210	1.7030	10.4176	94.66	88.29	1.979	8237	38
42	11.2688	8.1418	.2432	0.2195	1.6850	10.4309	94.79	87.95	1.979	8237	31
43	11.4891	8.3621	.2436	0.2203	1.7000	10.4500	94.96	88.42	1.979	8237	28
44	11.7082	8.5812	.2438	0.2191	1.6800	10.3660	94.20	87.85	1.979	8237	27
45	11.9258	8.7988	.2442	0.2176	1.6800	10.4022	94.52	88.46	1.979	8237	26
46	12.1364	9.0094	.2437	0.2106	1.6260	10.4466	94.93	88.49	1.979	8237	25
47	12.3251	9.1981	.2436	0.1887	1.4560	10.4489	94.95	88.41	1.980	8237	125
48	12.5386	9.4116	.2427	0.2135	1.6320	10.4310	94.79	87.56	1.966	8237	9
49	12.7475	9.6205	.2439	0.2089	1.5860	10.2551	93.19	86.99	1.966	8237	21
50	12.9572	9.8302	.2432	0.2097	1.5900	10.3028	93.62	86.87	1.966	8237	22
51	13.1582	10.0312	.2439	0.2010	1.5380	10.3256	93.92	87.67	1.966	8237	23
52	13.3708	10.2438	.2436	0.2126	1.6420	10.4590	95.04	88.49	1.979	8237	44
53	13.5867	10.4597	.2434	0.2159	1.6670	10.4737	95.17	88.47	1.979	8237	45
54	13.8007	10.6737	.2434	0.2140	1.6530	10.4780	95.21	88.50	1.979	8237	46
55	14.0124	10.8854	.2433	0.2117	1.6310	10.4597	95.05	88.27	1.979	8237	47
56	14.2260	11.0990	.2434	0.2136	1.6430	10.4341	94.81	88.13	1.979	8237	48
57	14.4401	11.3131	.2435	0.2141	1.6530	10.4642	95.09	88.46	1.979	8237	49
58	14.6543	11.5273	.2434	0.2142	1.6490	10.4429	94.89	88.21	1.979	8237	50
59	14.8623	11.7353	.2438	0.2080	1.6120	10.4772	95.21	88.80	1.979	8237	51
60	15.0742	11.9472	.2435	0.2119	1.6390	10.4833	95.26	88.62	1.979	8237	52
61	15.2834	12.1564	.2435	0.2092	1.6170	10.4761	95.20	88.56	1.979	8237	53
62	15.4954	12.3684	.2434	0.2120	1.6350	10.4617	95.06	88.36	1.979	8237	54
63	15.7236	12.5966	.2434	0.2262	1.7600	10.4620	95.07	88.37	1.979	8237	41
64	15.9339	12.8069	.2434	0.2103	1.6260	10.4682	95.31	88.59	1.979	8237	42
65	16.1649	13.0379	.2434	0.2310	1.7720	10.4057	94.56	87.89	1.977	8237	165
66	16.4028	13.2758	.2436	0.2379	1.8280	10.4055	94.55	88.04	1.977	8237	164
67	16.6505	13.5235	.2431	0.2477	1.9070	10.4701	95.14	88.21	1.980	8237	128
68	17.1483	14.0213	.2458	0.4978	4.0740	10.5301	96.09	94.16	2.000	U51	
69	17.6461	14.5191	.2460	0.4978	4.0770	10.5207	96.00	94.23	2.000	U51	
70	18.1439	15.0169	.2458	0.4978	4.0730	10.5275	96.06	94.14	2.000	U51	
71	18.6417	15.5147	.2458	0.4978	4.0590	10.4913	95.73	93.81	2.000	U51	
72	19.1395	16.0125	.2459	0.4978	4.0600	10.4854	95.68	93.84	2.000	U51	

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TABLE A-9
 PELLET LINEUP FOR PIN F3B-2

PELLET NO.	DIST. FROM BOTTOM OF PIN TO TOP OF THIS PELLET (INCHES)	DIST. FROM BOTTOM OF FUEL TO TOP OF THIS PELLET (INCHES)	PELLET DIAMETER (INCHES)	PELLET LENGTH (INCHES)	PELLET WEIGHT (GRAMS)	PELLET DENSITY (GMS/CC)	PELLET DENSITY (MT./D.)	PELLET DENSITY SMEARED	PELLET O/M	BATCH NO.	PELLET NUMBER IN BATCH
*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****
1	1.1360		2459	0.4960	4.0370	10.4638	95.48	93.64	2.000	U51	
2	1.6320		2454	0.4960	3.9990	10.4076	94.97	92.76	2.000	U51	
3	2.1280		2459	0.4960	4.0700	10.5494	96.26	94.41	2.000	U51	
4	2.6240		2458	0.4960	4.0930	10.6176	96.88	94.94	2.000	U51	
5	3.1200		2458	0.4960	4.0640	10.5424	96.20	94.27	2.000	U51	
6	3.3723	0.2523	2439	0.2523	1.9340	10.0172	91.06	87.86	1.976	B233	311
7	3.6291	0.5091	2441	0.2568	1.9720	10.0186	91.07	88.02	1.976	B233	310
8	3.8829	0.7629	2440	0.2538	1.9550	10.0579	91.43	88.29	1.976	B233	309
9	4.1370	1.0170	2440	0.2541	1.9560	10.0511	91.37	88.23	1.976	B233	308
10	4.3918	1.2718	2436	0.2548	1.9650	10.1027	91.84	88.39	1.976	B233	305
11	4.6459	1.5259	2439	0.2541	1.9540	10.0491	91.35	88.14	1.976	B233	304
12	4.9015	1.7815	2442	0.2556	1.9640	10.0166	91.06	88.07	1.976	B233	303
13	5.1770	2.0370	2439	0.2755	2.1230	10.0701	91.54	88.33	1.981	B233	450
14	5.4596	2.3396	2438	0.2826	2.1740	10.0612	91.46	88.18	1.981	B233	459
15	5.7491	2.6251	2439	0.2855	2.1640	9.9051	90.04	86.88	1.981	B233	454
16	6.0316	2.9116	2439	0.2865	2.1720	9.9070	90.06	86.90	1.981	B233	458
17	6.3186	3.1986	2437	0.2870	2.2030	10.0474	91.34	87.98	1.981	B233	452
18	6.6034	3.4834	2440	0.2848	2.1850	10.0176	91.06	87.94	1.981	B233	451
19	6.8977	3.7677	2436	0.2843	2.1750	10.0221	91.11	87.69	1.981	B233	450
20	7.1742	4.0542	2441	0.2865	2.1960	10.0001	90.91	87.86	1.981	B233	456
21	7.4584	4.3384	2439	0.2842	2.1790	10.0194	91.08	87.88	1.981	B233	457
22	7.7418	4.6218	2436	0.2834	2.1770	10.0632	91.48	88.05	1.981	B233	450
23	8.0145	4.8945	2436	0.2727	2.0790	9.9872	90.79	87.38	1.981	B233	462
24	8.3156	5.1956	2435	0.3011	2.3070	10.0455	91.32	87.82	1.981	B233	441
25	8.6022	5.4822	2436	0.2866	2.2020	10.0651	91.50	88.07	1.981	B233	448
26	8.8877	5.7677	2440	0.2855	2.1860	9.9976	90.88	87.76	1.981	B233	449
27	9.1724	6.0524	2442	0.2847	2.1900	10.0276	91.16	88.17	1.981	B233	444
28	9.4755	6.3555	2442	0.3031	2.3240	9.9952	90.86	87.88	1.981	B233	440
29	9.8003	6.6803	2440	0.3248	2.4920	10.0181	91.07	87.94	1.981	B233	439
30	10.0723	6.9523	2441	0.2720	2.0790	9.9720	90.65	87.61	1.981	B233	438
31	10.3463	7.2263	2442	0.2740	2.0990	9.9862	90.78	87.81	1.981	B233	434
32	10.6216	7.5016	2443	0.2753	2.1020	9.9451	90.41	87.52	1.981	B233	436
33	10.8974	7.7774	2439	0.2758	2.1010	9.9549	90.50	87.32	1.981	B233	435
34	11.1740	8.0540	2439	0.2766	2.1070	9.9545	90.49	87.31	1.981	B233	437
35	11.4444	8.3244	2442	0.2704	2.0750	10.0035	90.94	87.96	1.981	B233	438
36	11.7172	8.5972	2443	0.2728	2.0840	9.9583	90.45	87.56	1.981	B233	432
37	11.9893	8.8693	2443	0.2721	2.0740	9.9281	90.25	87.37	1.981	B233	431
38	12.2598	9.1398	2441	0.2705	2.0720	9.9635	90.85	87.80	1.981	B233	429
39	12.5302	9.4102	2438	0.2704	2.0740	10.0315	91.19	87.92	1.981	B233	428
40	12.8036	9.6836	2441	0.2734	2.0980	10.0116	91.01	87.96	1.981	B233	427

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TABLE A-9 continued (F3B-2)

PELLET NO.	DIST. FROM BOTTOM OF PIN TO TOP OF THIS PELLET (INCHES)	DIST. FROM BOTTOM OF FUEL TO TOP OF THIS PELLET (INCHES)	PELLET DIAMETER (INCHES)	PELLET LENGTH (INCHES)	PELLET WEIGHT (GRAMS)	PELLET DENSITY (GMS/CC)	PELLET DENSITY (XT, P.)	PELLET DENSITY SMEARED	PELLET O/M	BATCH NO.	PELLET NUMBER IN BATCH
41	13.0797	9.9597	.2438	0.2761	2.0668	9.7865	88.96	88.77	1.979	8233	413
42	13.3532	10.2332	.2441	0.2735	2.0688	9.8266	89.33	88.33	1.979	8233	418
43	13.6260	10.5060	.2440	0.2728	2.0588	9.8504	89.54	88.47	1.979	8233	407
44	13.9012	10.7812	.2438	0.2752	2.0760	9.8660	89.69	88.47	1.979	8233	408
45	14.1747	11.0547	.2441	0.2735	2.0908	9.9698	90.63	88.59	1.979	8233	403
46	14.4494	11.3294	.2440	0.2747	2.0648	9.9108	89.18	88.12	1.979	8233	409
47	14.7229	11.6029	.2436	0.2735	2.0548	9.8383	89.43	88.08	1.979	8233	404
48	14.9963	11.8763	.2441	0.2734	2.0918	9.9782	90.71	88.66	1.979	8233	406
49	15.2712	12.1512	.2442	0.2749	2.0848	9.8824	89.84	88.89	1.979	8233	402
50	15.5303	12.4103	.2443	0.2591	1.9878	9.9888	90.80	87.90	1.979	8233	368
51	15.8059	12.6859	.2438	0.2756	2.1248	10.0795	91.83	88.34	1.979	8233	385
52	16.0892	12.9492	.2442	0.2833	1.9778	9.7880	88.98	88.06	1.979	8233	344
53	16.3389	13.2139	.2442	0.2647	2.0308	9.9973	90.88	88.90	1.979	8233	388
54	16.5899	13.4699	.2441	0.2560	1.9538	9.9531	90.48	87.44	1.979	8233	382
55	16.6795	13.5595	.2440	0.0896	0.6788	9.8512	89.55	88.48	1.981	8233	386
56	17.1765	14.0565	.2460	0.4970	4.0908	10.9713	96.46	95.68	2.008	U51	
57	17.6735	14.5535	.2458	0.4970	4.0888	10.6006	96.13	95.64	2.008	U51	
58	18.1705	15.0505	.2458	0.4970	4.0298	10.4476	95.83	95.27	2.008	U51	
59	18.6675	15.5475	.2459	0.4970	4.0828	10.9592	96.35	96.50	2.008	U51	
60	19.1645	16.0445	.2459	0.4970	4.0388	10.4454	95.81	95.48	2.008	U51	

TABLE A-10
 PELLET LINEUP FOR PIN F3B-3

PELLET NO.	DIST. FROM BOTTOM OF PIN TO TOP OF THIS PELLET (INCHES)	DIST. FROM BOTTOM OF FUEL TO TOP OF THIS PELLET (INCHES)	PELLET DIAMETER (INCHES)	PELLET LENGTH (INCHES)	PELLET WEIGHT (GRAMS)	PELLET DENSITY (GMS/CC)	PELLET DENSITY (XT,D.)	PELLET DENSITY SMEARED	PELLET O/M	BATCH NO.	PELLET NUMBER IN BATCH
*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****
1	1.1367		.2457	0.4967	4.0660	10.5413	96.19	94.26	2.000	U51	
2	1.6364		.2457	0.4997	4.0930	10.5476	96.24	94.32	2.000	U51	
3	2.1356		.2456	0.4992	4.0770	10.5254	96.04	94.04	2.000	U51	
4	2.6358		.2454	0.5002	4.0720	10.5086	95.89	93.74	2.000	U51	
5	3.1329		.2456	0.4971	4.0700	10.9346	96.13	94.28	2.000	U51	
6	3.3505	0.2176	.2443	0.2176	1.6788	10.3315	93.88	88.00	2.000	B237	488
7	3.5798	0.4429	.2443	0.2253	1.7260	10.3130	93.71	87.85	2.000	B237	488
8	3.7938	0.6689	.2444	0.2180	1.6660	10.2791	93.41	87.63	2.000	B237	489
9	4.0161	0.8832	.2443	0.2223	1.6980	10.2826	93.44	87.59	2.000	B237	484
10	4.2377	1.1048	.2443	0.2216	1.6960	10.3029	93.62	87.76	2.000	B237	486
11	4.4581	1.3252	.2442	0.2204	1.6890	10.3250	93.82	87.87	2.000	B237	482
12	4.6794	1.5465	.2441	0.2213	1.6870	10.2796	93.41	87.41	2.000	B237	482
13	4.9042	1.7713	.2442	0.2248	1.7150	10.2788	93.40	87.48	2.000	B237	487
14	5.1280	1.9951	.2442	0.2238	1.7080	10.2829	93.44	87.51	2.000	B237	488
15	5.3503	2.2174	.2443	0.2223	1.6990	10.2887	93.49	87.64	2.000	B237	487
16	5.5773	2.4444	.2443	0.2270	1.7340	10.2832	93.44	87.59	2.001	B237	488
17	5.8052	2.6723	.2442	0.2279	1.7400	10.2867	93.47	87.55	2.000	B237	486
18	6.0246	2.8917	.2444	0.2194	1.6720	10.2503	93.14	87.39	2.000	B237	484
19	6.2531	3.1202	.2441	0.2285	1.7420	10.2802	93.42	87.42	2.000	B237	488
20	6.4736	3.3207	.2441	0.2085	1.5260	10.2632	93.26	87.27	2.000	B237	488
21	6.6687	3.5358	.2443	0.2151	1.6400	10.2630	93.27	87.43	2.000	B237	488
22	6.8842	3.7513	.2442	0.2155	1.6430	10.2722	93.34	87.42	2.000	B237	488
23	7.1004	3.9675	.2441	0.2162	1.6460	10.2663	93.29	87.30	2.000	B237	487
24	7.2837	4.1808	.2442	0.1833	1.3960	10.2611	93.24	87.33	2.000	B237	488
25	7.5014	4.3885	.2444	0.2177	1.6610	10.2624	93.25	87.49	2.000	B237	487
26	7.7088	4.5759	.2442	0.2074	1.5810	10.2706	93.33	87.41	2.000	B237	486
27	7.9270	4.7941	.2441	0.2182	1.6620	10.2711	93.33	87.34	2.000	B237	484
28	8.1435	5.0106	.2442	0.2165	1.6520	10.2808	93.42	87.50	2.000	B237	483
29	8.3609	5.2280	.2444	0.2174	1.6600	10.2764	93.33	87.56	2.000	B237	482
30	8.5733	5.4404	.2442	0.2124	1.6220	10.2889	93.49	87.57	2.000	B237	483
31	8.7875	5.6546	.2444	0.2142	1.6360	10.2731	93.35	87.58	2.000	B237	397
32	9.0307	5.8978	.2441	0.2432	1.8490	10.2521	93.16	87.18	2.001	B237	459
33	9.2468	6.1139	.2441	0.2161	1.6570	10.3397	93.96	87.93	2.001	B237	484
34	9.4439	6.3110	.2443	0.1971	1.5010	10.2518	93.16	87.33	2.001	B237	488
35	9.6658	6.5329	.2441	0.2219	1.6990	10.3247	93.82	87.80	2.001	B237	458
36	9.8794	6.7465	.2441	0.2136	1.6330	10.3092	93.68	87.67	2.001	B237	458
37	10.0987	6.9658	.2440	0.2193	1.6690	10.2713	93.33	87.27	2.001	B237	469
38	10.3151	7.1822	.2443	0.2164	1.6580	10.3141	93.72	87.86	2.001	B237	468
39	10.5067	7.3738	.2440	0.1916	1.4670	10.3334	93.90	87.80	2.001	B237	467
40	10.7132	7.5603	.2441	0.2065	1.5740	10.2784	93.40	87.40	2.001	B237	466

TABLE A-10 continued (F3B-3)

PELLET NO.	DIST. FROM BOTTOM OF PIN TO TOP OF THIS PELLET (INCHES)	DIST. FROM BOTTOM OF FUEL TO TOP OF THIS PELLET (INCHES)	PELLET DIAMETER (INCHES)	PELLET LENGTH (INCHES)	PELLET WEIGHT (GRAMS)	PELLET DENSITY (GMS/CC)	PELLET DENSITY (%T.D.)	PELLET DENSITY SMEARED	PELLET O/M	BATCH NO.	PELLET NUMBER IN BATCH
*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****
41	10.9562	7.8233	.2441	0.2430	1.6520	10.2772	93.39	87.39	2.001	8237	445
42	11.1888	8.0559	.2440	0.2326	1.7670	10.2526	93.16	87.11	2.001	8237	444
43	11.4029	8.2700	.2442	0.2141	1.6280	10.2450	93.10	87.19	2.001	8237	443
44	11.5871	8.4542	.2440	0.1842	1.4030	10.2796	93.41	87.34	2.001	8237	442
45	11.8017	8.6688	.2441	0.2146	1.6430	10.3240	93.81	87.79	2.001	8237	441
46	12.0272	8.8943	.2441	0.2255	1.7250	10.3153	93.73	87.72	2.001	8237	440
47	12.2461	9.1132	.2439	0.2169	1.6670	10.2865	93.47	87.32	2.001	8237	439
48	12.4631	9.3302	.2441	0.2170	1.6540	10.2782	93.40	87.40	2.001	8237	438
49	12.6880	9.5551	.2440	0.2249	1.7180	10.3096	93.68	87.59	2.001	8237	437
50	12.9100	9.7771	.2439	0.2220	1.6870	10.2645	93.27	87.14	2.001	8237	436
51	13.1242	9.9913	.2441	0.2142	1.6370	10.3055	93.65	87.63	2.001	8237	435
52	13.3401	10.2072	.2440	0.2159	1.6470	10.2955	93.55	87.48	2.001	8237	434
53	13.5626	10.4297	.2440	0.2225	1.6940	10.2752	93.37	87.30	2.001	8237	433
54	13.7848	10.6519	.2441	0.2222	1.6960	10.2925	93.53	87.52	2.001	8237	432
55	14.0008	10.8679	.2443	0.2160	1.6550	10.3145	93.73	87.86	2.000	8237	430
56	14.2216	11.0867	.2443	0.2208	1.6880	10.2915	93.52	87.66	2.000	8237	429
57	14.4516	11.3187	.2443	0.2300	1.7600	10.3013	93.61	87.75	2.000	8237	428
58	14.6711	11.5382	.2442	0.2195	1.6730	10.2691	93.32	87.40	1.999	8237	468
59	14.8837	11.7508	.2442	0.2126	1.6190	10.2602	93.23	87.32	1.999	8237	465
60	15.1044	11.9715	.2441	0.2207	1.6880	10.3136	93.72	87.70	1.999	8237	464
61	15.3262	12.1933	.2441	0.2218	1.6980	10.3233	93.81	87.79	1.999	8237	463
62	15.5468	12.4139	.2443	0.2206	1.6880	10.3098	93.60	87.74	1.999	8237	462
63	15.7548	12.6219	.2443	0.2080	1.5890	10.2841	93.45	87.60	1.999	8237	461
64	15.9657	12.8328	.2442	0.2109	1.6150	10.3174	93.75	87.81	2.001	8237	460
65	16.1906	13.0577	.2437	0.2249	1.7150	10.3178	93.76	87.44	2.001	8237	459
66	16.4058	13.2729	.2443	0.2152	1.6490	10.3153	93.73	87.87	2.001	8237	458
67	16.6267	13.4938	.2441	0.2209	1.6900	10.3165	93.75	87.73	2.001	8237	457
68	17.1233	13.9904	.2457	0.4966	4.0560	10.5175	95.97	94.05	2.000	U51	
69	17.6210	14.4861	.2457	0.4977	4.0650	10.5175	95.97	94.05	2.000	U51	
70	18.1190	14.9861	.2456	0.4980	4.0590	10.5042	95.85	93.85	2.000	U51	
71	18.6149	15.4820	.2459	0.4959	4.0670	10.5437	96.21	94.43	2.000	U51	
72	19.1107	15.9778	.2455	0.4958	4.0520	10.5412	96.19	94.11	2.000	U51	

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TABLE A-11
 PELLET LINEUP FOR PIN F3B-4

PELLET NO.	DIST. FROM BOTTOM OF PIN TO TOP OF THIS PELLET (INCHES)	DIST. FROM BOTTOM OF FUEL TO TOP OF THIS PELLET (INCHES)	PELLET DIAMETER (INCHES)	PELLET LENGTH (INCHES)	PELLET WEIGHT (GRAMS)	PELLET DENSITY (GMS/CC)	PELLET DENSITY (%T.D.)	PELLET DENSITY SMEARED	PELLET O/M	BATCH NO.	PELLET NUMBER IN BATCH
*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****
1	1.1352		.2458	0.4952	4.0000	10.3931	94.84	92.94	2.000	U51	
2	1.6304		.2455	0.4952	4.0610	10.5774	96.52	94.35	2.000	U51	
3	2.1256		.2456	0.4952	4.0660	10.5818	96.56	94.47	2.000	U51	
4	2.6208		.2460	0.4952	4.0730	10.5656	96.41	94.63	2.000	U51	
5	3.1160		.2460	0.4952	4.0510	10.5085	95.89	94.12	2.000	U51	
6	3.4080	0.2920	.2442	0.2920	2.1990	9.8171	89.24	86.32	1.999	B233	542
7	3.6950	0.5790	.2435	0.2870	2.1500	9.8218	89.28	85.87	1.999	B233	538
8	3.9352	0.8192	.2441	0.2402	1.8060	9.8093	89.17	86.16	1.999	B233	537
9	4.2148	1.0968	.2436	0.2796	2.0900	9.7923	89.02	85.68	1.999	B233	536
10	4.4918	1.3758	.2443	0.2770	2.0890	9.8230	89.30	86.44	1.999	B233	534
11	4.7661	1.6501	.2426	0.2743	2.0440	9.8425	89.47	87.41	1.999	B233	532
12	5.0727	1.9567	.2437	0.3066	2.3710	10.1223	92.02	88.64	2.000	B233	569
13	5.3712	2.2552	.2420	0.2985	2.2260	9.8988	89.98	87.48	1.999	B233	531
14	5.6791	2.5631	.2437	0.3079	2.3790	10.1136	91.94	88.56	2.000	B233	568
15	5.9870	2.8710	.2436	0.3079	2.3770	10.1134	91.94	88.49	2.000	B233	567
16	6.2940	3.1780	.2436	0.3070	2.3740	10.1302	92.09	88.64	2.000	B233	566
17	6.5921	3.4161	.2422	0.2381	1.7770	9.8903	89.91	87.54	1.999	B233	533
18	6.8422	3.7262	.2438	0.3101	2.3980	10.1137	91.94	88.64	2.000	B233	565
19	7.1472	4.0312	.2438	0.3050	2.3600	10.1199	91.99	88.69	2.000	B233	565
20	7.4551	4.3391	.2436	0.3079	2.3780	10.1176	91.97	88.53	2.000	B233	562
21	7.7640	4.6480	.2437	0.3089	2.3880	10.1190	91.99	88.61	2.000	B233	561
22	8.0538	4.9378	.2438	0.2898	2.2370	10.0956	91.77	88.48	1.999	B233	560
23	8.3604	5.2444	.2438	0.3066	2.3690	10.1055	91.86	88.56	1.999	B233	559
24	8.6477	5.5817	.2437	0.2873	2.2300	10.1599	92.36	88.97	1.999	B233	558
25	8.9487	5.8827	.2438	0.3010	2.3370	10.1544	92.31	88.99	1.999	B233	557
26	9.2485	6.1825	.2438	0.2998	2.3200	10.1209	92.00	88.70	1.999	B233	556
27	9.5445	6.4285	.2437	0.2960	2.2960	10.1531	92.30	88.91	1.999	B233	555
28	9.8415	6.7255	.2437	0.2970	2.3030	10.1498	92.27	88.88	1.999	B233	554
29	10.1448	7.0288	.2436	0.3033	2.3460	10.1329	92.11	88.66	1.999	B233	553
30	10.4391	7.3231	.2436	0.2943	2.2020	10.1578	92.34	88.88	1.999	B233	552
31	10.7471	7.6311	.2438	0.3060	2.3850	10.1275	92.06	88.76	2.000	B233	579
32	11.0559	7.9399	.2436	0.3088	2.3920	10.1475	92.25	88.79	2.000	B233	574
33	11.3648	8.2488	.2437	0.3089	2.3900	10.1274	92.06	88.68	2.000	B233	578
34	11.6733	8.5573	.2436	0.3085	2.3700	10.0640	91.49	88.06	2.000	B233	572
35	11.9812	8.8652	.2437	0.3079	2.3770	10.1051	91.86	88.49	2.000	B233	571
36	12.2893	9.1733	.2436	0.3061	2.3890	10.1578	92.34	88.88	2.000	B233	570
37	12.5972	9.4812	.2437	0.3079	2.3790	10.1136	91.94	88.56	2.000	B233	569
38	12.8713	9.7953	.2430	0.2741	2.1210	10.1871	92.61	88.69	2.000	B233	520
39	13.1411	10.0251	.2430	0.2698	2.0820	10.1591	92.35	88.45	2.000	B233	521
40	13.4036	10.2876	.2430	0.2625	2.0310	10.1859	92.59	88.68	2.000	B233	522

TABLE A-11 continued (F3B-4)

PELLET NO.	DIST. FROM BOTTOM OF PIN TO TOP OF THIS PELLET (INCHES)	DIST. FROM BOTTOM OF FUEL TO TOP OF THIS PELLET (INCHES)	PELLET DIAMETER (INCHES)	PELLET LENGTH (INCHES)	PELLET WEIGHT (GRAMS)	PELLET DENSITY (GMS/CC)	PELLET DENSITY (%T,P.)	PELLET DENSITY SMEARED	PELLET O/M	BATCH NO.	PELLET NUMBER IN BATCH
*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****
41	13.6724	10.5564	.2430	0.2668	2.0770	10.1725	92.47	89.57	2.000	8233	323
42	13.9416	10.8256	.2430	0.2692	2.0820	10.1818	92.56	89.65	2.000	8233	324
43	14.2179	11.1019	.2430	0.2763	2.1358	10.1727	92.47	89.57	2.000	8233	325
44	14.4870	11.3710	.2430	0.2691	2.0820	10.1856	92.59	89.66	2.000	8233	326
45	14.7649	11.6489	.2430	0.2779	2.1480	10.1757	92.50	89.60	2.000	8233	327
46	15.0208	11.9048	.2437	0.2559	1.9268	9.8516	89.56	86.27	2.000	8233	346
47	15.2041	12.0881	.2430	0.1833	1.4158	10.1628	92.38	88.48	2.000	8233	316
48	15.4432	12.3272	.2444	0.2391	1.8070	9.8357	89.41	86.62	2.000	8233	348
49	15.7440	12.6280	.2444	0.3008	2.2750	9.8431	89.48	86.69	2.000	8233	349
50	16.0422	12.9262	.2438	0.2982	2.2558	9.8901	89.91	86.68	2.000	8233	339
51	16.3374	13.2214	.2436	0.2952	2.2150	9.8296	89.36	86.00	2.000	8233	340
52	16.6387	13.5227	.2442	0.3013	2.2760	9.8472	89.92	86.56	2.000	8233	344
53	17.1367	14.0207	.2459	0.4980	4.0710	10.5096	95.90	94.05	2.000	U51	
54	17.6347	14.5187	.2455	0.4980	4.0620	10.5206	96.00	95.85	2.000	U51	
55	18.1327	15.0167	.2458	0.4980	4.0698	10.5130	95.93	94.01	2.000	U51	
56	18.6307	15.5147	.2459	0.4980	4.1078	10.6025	96.75	94.88	2.000	U51	
57	19.1287	16.0127	.2456	0.4980	4.0710	10.5353	96.13	94.05	2.000	U51	

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TABLE A-12
 PELLET LINEUP FOR PIN F3B-5

PELLET NO.	DIST. FROM BOTTOM OF PIN TO TOP OF THIS PELLET (INCHES)	DIST. FROM BOTTOM OF FUEL TO TOP OF THIS PELLET (INCHES)	PELLET DIAMETER (INCHES)	PELLET LENGTH (INCHES)	PELLET WEIGHT (GRAMS)	PELLET DENSITY (GMS/CC)	PELLET DENSITY (XT,D,)	PELLET DENSITY SMEARED	PELLET Q/M	BATCH NO.	PELLET NUMBER IN BATCH
1	1.1380		2455	0.4980	4.0080	10.3807	94.72	98.60	2.000	U31	
2	1.6360		2456	0.4980	4.0830	10.5663	96.42	94.33	2.000	U31	
3	2.1340		2459	0.4980	4.1068	10.5999	96.72	96.86	2.000	U31	
4	2.6320		2458	0.4980	4.0920	10.5724	96.47	94.54	2.000	U31	
5	3.1300		2457	0.4980	4.0818	10.5526	96.29	96.28	2.000	U31	
6	3.4023	0.2723	2433	0.2723	1.9430	9.3707	83.18	81.79	1.977	8233	182
7	3.6793	0.5453	2436	0.2730	1.9430	9.3237	84.76	81.58	1.977	8233	186
8	3.9479	0.8179	2435	0.2726	1.9400	9.3306	84.82	81.57	1.977	8233	188
9	4.2218	1.0918	2441	0.2739	1.9508	9.2883	84.44	81.60	1.977	8233	189
10	4.4994	1.3654	2434	0.2736	1.9478	9.3377	84.88	81.57	1.977	8233	188
11	4.7685	1.6385	2433	0.2731	1.9440	9.3481	84.98	81.59	1.977	8233	187
12	5.0365	1.9065	2436	0.2680	1.9500	9.5318	86.65	83.40	1.983	8233	189
13	5.3101	2.1801	2429	0.2736	1.9470	9.3762	85.23	81.57	1.977	8233	189
14	5.5819	2.4519	2439	0.2718	1.9480	9.3658	85.14	82.15	1.983	8233	189
15	5.8555	2.7255	2436	0.2736	1.9590	9.3798	85.27	82.07	1.978	8233	189
16	6.1262	2.9962	2439	0.2707	1.9680	9.5004	86.36	83.33	1.978	8233	182
17	6.4000	3.2700	2439	0.2738	1.9910	9.5027	86.38	83.35	1.978	8233	189
18	6.6733	3.5433	2438	0.2733	1.9868	9.5039	86.40	83.29	1.978	8233	189
19	6.9458	3.8158	2440	0.2725	1.9740	9.4587	85.98	83.03	1.978	8233	189
20	7.2169	4.0869	2439	0.2711	1.9620	9.4975	85.97	82.95	1.978	8233	189
21	7.4921	4.3621	2441	0.2752	1.9860	9.4151	85.99	82.72	1.978	8233	189
22	7.7644	4.6344	2440	0.2723	1.9720	9.4561	85.96	83.01	1.978	8233	189
23	8.0397	4.9057	2440	0.2713	1.9680	9.4717	86.10	83.15	1.978	8233	189
24	8.3066	5.1766	2441	0.2709	1.9700	9.4875	86.25	83.35	1.978	8233	189
25	8.5784	5.4484	2439	0.2718	1.9470	9.3610	85.10	82.11	1.988	8233	189
26	8.8515	5.7215	2442	0.2731	1.9850	9.4750	86.13	83.31	1.978	8233	189
27	9.1241	5.9941	2437	0.2726	1.9820	9.5169	86.21	83.34	1.983	8233	189
28	9.4249	6.2949	2439	0.3008	2.1858	9.4925	86.29	83.26	1.988	8233	206
29	9.6998	6.5688	2437	0.2739	1.9810	9.4670	86.06	82.90	1.988	8233	206
30	9.9726	6.8426	2438	0.2730	1.9800	9.4579	85.98	82.89	1.983	8233	209
31	10.1963	7.0663	2438	0.2237	1.6300	9.5298	86.63	83.52	1.983	8233	214
32	10.4829	7.3529	2441	0.2866	2.0800	9.4685	86.07	83.19	1.983	8233	206
33	10.7781	7.6481	2434	0.2952	2.1530	9.5701	87.00	83.60	1.988	8233	215
34	11.0550	7.9250	2441	0.2769	2.0130	9.4845	86.22	83.33	1.983	8233	215
35	11.3256	8.1956	2440	0.2706	1.7680	9.4962	86.32	83.36	1.983	8233	213
36	11.5665	8.4365	2439	0.2409	1.7490	9.4877	86.25	83.22	1.988	8233	213
37	11.8463	8.7163	2440	0.2798	2.0280	9.4639	86.03	83.06	1.988	8233	213
38	12.1313	9.0013	2439	0.2850	2.0730	9.5052	86.41	83.37	1.983	8233	209
39	12.4054	9.2754	2440	0.2741	2.0000	9.5274	86.61	83.63	1.983	8233	204
40	12.6788	9.5488	2440	0.2734	1.9880	9.4944	86.31	83.35	1.983	8233	203

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TABLE A-12 continued (F3B-5)

PELLET NO.	DIST. FROM BOTTOM OF PIN TO TOP OF THIS PELLET (INCHES)	DIST. FROM BOTTOM OF FUEL TO TOP OF THIS PELLET (INCHES)	PELLET DIAMETER (INCHES)	PELLET LENGTH (INCHES)	PELLET WEIGHT (GRAMS)	PELLET DENSITY (GMS/CC)	PELLET DENSITY (G/T, D.)	PELLET DENSITY SMKARED	PELLET O/M	BATCH NO.	PELLET NUMBER IN BATCH
*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****
41	12.9508	9.8208	.2437	0.2720	1.9700	9.4802	86.18	83.02	1.988	8233	202
42	13.2231	10.0931	.2438	0.2723	1.9820	9.5196	86.54	83.43	1.988	8233	203
43	13.4488	10.3188	.2433	0.2257	1.6350	9.5133	86.48	83.03	1.977	8233	31
44	13.6767	10.5467	.2432	0.2279	1.6530	9.5331	86.66	83.14	1.977	8233	30
45	13.9039	10.7739	.2434	0.2272	1.6490	9.5236	86.57	83.19	1.977	8233	29
46	14.1302	11.0002	.2434	0.2263	1.6430	9.5267	86.60	83.22	1.977	8233	28
47	14.3553	11.2253	.2432	0.2251	1.6410	9.5816	87.10	83.56	1.977	8233	20
48	14.5814	11.4514	.2434	0.2261	1.6400	9.5177	86.52	83.14	1.977	8233	25
49	14.8071	11.6771	.2431	0.2257	1.6430	9.9756	87.05	83.44	1.977	8233	24
50	15.0331	11.9031	.2431	0.2260	1.6380	9.5338	86.67	83.07	1.977	8233	23
51	15.2592	12.1292	.2431	0.2261	1.6410	9.5470	86.79	83.19	1.977	8233	22
52	15.4875	12.3575	.2435	0.2283	1.6500	9.4757	86.14	82.84	1.977	8233	21
53	15.7133	12.5833	.2431	0.2258	1.6360	9.5306	86.64	83.05	1.977	8233	20
54	15.9394	12.8094	.2432	0.2261	1.6400	9.5334	86.66	83.14	1.977	8233	19
55	16.1699	13.0399	.2438	0.2305	1.6540	9.3849	85.31	82.25	1.977	8233	18
56	16.3987	13.2687	.2439	0.2288	1.6380	9.3555	85.05	82.06	1.977	8233	17
57	16.6271	13.4971	.2439	0.2284	1.6370	9.3661	85.14	82.15	1.977	8233	16
58	17.1247	13.9947	.2456	0.4976	4.0670	10.5334	96.12	94.04	2.000	U51	
59	17.6223	14.4923	.2458	0.4976	4.0660	10.5137	95.94	94.01	2.000	U51	
60	18.1199	14.9899	.2457	0.4976	4.1090	10.6335	97.03	95.01	2.000	U91	
61	18.6175	15.4875	.2456	0.4976	4.0440	10.4738	95.57	93.50	2.000	U91	
62	19.1151	15.9851	.2458	0.4976	4.0500	10.4723	95.56	93.64	2.000	U51	

TABLE A-13
 PELLET LINEUP FOR PIN F3B-6

PELLET NO.	DIST. FROM BOTTOM OF PIN TO TOP OF THIS PELLET (INCHES)	DIST. FROM BOTTOM OF FUEL TO TOP OF THIS PELLET (INCHES)	PELLET DIAMETER (INCHES)	PELLET LENGTH (INCHES)	PELLET WEIGHT (GRAMS)	PELLET DENSITY (GMS/CC)	PELLET DENSITY (%T.D.)	PELLET DENSITY SMEARED	PELLET O/M	BATCH NO.	PELLET NUMBER IN BATCH
*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****
1	1.1370		.2460	0.4970	4.0830	10.5532	96.30	98.52	2.000	U91	1
2	1.6340		.2458	0.4970	4.0240	10.4176	95.86	93.15	2.000	U91	2
3	2.1310		.2458	0.4970	4.0588	10.5056	95.86	93.94	2.000	U91	3
4	2.6280		.2456	0.4970	4.0530	10.5098	95.90	93.83	2.000	U91	4
5	3.1250		.2458	0.4970	4.0880	10.5833	96.97	94.64	2.000	U91	5
6	3.3982	0.2732	.2433	0.2732	1.9300	9.2773	84.34	80.97	1.999	8233	255
7	3.6712	0.5462	.2439	0.2730	1.9250	9.2146	83.76	80.82	1.999	8233	227
8	3.9471	0.8221	.2440	0.2759	1.9570	9.2617	84.19	81.30	1.999	8233	268
9	4.2241	1.0991	.2433	0.2770	1.9480	9.2354	83.95	80.61	1.999	8233	266
10	4.5003	1.3753	.2438	0.2762	1.9440	9.2053	83.68	80.67	1.999	8233	257
11	4.7760	1.6510	.2433	0.2757	1.9510	9.2932	84.48	81.11	1.999	8233	260
12	5.0520	1.9270	.2444	0.2760	1.9730	9.3035	84.57	81.94	1.999	8233	268
13	5.3260	2.2010	.2443	0.2740	1.9530	9.2840	84.40	81.70	1.999	8233	269
14	5.6027	2.4777	.2444	0.2767	1.9618	9.3235	83.85	81.23	1.999	8233	267
15	5.8750	2.7500	.2431	0.2723	1.9310	9.3282	84.80	81.28	1.999	8233	241
16	6.1513	3.0253	.2438	0.2763	1.9570	9.2635	84.21	81.18	1.999	8233	242
17	6.4279	3.3029	.2433	0.2766	1.9420	9.2203	83.82	80.48	1.999	8233	240
18	6.7038	3.5788	.2424	0.2759	1.9458	9.3268	84.79	80.80	1.999	8233	244
19	6.9798	3.8548	.2436	0.2760	1.9468	9.2366	83.96	80.82	1.999	8233	245
20	7.2584	4.1334	.2430	0.2786	1.9568	9.2429	84.82	80.47	1.999	8233	246
21	7.5762	4.4112	.2433	0.3178	2.2358	9.2357	83.96	80.61	1.999	8233	248
22	7.8519	4.7869	.2431	0.2757	1.9560	9.3324	84.84	81.32	1.999	8233	249
23	8.1279	5.0629	.2433	0.2760	1.9468	9.2593	84.17	80.82	1.999	8233	247
24	8.4217	5.2967	.2422	0.2938	2.0600	9.2918	84.47	80.37	1.999	8233	250
25	8.6975	5.5725	.2437	0.2758	1.9528	9.2641	84.22	81.12	1.999	8233	251
26	8.9726	5.8476	.2436	0.2751	1.9408	9.2382	83.98	80.83	1.999	8233	268
27	9.2467	6.1217	.2433	0.2741	1.9340	9.2660	84.23	80.87	1.999	8233	269
28	9.5217	6.3967	.2433	0.2750	1.9408	9.2644	84.22	80.86	1.999	8233	268
29	9.7955	6.6705	.2433	0.2738	1.9390	9.3002	84.94	81.17	1.999	8233	268
30	10.0705	6.9455	.2434	0.2750	1.9510	9.3092	84.63	81.32	1.999	8233	273
31	10.3466	7.2216	.2434	0.2761	1.9540	9.2864	84.42	81.12	1.999	8233	273
32	10.6194	7.4944	.2434	0.2728	1.9380	9.3218	84.74	81.43	1.999	8233	274
33	10.8945	7.7695	.2435	0.2751	1.9538	9.3077	84.61	81.37	1.999	8233	274
34	11.1698	8.0448	.2433	0.2753	1.9530	9.3163	84.69	81.31	1.999	8233	271
35	11.4442	8.3192	.2432	0.2744	1.9410	9.2971	84.51	81.08	1.999	8233	271
36	11.7182	8.5932	.2441	0.2740	1.9498	9.2802	84.36	81.53	1.999	8233	277
37	11.9932	8.8682	.2436	0.2750	1.9508	9.2892	84.44	81.28	1.999	8233	277
38	12.2662	9.1412	.2441	0.2730	1.9510	9.3237	84.76	81.91	1.999	8233	278
39	12.5395	9.4145	.2436	0.2733	1.9470	9.3326	84.84	81.66	1.999	8233	278
40	12.8155	9.6905	.2441	0.2760	1.9610	9.2697	84.27	81.44	1.999	8233	279

TABLE A-13 continued (F3B-6)

PELLET NO.	DIST. FROM BOTTOM OF PIN TO TOP OF THIS PELLET (INCHES)	DIST. FROM BOTTOM OF FUEL TO TOP OF THIS PELLET (INCHES)	PELLET DIAMETER (INCHES)	PELLET LENGTH (INCHES)	PELLET WEIGHT (GRAMS)	PELLET DENSITY (GMS/CC)	PELLET DENSITY (%T.D.)	PELLET DENSITY SMEARED	PELLET O/M.	BATCH NO.	PELLET NUMBER IN BATCH
*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****
41	13.0915	9.9665	.2435	0.2760	1.9510	9.2679	84.25	81.02	1.999	8233	274
42	13.3643	10.2393	.2441	0.2728	1.9490	9.3210	84.73	81.89	1.999	8233	255
43	13.6394	10.5144	.2440	0.2751	1.9540	9.2744	84.31	81.41	1.999	8233	272
44	13.9132	10.7882	.2443	0.2738	1.9590	9.3193	84.72	82.01	1.999	3233	252
45	14.1872	11.0622	.2433	0.2740	1.9270	9.2359	83.96	80.61	1.999	8233	240
46	14.4612	11.3362	.2437	0.2740	1.9340	9.2390	83.99	80.90	1.999	8233	289
47	14.7342	11.6092	.2436	0.2730	1.9360	9.2901	84.45	81.28	1.999	3233	288
48	15.0065	11.8815	.2441	0.2723	1.9470	9.3285	84.80	81.96	1.999	3233	287
49	15.2797	12.1547	.2440	0.2732	1.9370	9.2576	84.16	81.27	1.999	3233	286
50	15.5526	12.4276	.2435	0.2729	1.9270	9.2579	84.16	80.94	1.999	3233	289
51	15.8264	12.7014	.2436	0.2738	1.9330	9.2486	84.17	80.92	1.999	3233	234
52	16.0988	12.9738	.2436	0.2724	1.9400	9.3298	84.81	81.63	1.999	3233	233
53	16.3733	13.2483	.2438	0.2745	1.9220	9.1574	83.25	80.20	1.999	8233	231
54	16.6473	13.5223	.2438	0.2740	1.9320	9.2219	83.83	80.82	1.999	8233	230
55	17.1435	14.0185	.2459	0.4962	4.0690	10.5425	96.20	94.35	2.000	U51	8
56	17.6397	14.5147	.2458	0.4962	4.0430	10.4837	95.66	93.74	2.000	U51	7
57	18.1359	15.0109	.2459	0.4962	4.0580	10.5140	95.94	94.09	2.000	U51	6
58	18.6321	15.5071	.2460	0.4962	4.0770	10.5547	96.31	94.53	2.000	U51	5
59	19.1283	16.0033	.2455	0.4962	4.0630	10.5613	96.37	94.21	2.000	U51	10

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TABLE A-14
 PELLET LINEUP FOR PIN F3B-7

PELLET NO.	DIST. FROM BOTTOM OF PIN TO TOP OF THIS PELLET (INCHES)	DIST. FROM BOTTOM OF FUEL TO TOP OF THIS PELLET (INCHES)	PELLET DIAMETER (INCHES)	PELLET LENGTH (INCHES)	PELLET WEIGHT (GRAMS)	PELLET DENSITY (GMS/CC)	PELLET DENSITY (X T, D.)	PELLET DENSITY SMEARED	PELLET O/M	BATCH NO.	PELLET NUMBER IN BATCH
1	1.1388		.2458	0.4988	4.0910	10.5529	96.29	92.64	2.000	U51	
2	1.5376		.2458	0.4988	4.0760	10.5142	95.94	92.30	2.000	U51	
3	2.1364		.2459	0.4988	4.1020	10.5776	96.47	92.89	2.000	U51	
4	2.6352		.2457	0.4988	4.0590	10.4788	95.62	91.91	2.000	U51	
5	3.1340		.2460	0.4988	4.0590	10.4533	95.38	91.91	2.000	U51	
6	3.3390	0.2050	.2436	0.2050	1.5800	10.4372	94.84	86.69	1.970	3237	18
7	3.5195	0.3855	.2435	0.1805	1.3970	10.4899	95.32	87.06	1.970	3237	17
8	3.7015	0.5675	.2432	0.1820	1.4020	10.4673	95.12	86.65	1.970	3237	16
9	3.9075	0.7735	.2432	0.2060	1.5660	10.3296	93.86	85.51	1.977	3237	145
10	4.1171	0.9831	.2430	0.2096	1.6040	10.4162	94.65	86.08	1.970	3237	14
11	4.3424	1.2084	.2437	0.2253	1.7350	10.4196	94.68	86.62	1.977	3237	100
12	4.5880	1.4540	.2435	0.2456	1.8940	10.4521	94.98	86.74	1.977	3237	199
13	4.8028	1.6688	.2431	0.2148	1.6450	10.4150	94.64	86.14	1.977	3237	198
14	5.0120	1.8780	.2431	0.2092	1.5830	10.2907	93.51	85.11	1.966	3237	80
15	5.2299	2.0959	.2437	0.2179	1.6860	10.4692	95.13	87.03	1.980	3237	182
16	5.4553	2.3213	.2433	0.2254	1.7440	10.5046	95.45	87.03	1.980	3237	181
17	5.6926	2.5586	.2431	0.2373	1.8330	10.5049	95.46	86.69	1.980	3237	180
18	5.9008	2.7668	.2433	0.2082	1.5880	10.3552	94.10	85.79	1.977	3237	142
19	6.1226	2.9886	.2430	0.2218	1.7030	10.4508	94.97	86.37	1.980	3237	140
20	6.3426	3.2086	.2433	0.2200	1.7000	10.4909	95.33	86.92	1.980	3237	117
21	6.5646	3.4306	.2433	0.2220	1.7200	10.5187	95.58	87.15	1.980	3237	116
22	6.8167	3.6827	.2436	0.2521	1.9470	10.4586	95.04	86.87	1.977	3237	162
23	7.0201	3.8861	.2431	0.2034	1.5550	10.3969	94.48	85.99	1.977	3237	147
24	7.2218	4.0878	.2433	0.2017	1.5830	10.6552	96.82	88.26	1.977	3237	146
25	7.4291	4.2951	.2433	0.2073	1.5850	10.3805	94.33	86.00	1.977	3237	144
26	7.6443	4.5103	.2436	0.2152	1.6410	10.3264	93.84	85.77	1.977	3237	143
27	7.8515	4.7175	.2435	0.2072	1.5800	10.3352	93.91	85.77	1.977	3237	141
28	8.0608	4.9268	.2429	0.2093	1.5900	10.3489	94.04	85.45	1.977	3237	140
29	8.2684	5.1344	.2440	0.2076	1.5900	10.3366	93.93	86.15	1.977	3237	139
30	8.4738	5.3398	.2438	0.2054	1.5820	10.4124	94.62	86.63	1.977	3237	138
31	8.6819	5.5479	.2436	0.2081	1.5910	10.3533	94.08	86.00	1.977	3237	137
32	8.8897	5.7557	.2436	0.2078	1.5880	10.3487	94.04	85.96	1.977	3237	136
33	9.1068	5.9728	.2439	0.2171	1.6790	10.4464	94.93	86.99	1.980	3237	80
34	9.3258	6.1911	.2439	0.2183	1.6900	10.4571	95.02	87.08	1.980	3237	79
35	9.5393	6.4053	.2439	0.2142	1.6610	10.4743	95.18	87.22	1.980	3237	78
36	9.7535	6.6195	.2439	0.2142	1.6560	10.4428	94.89	86.96	1.980	3237	77
37	9.9727	6.8387	.2440	0.2192	1.6880	10.3930	94.44	86.62	1.980	3237	76
38	10.1875	7.0535	.2442	0.2148	1.6630	10.4311	94.79	87.09	1.980	3237	75
39	10.4166	7.2826	.2448	0.2291	1.7720	10.3683	94.22	87.01	1.980	3237	74
40	10.6334	7.4994	.2444	0.2168	1.6750	10.4919	94.43	86.90	1.980	3237	73

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TABLE A-14 continued (F3B-7)

PELLET NO.	DIST. FROM BOTTOM OF PIN TO TOP OF THIS PELLET (INCHES)	DIST. FROM BOTTOM OF FUEL TO TOP OF THIS PELLET (INCHES)	PELLET DIAMETER (INCHES)	PELLET LENGTH (INCHES)	PELLET WEIGHT (GRAMS)	PELLET DENSITY (GMS/CC)	PELLET DENSITY (%T.D.)	PELLET DENSITY SMEARED	PELLET O/M	BATCH NO.	PELLET NUMBER IN BATCH
*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****
41	10.8505	7.7165	.2445	0.2171	1.6730	10.3564	94.11	86.68	1.980	9237	72
42	11.0636	7.9296	.2448	0.2131	1.6480	10.3668	94.20	86.99	1.980	9237	71
43	11.2823	8.1483	.2446	0.2187	1.6820	10.3272	93.84	86.51	1.980	9237	70
44	11.5028	8.3688	.2446	0.2205	1.6970	10.3342	93.91	86.57	1.980	9237	69
45	11.7196	8.5856	.2445	0.2168	1.6650	10.3211	93.79	86.39	1.980	9237	68
46	11.9371	8.8031	.2446	0.2175	1.6700	10.3101	93.69	86.37	1.980	9237	67
47	12.1562	9.0222	.2446	0.2191	1.6830	10.3144	93.73	86.40	1.980	9237	66
48	12.3727	9.2387	.2447	0.2165	1.6610	10.2932	93.53	86.30	1.980	9237	65
49	12.5934	9.4594	.2442	0.2207	1.6930	10.3354	93.92	86.29	1.980	9237	64
50	12.8060	9.6720	.2441	0.2126	1.6820	10.0685	96.94	88.99	1.980	9237	63
51	13.0225	9.8885	.2454	0.2165	1.6660	10.2634	93.26	86.56	1.980	9237	62
52	13.2409	10.1069	.2445	0.2184	1.6680	10.2639	93.27	85.91	1.980	9237	61
53	13.4586	10.3246	.2447	0.2177	1.6660	10.2672	93.30	86.08	1.980	9237	60
54	13.6793	10.5453	.2450	0.2207	1.6840	10.2112	92.79	85.83	1.980	9237	59
55	13.8985	10.7645	.2440	0.2192	1.6820	10.3560	94.10	86.31	1.980	9237	58
56	14.1156	10.9816	.2446	0.2171	1.6730	10.3476	94.03	86.66	1.980	9237	57
57	14.3339	11.1999	.2443	0.2183	1.6840	10.3847	94.37	86.77	1.980	9237	56
58	14.5400	11.4060	.2431	0.2061	1.5850	10.4587	95.04	86.50	1.977	9237	127
59	14.7480	11.6140	.2428	0.2080	1.5820	10.3700	94.23	85.55	1.977	9237	128
60	14.9546	11.8206	.2444	0.2066	1.5840	10.3125	93.71	86.24	1.977	9237	132
61	15.1612	12.0272	.2440	0.2066	1.5840	10.3474	94.03	86.24	1.977	9237	138
62	15.3847	12.2507	.2428	0.2235	1.6980	10.3585	94.13	85.46	1.977	9237	148
63	15.5869	12.4529	.2435	0.2022	1.5490	10.3829	94.35	86.17	1.977	9237	149
64	15.7964	12.6624	.2433	0.2095	1.5950	10.3363	93.93	85.64	1.977	9237	151
65	16.0038	12.8698	.2432	0.2074	1.5910	10.4236	94.72	86.29	1.977	9237	152
66	16.2204	13.0864	.2440	0.2166	1.6770	10.4492	94.95	87.09	1.977	9237	156
67	16.4132	13.2992	.2431	0.1928	1.4760	10.4113	94.61	86.11	1.977	9237	157
68	16.6597	13.5257	.2434	0.2465	1.9000	10.4578	95.01	86.70	1.977	9237	163
69	17.1553	14.0213	.2457	0.4956	4.0100	10.4172	95.07	91.39	2.000	U51	
70	17.6509	14.5169	.2458	0.4956	4.1020	10.6456	97.16	93.49	2.000	U51	
71	18.1465	15.0125	.2459	0.4956	4.0800	10.5838	96.58	92.99	2.000	U51	
72	18.6421	15.5081	.2458	0.4956	4.0430	10.4964	95.78	92.14	2.000	U51	
73	19.1377	16.0037	.2454	0.4956	4.0380	10.5176	95.97	92.03	2.000	U51	

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TABLE A-15
 PELLET LINEUP FOR PIN F3B-8

PELLET NO.	DIST. FROM BOTTOM OF PIN TO TOP OF THIS PELLET (INCHES)	DIST. FROM BOTTOM OF FUEL TO TOP OF THIS PELLET (INCHES)	PELLET DIAMETER (INCHES)	PELLET LENGTH (INCHES)	PELLET WEIGHT (GRAMS)	PELLET DENSITY (GMS/CC)	PELLET DENSITY (%T.D.)	PELLET DENSITY SMEARED	PELLET O/M	BATCH NO.	PELLET NUMBER IN BATCH
*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****
1	1.1366		.2459	0.4966	3.9790	10.3010	93.99	90.36	2,000	U51	
2	1.6332		.2457	0.4966	4.0850	10.5927	96.66	92.77	2,000	U51	
3	2.1298		.2459	0.4966	4.0970	10.6065	96.78	93.04	2,000	U51	
4	2.6264		.2450	0.4966	4.0710	10.5392	96.17	92.45	2,000	U51	
5	3.1230		.2458	0.4966	4.0620	10.5245	96.03	92.24	2,000	U51	
6	3.3915	0.2685	.2451	0.2685	2.0810	10.0293	91.17	87.07	1,979	8233	354
7	3.6620	0.5390	.2445	0.2705	2.0840	10.0185	91.07	86.56	1,983	8233	358
8	3.9302	0.8072	.2444	0.2682	2.0610	10.0011	90.91	86.33	1,983	8233	359
9	4.2059	1.0829	.2442	0.2757	2.1140	9.9956	90.86	86.15	1,983	8233	360
10	4.4766	1.3536	.2447	0.2707	2.1000	10.0715	91.55	87.16	1,983	8233	361
11	4.7560	1.6330	.2441	0.2794	2.1580	10.0767	91.60	86.77	1,983	8233	362
12	5.0344	1.9114	.2442	0.2784	2.1200	9.9267	90.24	85.55	1,983	8233	363
13	5.3046	2.1816	.2451	0.2702	2.0730	9.9279	90.25	86.19	1,983	8233	364
14	5.5762	2.4532	.2442	0.2716	2.1030	10.0937	91.76	86.99	1,983	8233	365
15	5.8444	2.7214	.2443	0.2682	2.0650	10.0287	91.17	86.50	1,983	8233	366
16	6.1154	2.9924	.2450	0.2710	2.0660	9.8732	89.75	85.65	1,983	8233	367
17	6.3862	3.2632	.2453	0.2708	2.0840	9.9423	90.38	86.46	1,983	8233	368
18	6.6566	3.5336	.2450	0.2704	2.0800	9.9622	90.56	86.42	1,983	8233	369
19	6.9295	3.8065	.2451	0.2729	2.0810	9.8676	89.70	85.67	1,983	8233	370
20	7.2012	4.0782	.2453	0.2717	2.0790	9.8855	89.86	85.97	1,983	8233	371
21	7.4749	4.3519	.2452	0.2737	2.0920	9.8827	89.84	85.87	1,983	8233	372
22	7.7477	4.6247	.2452	0.2728	2.0900	9.9059	90.05	86.07	1,983	8233	373
23	8.0192	4.8962	.2451	0.2715	2.0750	9.8899	89.90	85.86	1,983	8233	374
24	8.2889	5.1659	.2449	0.2697	2.0650	9.9241	90.22	86.02	1,983	8233	375
25	8.5633	5.4403	.2458	0.2744	2.0810	9.7579	88.70	85.20	1,983	8233	376
26	8.8665	5.7435	.2440	0.3032	2.3090	9.9437	90.39	85.56	1,979	8233	377
27	9.1117	5.9887	.2450	0.2452	1.9030	10.0512	91.37	87.19	1,979	8233	378
28	9.3773	6.2543	.2453	0.2656	2.0560	10.0007	90.91	86.97	1,979	8233	379
29	9.6386	6.5156	.2451	0.2618	2.0200	10.0402	91.34	87.24	1,979	8233	380
30	9.8914	6.7684	.2450	0.2528	1.9660	10.0718	91.56	87.37	1,979	8233	381
31	10.1646	7.0416	.2451	0.2732	2.0900	9.8994	89.99	85.95	1,983	8233	382
32	10.4367	7.3137	.2451	0.2721	2.0850	9.9157	90.14	86.09	1,983	8233	383
33	10.7086	7.5856	.2452	0.2719	2.0750	9.8673	89.70	85.74	1,983	8233	384
34	10.9801	7.8571	.2453	0.2715	2.0820	9.9071	90.06	86.15	1,983	8233	385
35	11.2564	8.1334	.2458	0.2763	2.1460	9.9935	90.85	87.20	1,979	8233	386
36	11.5177	8.4047	.2455	0.2613	2.0300	10.0224	91.04	87.20	1,979	8233	387
37	11.7841	8.6611	.2453	0.2604	2.0590	9.9857	90.77	86.83	1,979	8233	388
38	12.0561	8.9331	.2459	0.2720	2.0650	9.7603	88.73	85.29	1,983	8233	389
39	12.3280	9.2050	.2454	0.2719	2.0730	9.8417	89.47	85.65	1,983	8233	390
40	12.5997	9.4767	.2453	0.2717	2.0730	9.8570	89.60	85.72	1,983	8233	391

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TABLE A-15 continued (F3B-8)

PELLET NO.	DIST. FROM BOTTOM OF PIN TO TOP OF THIS PELLET (INCHES)	DIST. FROM BOTTOM OF FUEL TO TOP OF THIS PELLET (INCHES)	PELLET DIAMETER (INCHES)	PELLET LENGTH (INCHES)	PELLET WEIGHT (GRAMS)	PELLET DENSITY (GMS/CC)	PELLET DENSITY (GT./D.)	PELLET DENSITY SMKARED	PELLET O/M	BATCH NO.	PELLET NUMBER IN BATCH
*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****
41	12.8723	9.7493	.2459	0.2726	2.0660	9.7436	88.57	85.15	1.983	8233	381
42	13.1450	10.3220	.2457	0.2727	2.0720	9.7842	88.94	85.36	1.983	8233	383
43	13.4121	10.2891	.2447	0.2671	2.0400	9.9156	90.14	85.81	1.979	8233	389
44	13.6918	10.5698	.2452	0.2797	2.1150	9.7771	88.88	84.95	1.979	8233	395
45	13.9761	10.8531	.2440	0.2843	2.1620	9.9296	90.26	85.44	1.979	8233	397
46	14.2779	11.1949	.2458	0.3018	2.2820	9.7289	88.44	84.95	1.979	8233	398
47	14.5548	11.4318	.2459	0.2769	2.0940	9.7223	88.38	84.96	1.979	8233	401
48	14.8225	11.6995	.2441	0.2677	2.0610	10.0444	91.31	86.50	1.979	8233	398
49	15.0888	11.9858	.2442	0.2663	2.0510	10.0400	91.27	86.53	1.979	8233	399
50	15.3608	12.2378	.2441	0.2720	2.0940	10.0439	91.30	86.49	1.979	8233	340
51	15.5414	12.4184	.2440	0.1806	1.3980	10.1074	91.88	86.97	1.979	8233	341
52	15.8153	12.6923	.2450	0.2739	2.0800	9.8349	89.40	85.32	1.979	8233	413
53	16.0905	12.9675	.2452	0.2752	2.0860	9.8087	89.09	85.10	1.979	8233	415
54	16.3656	13.2426	.2455	0.2751	2.0900	9.7990	89.08	85.35	1.979	8233	416
55	16.6447	13.5217	.2451	0.2791	2.1148	9.8014	89.10	85.10	1.979	8233	417
56	17.1405	14.0175	.2457	0.4958	4.0680	10.5656	96.41	92.53	2.000	U51	
57	17.6363	14.5133	.2459	0.4958	4.0970	10.5236	96.94	93.19	2.000	U51	
58	18.1321	15.0091	.2459	0.4958	4.0660	10.5433	96.21	92.48	2.000	U51	
59	18.6279	15.5049	.2460	0.4958	3.9530	10.2419	93.46	89.91	2.000	U51	
60	19.1237	16.0007	.2457	0.4958	4.0790	10.5942	96.67	92.78	2.000	U51	

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TABLE A-16
 PELLET LINEUP FOR PIN F3B-9

PELLET NO.	DIST. FROM BOTTOM OF PIN TO TOP OF THIS PELLET (INCHES)	DIST. FROM BOTTOM OF FUEL TO TOP OF THIS PELLET (INCHES)	PELLET DIAMETER (INCHES)	PELLET LENGTH (INCHES)	PELLET WEIGHT (GRAMS)	PELLET DENSITY (GMS/CC)	PELLET DENSITY (%T.D.)	PELLET DENSITY SMEARED	PELLET O/M	BATCH NO.	PELLET NUMBER IN BATCH
1	1.1362		.2458	0.4962	4.0630	10.9375	96.13	92.27	2.000	U51	
2	1.6324		.2456	0.4962	4.0620	10.9501	96.27	92.24	2.000	U51	
3	2.1286		.2457	0.4962	4.0608	10.9363	96.14	92.20	2.000	U51	
4	2.6248		.2453	0.4962	4.0080	10.4353	95.22	91.02	2.000	U51	
5	3.1210		.2460	0.4962	4.0970	10.6064	96.78	90.04	2.000	U51	
6	3.3556	0.2346	.2450	0.2346	1.7870	10.1937	92.63	89.48	1.999	8237	358
7	3.5656	0.4446	.2452	0.2100	1.6040	10.2045	92.73	89.71	1.999	8237	357
8	3.7776	0.6566	.2445	0.2120	1.6220	10.2822	93.43	89.85	2.000	8237	362
9	3.9936	0.8726	.2454	0.2160	1.6450	10.1575	92.30	89.46	1.999	8237	389
10	4.2229	1.1019	.2458	0.2293	1.7380	10.0753	91.55	89.05	1.999	8237	356
11	4.4497	1.3287	.2442	0.2268	1.7430	10.3545	94.09	89.24	1.999	8237	358
12	4.6738	1.5528	.2458	0.2241	1.7170	10.1845	92.55	89.98	1.999	8237	195
13	4.9011	1.7801	.2460	0.2273	1.7508	10.2169	92.84	89.39	1.999	8237	194
14	5.1264	2.0054	.2458	0.2253	1.7200	10.1480	92.21	89.67	1.999	8237	187
15	5.3550	2.2340	.2454	0.2286	1.7510	10.2160	92.83	89.95	1.999	8237	188
16	5.5792	2.4582	.2459	0.2242	1.7240	10.2129	92.80	89.29	1.999	8237	169
17	5.8078	2.6868	.2453	0.2286	1.7410	10.1643	92.38	89.46	1.999	8237	168
18	6.0331	2.9121	.2460	0.2253	1.7350	10.2193	92.86	89.41	1.999	8237	167
19	6.2469	3.1859	.2449	0.2138	1.6190	10.1424	92.16	84.97	2.000	8237	326
20	6.4598	3.3388	.2450	0.2129	1.6230	10.2019	92.70	89.54	2.000	8237	325
21	6.6721	3.5511	.2449	0.2123	1.6128	10.1699	92.41	89.20	2.000	8237	324
22	6.8837	3.7627	.2448	0.2116	1.6168	10.2375	93.03	89.70	2.000	8237	323
23	7.0961	3.9751	.2445	0.2124	1.6410	10.1870	94.35	86.70	2.000	8237	322
24	7.3107	4.1897	.2447	0.2146	1.6320	10.2070	92.71	89.34	2.000	8237	321
25	7.5215	4.4005	.2449	0.2108	1.6090	10.2232	92.90	89.65	2.000	8237	320
26	7.7352	4.6142	.2449	0.2137	1.6220	10.1660	92.38	89.17	2.000	8237	319
27	7.9520	4.8310	.2448	0.2168	1.6470	10.1837	92.54	89.25	2.000	8237	318
28	8.1661	5.0451	.2448	0.2141	1.6370	10.2495	93.14	89.80	2.000	8237	317
29	8.3761	5.2551	.2452	0.2100	1.6080	10.2299	92.96	89.92	2.000	8237	316
30	8.5904	5.4694	.2450	0.2143	1.6400	10.2414	93.06	89.88	2.000	8237	315
31	8.7997	5.6787	.2454	0.2093	1.5930	10.1512	92.24	89.41	2.000	8237	307
32	9.0141	5.8931	.2448	0.2144	1.6380	10.2414	93.06	89.73	2.000	8237	313
33	9.2279	6.1069	.2448	0.2138	1.6270	10.2012	92.70	89.39	2.000	8237	312
34	9.4425	6.3215	.2449	0.2146	1.6370	10.2170	92.84	89.60	2.000	8237	311
35	9.6539	6.5329	.2450	0.2114	1.6070	10.1770	92.44	89.30	2.000	8237	310
36	9.8692	6.7482	.2450	0.2153	1.6420	10.2062	92.74	89.58	2.000	8237	309
37	10.0834	6.9624	.2451	0.2142	1.6370	10.2178	92.86	89.70	2.000	8237	308
38	10.2964	7.1754	.2449	0.2130	1.6250	10.2173	92.85	89.61	2.000	8237	314
39	10.5074	7.3864	.2450	0.2110	1.6150	10.2470	93.06	89.89	2.000	8237	305
40	10.7204	7.5994	.2447	0.2130	1.6230	10.2299	92.90	89.50	2.000	8237	304

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TABLE A-16 continued (F3B-9)

PELLET NO.	DIST. FROM BOTTOM OF PIN TO TOP OF THIS PELLET (INCHES)	DIST. FROM BOTTOM OF FUEL TO TOP OF THIS PELLET (INCHES)	PELLET DIAMETER (INCHES)	PELLET LENGTH (INCHES)	PELLET WEIGHT (GRAMS)	PELLET DENSITY (GMS/CC)	PELLET DENSITY (%T.D.)	PELLET DENSITY SMEARED	PELLET O/M	BATCH NO.	PELLET NUMBER IN BATCH
*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****
41	10.9353	7.8143	.2453	0.2149	1.6340	10.1497	92.23	85.32	2.000	8237	303
42	11.1496	8.3286	.2450	0.2143	1.6350	10.2162	92.78	85.61	2.000	9237	302
43	11.3510	8.2400	.2450	0.2114	1.6170	10.2363	93.02	85.83	2.000	9237	301
44	11.5745	8.4535	.2447	0.2135	1.6320	10.2556	93.19	85.78	2.000	9237	300
45	11.7972	8.6762	.2449	0.2227	1.6910	10.1701	92.42	85.21	2.000	9237	302
46	12.0117	8.8907	.2442	0.2145	1.6440	10.3264	93.83	86.00	1.999	8237	298
47	12.2245	9.1035	.2444	0.2128	1.6230	10.2585	93.22	85.58	1.999	9237	297
48	12.4368	9.3158	.2444	0.2123	1.6250	10.2954	93.55	85.89	1.999	8237	296
49	12.6490	9.5280	.2449	0.2122	1.6230	10.2442	93.09	85.83	1.999	8237	295
50	12.8641	9.7431	.2445	0.2151	1.6410	10.2527	93.17	85.61	1.999	8237	294
51	13.0776	9.9566	.2435	0.2135	1.6250	10.3159	93.74	85.41	1.999	8237	292
52	13.2897	10.1687	.2434	0.2121	1.6150	10.3288	93.86	85.44	1.999	8237	291
53	13.5023	10.3813	.2450	0.2126	1.6150	10.1659	92.38	85.24	1.999	8237	290
54	13.7167	10.5957	.2452	0.2144	1.6260	10.1321	92.07	85.10	1.999	8237	288
55	13.9294	10.8084	.2451	0.2127	1.6110	10.1274	92.03	84.99	1.999	8237	288
56	14.1443	11.0233	.2453	0.2149	1.6270	10.1062	91.83	84.96	1.999	8237	284
57	14.3593	11.2383	.2456	0.2150	1.6300	10.0946	91.73	85.07	1.999	8237	283
58	14.5746	11.4536	.2453	0.2153	1.6300	10.1061	91.83	84.96	1.999	8237	282
59	14.8248	11.7038	.2444	0.2502	1.9140	10.2895	93.50	85.84	2.000	8237	369
60	15.0499	11.9289	.2442	0.2251	1.7090	10.2291	92.95	85.19	2.000	8237	368
61	15.2677	12.1467	.2459	0.2178	1.6810	10.2508	93.15	86.61	2.000	8237	84
62	15.4839	12.3629	.2460	0.2162	1.6700	10.2504	93.15	86.66	2.000	8237	83
63	15.6999	12.5789	.2458	0.2160	1.6590	10.2095	92.77	86.14	2.000	8237	82
64	15.9157	12.8247	.2442	0.2458	1.8720	10.2612	93.24	85.46	2.000	8237	359
65	16.1711	13.0501	.2442	0.2254	1.7160	10.2574	93.21	85.43	2.000	8237	360
66	16.3914	13.2704	.2442	0.2203	1.6780	10.2624	93.25	85.47	2.000	8237	361
67	16.6117	13.4907	.2442	0.2203	1.6890	10.3297	93.87	86.03	2.000	8237	362
68	17.1087	13.9877	.2455	0.4970	4.0460	10.5002	95.81	91.73	2.000	U51	
69	17.6057	14.4847	.2456	0.4970	4.0250	10.4372	95.24	91.28	2.000	U51	
70	18.1027	14.9817	.2459	0.4970	4.0700	10.5281	96.07	92.28	2.000	U51	
71	18.5997	15.4787	.2457	0.4970	4.1030	10.6308	97.00	93.02	2.000	U51	
72	19.0967	15.9757	.2458	0.4970	4.0830	10.5704	96.45	92.57	2.000	U51	

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TABLE A-17
 PELLET LINEUP FOR PIN F3B-10

PELLET NO.	DIST. FROM BOTTOM OF PIN TO TOP OF THIS PELLET (INCHES)	DIST. FROM BOTTOM OF FUEL TO TOP OF THIS PELLET (INCHES)	PELLET DIAMETER (INCHES)	PELLET LENGTH (INCHES)	PELLET WEIGHT (GRAMS)	PELLET DENSITY (GMS/CC)	PELLET DENSITY (%T.D.)	PELLET DENSITY SHEARED	PELLET O/M	BATCH NO.	PELLET NUMBER IN BATCH
*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****
1	1.1358		.2455	0.4958	4.0550	18.5490	96.26	92.36	2.000	U51	
2	1.6316		.2459	0.4958	4.0720	18.5588	96.35	92.77	2.000	U51	
3	2.1274		.2454	0.4958	4.0900	10.6487	97.17	93.16	2.000	U51	
4	2.6232		.2456	0.4958	4.0200	10.4495	95.35	91.56	2.000	U51	
5	3.1190		.2459	0.4958	4.0130	10.4058	94.95	91.42	2.000	U51	
6	3.3768	0.2578	.2430	0.2578	1.9960	10.1929	92.66	87.12	2.000	8233	528
7	3.6330	0.3140	.2431	0.2562	1.9708	10.1146	91.95	86.53	2.000	8233	527
8	3.9008	0.7818	.2430	0.2678	2.0740	10.1957	92.68	87.15	2.000	8233	319
9	4.1549	1.0359	.2433	0.2541	1.9600	10.1297	92.08	86.80	2.000	8233	317
10	4.3609	1.2419	.2433	0.2060	1.5900	10.1362	92.14	86.85	2.000	8233	319
11	4.6139	1.4949	.2434	0.2530	1.9500	10.1136	91.94	86.73	2.000	8233	314
12	4.8687	1.7497	.2433	0.2548	1.9630	10.1174	91.97	86.69	2.000	8233	314
13	5.1270	2.0080	.2432	0.2583	1.9980	10.1666	92.42	87.04	2.000	8233	312
14	5.3497	2.2307	.2455	0.2227	1.6960	9.8228	89.26	85.66	1.999	8237	507
15	5.5694	2.4504	.2455	0.2197	1.6880	9.9099	90.05	86.42	1.999	8237	508
16	5.7512	2.6322	.2455	0.1818	1.3900	9.8616	89.61	86.00	1.999	8237	509
17	5.9511	2.8321	.2437	0.1999	1.5130	9.9071	90.03	85.14	1.999	8237	506
18	6.1494	3.0304	.2439	0.1983	1.5060	9.9572	90.48	85.43	1.999	8237	503
19	6.3663	3.2473	.2445	0.2169	1.6500	9.8923	89.89	85.57	1.999	8237	502
20	6.5855	3.4665	.2445	0.2192	1.6670	9.8894	89.86	85.54	1.999	8237	501
21	6.8019	3.6829	.2439	0.2164	1.6430	9.9217	90.16	85.40	1.999	8237	508
22	7.0207	3.9017	.2446	0.2188	1.6550	9.8281	89.31	85.06	1.999	8237	497
23	7.2806	4.1616	.2458	0.2599	1.9750	9.7775	88.88	85.51	2.000	8233	524
24	7.5965	4.4775	.2458	0.3159	2.4180	9.8486	89.53	86.13	2.000	8233	522
25	7.9103	4.7913	.2457	0.3138	2.3970	9.8364	89.42	85.95	2.000	8233	521
26	8.1664	5.0474	.2453	0.2561	1.9630	9.9025	90.02	86.25	2.000	8233	288
27	8.4197	5.3007	.2459	0.2533	1.9680	9.9886	90.80	87.43	2.000	8233	284
28	8.7435	5.6245	.2450	0.3238	2.4880	9.9511	90.46	86.46	1.999	8233	607
29	9.0691	5.9501	.2455	0.3256	2.4910	9.8677	89.70	86.09	1.999	8233	606
30	9.3697	6.2807	.2454	0.3806	2.2860	9.8168	89.24	85.57	1.999	8233	590
31	9.6715	6.5725	.2453	0.3218	2.4720	9.9243	90.22	86.44	1.999	8233	605
32	9.9900	6.8710	.2454	0.2985	2.2810	9.8642	89.67	85.99	1.999	8233	595
33	10.2889	7.1699	.2453	0.2989	2.2910	9.9023	90.02	86.25	1.999	8233	601
34	10.5872	7.4682	.2454	0.2983	2.2810	9.8708	89.73	86.05	1.999	8233	602
35	10.8860	7.7670	.2454	0.2988	2.2930	9.9062	90.05	86.35	1.999	8233	603
36	11.1838	8.0648	.2455	0.2778	2.2810	9.0794	89.81	86.15	1.999	8233	604
37	11.4842	8.3652	.2460	0.3004	2.2920	9.8011	89.10	85.86	1.999	8233	592
38	11.7837	8.6647	.2458	0.2995	2.2850	9.8165	89.24	85.85	1.999	8233	589
39	12.0822	8.9632	.2460	0.2965	2.2850	9.8374	89.39	86.14	1.999	8233	588
40	12.4059	9.2869	.2451	0.3237	2.4830	9.9261	90.23	86.32	1.999	8233	608

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TABLE A-17 continued (F3B-10)

PELLET NO.	DIST. FROM BOTTOM OF PIN TO TOP OF THIS PELLET (INCHES)	DIST. FROM BOTTOM OF FUEL TO TOP OF THIS PELLET (INCHES)	PELLET DIAMETER (INCHES)	PELLET LENGTH (INCHES)	PELLET WEIGHT (GRAMS)	PELLET DENSITY (GMS/CC)	PELLET DENSITY (%T.D.)	PELLET DENSITY SMEARED	PELLET O/H	BATCH NO.	PELLET NUMBER IN BATCH
*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****
41	12.7290	9.6100	.2450	0.3231	2.4870	9.9687	90.62	86.62	1.990	8233	609
42	13.0048	9.8858	.2448	0.2758	2.1220	9.9807	90.73	86.58	1.990	8233	610
43	13.3290	10.2100	.2448	0.3242	2.4910	9.9671	90.61	86.46	1.990	8233	611
44	13.6546	10.5356	.2458	0.3256	2.4850	9.8199	89.27	85.88	1.990	8233	612
45	13.9518	10.8328	.2447	0.2972	2.2830	9.9729	90.66	86.44	1.990	8233	585
46	14.2505	11.1315	.2458	0.2967	2.2820	9.8299	89.36	85.97	1.990	8233	584
47	14.5493	11.4303	.2460	0.2988	2.2840	9.8192	89.26	86.01	1.990	8233	588
48	14.8483	11.7293	.2460	0.2990	2.2820	9.8040	89.12	85.88	1.990	8233	582
49	15.1469	12.0279	.2456	0.2986	2.2810	9.8449	89.49	85.96	1.990	8233	581
50	15.4421	12.3231	.2441	0.2952	2.2830	10.0899	91.72	87.03	1.990	8233	580
51	15.7406	12.6216	.2449	0.2985	2.2950	9.9653	90.59	86.52	1.990	8233	579
52	16.0386	12.9196	.2452	0.2980	2.2870	9.9229	90.20	86.36	1.990	8233	588
53	16.2436	13.1246	.2460	0.2050	1.5598	9.7691	88.81	85.58	1.990	8233	588
54	16.4259	13.3069	.2456	0.1823	1.3928	9.8407	89.46	85.92	1.990	8233	589
55	16.6448	13.5858	.2448	0.2189	1.6600	9.8372	89.42	85.33	1.990	8233	588
56	17.1420	14.0830	.2458	0.4972	4.0740	10.5428	96.20	92.55	2.000	U51	
57	17.6392	14.5202	.2459	0.4972	4.0420	10.4515	95.37	91.82	2.000	U51	
58	18.1364	15.0174	.2459	0.4972	4.1040	10.6118	96.83	93.23	2.000	U51	
59	18.6336	15.5146	.2458	0.4972	4.0660	10.5221	96.81	92.37	2.000	U51	
60	19.1308	16.0118	.2456	0.4972	4.0400	10.4719	95.95	91.78	2.000	U51	

TABLE A-18
 PELLET LINEUP FOR PIN F3B-11

PELLET NO.	DIST. FROM BOTTOM OF PIN TO TOP OF THIS PELLET (INCHES)	DIST. FROM BOTTOM OF FUEL TO TOP OF THIS PELLET (INCHES)	PELLET DIAMETER (INCHES)	PELLET LENGTH (INCHES)	PELLET WEIGHT (GRAMS)	PELLET DENSITY (GMS/CC)	PELLET DENSITY (%T.D.)	PELLET DENSITY SMEARED	PELLET O/H	BATCH NO.	PELLET NUMBER IN BATCH
1	1.1368		.2458	0.4968	4.0500	10.4892	95.71	92.01	2.000	U51	
2	1.6336		.2459	0.4968	4.0606	10.5065	95.87	92.23	2.000	U51	
3	2.1304		.2455	0.4968	4.0900	10.6187	96.89	92.92	2.000	U51	
4	2.6272		.2459	0.4968	4.0600	10.5065	95.87	92.23	2.000	U51	
5	3.1240		.2457	0.4968	4.0360	10.4614	95.46	91.69	2.000	U51	
6	3.3982	0.2742	.2450	0.2742	1.9828	9.3613	85.10	81.27	1.977	B233	133
7	3.6727	0.5487	.2450	0.2745	1.9960	9.4171	85.61	81.76	1.977	B233	134
8	3.9464	0.8224	.2449	0.2737	1.9840	9.3955	85.41	81.50	1.977	B233	135
9	4.2209	1.0969	.2449	0.2745	1.9910	9.4012	85.46	81.55	1.977	B233	136
10	4.4939	1.3699	.2449	0.2730	1.9880	9.4306	85.80	81.88	1.977	B233	137
11	4.7676	1.6436	.2450	0.2737	1.9820	9.3784	85.25	81.42	1.977	B233	138
12	5.0413	1.9173	.2451	0.2737	1.9800	9.3613	85.10	81.34	1.977	B233	139
13	5.3152	2.1912	.2451	0.2739	1.9800	9.3544	85.04	81.28	1.977	B233	140
14	5.5885	2.4645	.2449	0.2733	1.9800	9.3903	85.36	81.46	1.977	B233	141
15	5.8653	2.7413	.2449	0.2768	1.9960	9.3465	84.96	81.08	1.977	B233	142
16	6.1395	3.0155	.2448	0.2742	1.9930	9.4286	85.71	81.72	1.977	B233	143
17	6.4129	3.2889	.2446	0.2734	1.9950	9.4812	86.19	82.05	1.977	B233	144
18	6.6846	3.5606	.2447	0.2717	1.9870	9.4945	86.31	82.23	1.977	B233	145
19	6.9576	3.8336	.2446	0.2730	1.9850	9.4475	85.88	81.75	1.977	B233	146
20	7.2336	4.1096	.2448	0.2760	2.0030	9.4141	85.58	81.60	1.977	B233	147
21	7.5068	4.3828	.2449	0.2732	1.9700	9.3463	84.96	81.08	1.977	B233	148
22	7.7817	4.6577	.2450	0.2749	2.0050	9.4458	85.87	82.01	1.977	B233	149
23	8.0563	4.9323	.2448	0.2746	2.0000	9.4479	85.89	81.89	1.977	B233	150
24	8.3293	5.2053	.2449	0.2730	1.9860	9.4291	85.71	81.74	1.977	B233	151
25	8.6020	5.4780	.2449	0.2727	1.9830	9.4252	85.68	81.76	1.977	B233	152
26	8.8768	5.7528	.2441	0.2748	1.9880	9.4383	85.80	81.34	1.976	B233	153
27	9.1519	6.0279	.2440	0.2751	1.9940	9.4642	86.03	81.50	1.976	B233	154
28	9.4249	6.3009	.2443	0.2730	1.9790	9.4421	85.83	81.51	1.976	B233	155
29	9.6979	6.5739	.2443	0.2730	1.9810	9.4516	85.92	81.59	1.976	B233	156
30	9.9711	6.8471	.2443	0.2732	1.9790	9.4352	85.77	81.45	1.976	B233	157
31	10.2434	7.1194	.2442	0.2723	1.9750	9.4549	85.95	81.55	1.976	B233	158
32	10.5154	7.3914	.2444	0.2720	1.9600	9.4781	85.25	81.02	1.976	B233	159
33	10.7877	7.6637	.2440	0.2723	1.9810	9.4992	86.35	81.80	1.976	B233	160
34	11.0602	7.9362	.2447	0.2725	1.9600	9.4380	84.89	80.87	1.976	B233	161
35	11.3296	8.2056	.2441	0.2694	1.9490	9.4386	85.80	81.34	1.976	B233	162
36	11.6028	8.4788	.2443	0.2732	1.9540	9.4160	84.69	80.42	1.976	B233	163
37	11.8768	8.7528	.2440	0.2740	1.9770	9.4212	85.64	81.13	1.976	B233	164
38	12.1568	9.0328	.2439	0.2800	2.0090	9.4763	85.23	80.67	1.976	B233	165
39	12.4289	9.3049	.2441	0.2721	1.9860	9.4224	86.56	82.07	1.976	B233	166
40	12.7060	9.5820	.2441	0.2773	1.9960	9.4977	85.43	80.99	1.976	B233	167

TABLE A-18 continued (F3B-11)

PELLET NO.	DIST. FROM BOTTOM OF PIN TO TOP OF THIS PELLET (INCHES)	DIST. FROM BOTTOM OF FUEL TO TOP OF THIS PELLET (INCHES)	PELLET DIAMETER (INCHES)	PELLET LENGTH (INCHES)	PELLET WEIGHT (GRAMS)	PELLET DENSITY (GMS/CC)	PELLET DENSITY (%T.D.)	PELLET DENSITY SHEARED	PELLET O/M	BATCH NO.	PELLET NUMBER IN BATCH
*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****
41	12.9861	9.8621	.2440	0.2801	2.0270	9.4491	85.90	81.37	1.976	8233	87
42	13.2582	10.1342	.2438	0.2721	1.9720	9.4785	86.16	81.49	1.976	8233	107
43	13.5322	10.4082	.2445	0.2740	1.9770	9.4827	85.29	81.13	1.976	8233	105
44	13.8081	10.6841	.2445	0.2759	1.9990	9.4218	85.65	81.40	1.976	8233	108
45	14.0826	10.9586	.2439	0.2745	1.9800	9.4261	85.69	81.10	1.979	8233	49
46	14.3557	11.2317	.2432	0.2731	1.9880	9.5675	86.97	81.85	1.979	8233	57
47	14.6285	11.5045	.2433	0.2728	1.9780	9.5220	86.56	81.53	1.979	8233	56
48	14.9015	11.7775	.2434	0.2730	1.9870	9.5505	86.82	81.84	1.979	8233	55
49	15.1739	12.0499	.2434	0.2724	1.9840	9.5571	86.88	81.89	1.979	8233	54
50	15.4471	12.3231	.2433	0.2732	1.9840	9.5369	86.70	81.65	1.979	8233	53
51	15.7199	12.5959	.2434	0.2728	1.9840	9.5430	86.75	81.77	1.979	8233	52
52	15.9944	12.8704	.2437	0.2745	1.9800	9.4415	85.83	81.10	1.979	8233	51
53	16.2241	13.1001	.2440	0.2297	1.6420	9.3339	84.85	80.35	1.977	8233	14
54	16.4513	13.3273	.2437	0.2272	1.6330	9.4080	85.52	80.81	1.977	8233	12
55	16.6433	13.5193	.2446	0.1920	1.3910	9.4133	85.57	81.46	1.977	8233	78
56	17.1413	14.0173	.2459	0.4980	4.0730	10.5147	95.95	92.31	2.000	U51	
57	17.6393	14.5153	.2456	0.4980	4.0650	10.5197	95.99	92.12	2.000	U51	
58	18.1373	15.0133	.2458	0.4980	4.0690	10.5130	95.93	92.22	2.000	U51	
59	18.6353	15.5113	.2457	0.4980	4.1000	10.6017	96.74	92.92	2.000	U51	
60	19.1333	16.0093	.2459	0.4980	4.0690	10.5044	95.85	92.22	2.000	U51	

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TABLE A-19
 PELLET LINEUP FOR PIN F3B-12

PELLET NO.	DIST. FROM BOTTOM OF PIN TO TOP OF THIS PELLET (INCHES)	DIST. FROM BOTTOM OF FUEL TO TOP OF THIS PELLET (INCHES)	PELLET DIAMETER (INCHES)	PELLET LENGTH (INCHES)	PELLET WEIGHT (GRAMS)	PELLET DENSITY (GMS/CC)	PELLET DENSITY (MT/D.)	PELLET DENSITY SMEARED	PELLET O/M	BATCH NO.	PELLET NUMBER IN BATCH
*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****
1	1.1414		.2456	0.5014	4.0988	10.5332	96.11	93.88	2.000	U51	
2	1.6410		.2457	0.4996	4.0870	10.5342	96.12	93.97	2.000	U51	
3	2.1373		.2460	0.4963	4.0690	10.5318	96.10	94.16	2.000	U51	
4	2.6380		.2458	0.5007	4.0950	10.5231	96.02	93.95	2.000	U51	
5	3.1369		.2458	0.4989	4.0830	10.5301	96.09	94.01	2.000	U51	
6	3.5574	0.2205	.2438	0.2205	1.7000	10.4228	94.71	88.19	1.978	8237	221
7	3.5786	0.4417	.2441	0.2212	1.7050	10.3939	94.45	88.17	1.978	8237	222
8	3.8046	0.6677	.2437	0.2260	1.7350	10.3873	94.39	87.82	1.978	8237	223
9	4.0260	0.8891	.2439	0.2214	1.7070	10.4144	94.63	88.20	1.978	8237	224
10	4.2553	1.1184	.2434	0.2293	1.7630	10.4296	94.77	87.95	1.978	8237	227
11	4.4780	1.3411	.2443	0.2227	1.7130	10.3548	94.09	87.99	1.978	8237	228
12	4.7032	1.5663	.2439	0.2252	1.7240	10.3406	93.96	87.57	1.978	8237	229
13	4.9259	1.7890	.2443	0.2227	1.7160	10.3730	94.26	88.14	1.978	8237	230
14	5.1502	2.0133	.2438	0.2243	1.7290	10.4210	94.70	88.15	1.978	8237	231
15	5.3748	2.2379	.2442	0.2246	1.7270	10.3599	94.14	87.96	1.978	8237	232
16	5.6006	2.4637	.2443	0.2258	1.7420	10.3856	94.37	88.25	1.978	8237	233
17	5.8249	2.6880	.2440	0.2243	1.7240	10.3733	94.26	87.92	1.978	8237	234
18	6.0431	2.9062	.2440	0.2182	1.6900	10.4530	94.99	88.60	1.978	8237	235
19	6.2941	3.1572	.2436	0.2510	1.9370	10.4505	94.96	88.26	1.978	8237	236
20	6.5174	3.3805	.2440	0.2233	1.7200	10.3956	94.46	88.11	1.978	8237	237
21	6.7422	3.6053	.2437	0.2248	1.7320	10.4247	94.73	88.13	1.978	8237	238
22	6.9680	3.8311	.2438	0.2258	1.7480	10.4656	95.10	88.55	1.978	8237	239
23	7.1914	4.0545	.2438	0.2234	1.7280	10.4570	95.02	88.46	1.978	8237	240
24	7.4512	4.3143	.2430	0.2598	2.0020	10.4887	95.31	88.15	1.981	8237	119
25	7.7009	4.5640	.2435	0.2497	1.9170	10.4053	94.55	87.82	1.977	8237	162
26	7.9239	4.7870	.2434	0.2230	1.7280	10.5113	95.52	88.64	1.980	8237	115
27	8.1460	5.0091	.2438	0.2221	1.7080	10.3964	94.47	87.97	1.978	8237	196
28	8.3659	5.2290	.2439	0.2199	1.6910	10.3871	94.39	87.97	1.978	8237	202
29	8.5905	5.4536	.2437	0.2246	1.7250	10.3918	94.43	87.80	1.978	8237	205
30	8.8156	5.6787	.2443	0.2251	1.7380	10.3939	94.45	88.32	1.978	8237	199
31	9.0377	5.9008	.2442	0.2221	1.7180	10.4219	94.70	88.49	1.978	8237	208
32	9.2651	6.1282	.2440	0.2274	1.7530	10.4040	94.54	88.16	1.978	8237	201
33	9.4921	6.3552	.2441	0.2270	1.7530	10.4135	94.63	88.34	1.978	8237	197
34	9.7197	6.5828	.2440	0.2276	1.7500	10.3771	94.30	87.96	1.978	8237	203
35	9.9457	6.8088	.2442	0.2260	1.7390	10.3673	94.21	88.02	1.978	8237	204
36	10.1720	7.0351	.2441	0.2263	1.7380	10.3563	94.11	87.85	1.978	8237	198
37	10.3928	7.2559	.2440	0.2238	1.7010	10.3971	94.48	88.13	1.978	8237	206
38	10.6189	7.4820	.2441	0.2261	1.7440	10.4013	94.52	88.24	1.978	8237	207
39	10.8423	7.7054	.2440	0.2234	1.7230	10.4090	94.59	88.23	1.978	8237	208
40	11.0603	7.9234	.2437	0.2180	1.6770	10.4085	94.58	88.00	1.978	8237	209

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TABLE A-19 continued (F3B-12)

PELLET NO.	DIST. FROM BOTTOM OF PIN TO TOP OF THIS PELLET (INCHES)	DIST. FROM BOTTOM OF FUEL TO TOP OF THIS PELLET (INCHES)	PELLET DIAMETER (INCHES)	PELLET LENGTH (INCHES)	PELLET WEIGHT (GRAMS)	PELLET DENSITY (GMS/CC)	PELLET DENSITY (X.T.D.)	PELLET DENSITY SMEARED	PELLET Q/M	BATCH NO.	PELLET NUMBER IN BATCH
*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****
41	11.2822	8.1453	.2440	0.2219	1.7080	10.3682	94.40	88.05	1.976	8237	210
42	11.5031	8.3662	.2441	0.2209	1.7080	10.4264	94.74	88.45	1.978	8237	211
43	11.7245	8.5876	.2439	0.2214	1.7080	10.4205	94.69	88.25	1.976	8237	212
44	11.9454	8.8085	.2438	0.2209	1.6990	10.3978	94.48	87.96	1.978	8237	213
45	12.0901	8.9932	.2439	0.1447	1.1150	10.4084	94.58	88.15	1.978	8237	214
46	12.3112	9.1743	.2439	0.2211	1.7100	10.4468	94.93	88.47	1.978	8237	215
47	12.5325	9.3956	.2440	0.2213	1.7110	10.4346	94.82	88.44	1.978	8237	216
48	12.7541	9.6172	.2438	0.2216	1.7100	10.4321	94.80	88.27	1.978	8237	217
49	12.9794	9.8425	.2437	0.2253	1.7390	10.4436	94.90	88.29	1.978	8237	218
50	13.2011	10.0642	.2435	0.2217	1.7070	10.4356	94.83	88.08	1.978	8237	219
51	13.4217	10.2848	.2438	0.2206	1.7018	10.4242	94.72	88.21	1.978	8237	220
52	13.6450	10.5081	.2431	0.2233	1.7080	10.4022	94.52	87.50	1.975	8237	221
53	13.8680	10.7311	.2438	0.2230	1.7010	10.3120	93.70	87.26	1.975	8237	222
54	14.0965	10.9596	.2430	0.2285	1.7380	10.3528	94.08	87.01	1.975	8237	223
55	14.3227	11.1858	.2434	0.2262	1.7250	10.3446	94.00	87.24	1.975	8237	224
56	14.5488	11.4119	.2433	0.2261	1.7220	10.3400	93.96	87.12	1.975	8237	225
57	14.7781	11.6412	.2431	0.2293	1.7410	10.3257	93.83	86.85	1.975	8237	226
58	15.0063	11.8694	.2431	0.2282	1.7360	10.3457	94.01	87.02	1.975	8237	227
59	15.2479	12.1210	.2430	0.2416	1.8270	10.2929	93.53	86.50	1.975	8237	228
60	15.4763	12.3394	.2434	0.2284	1.7330	10.2925	93.53	86.80	1.975	8237	229
61	15.7031	12.5662	.2430	0.2268	1.7250	10.3524	94.07	87.00	1.975	8237	230
62	15.9276	12.7907	.2433	0.2245	1.7080	10.3290	93.86	87.03	1.975	8237	231
63	16.1708	13.0339	.2430	0.2432	1.8508	10.3539	94.09	87.02	1.975	8237	232
64	16.4011	13.2642	.2433	0.2303	1.7420	10.2693	93.32	86.53	1.975	8237	233
65	16.6240	13.4871	.2433	0.2229	1.6930	10.3118	93.70	86.88	1.975	8237	234
66	17.1216	13.9847	.2457	0.4976	4.0690	10.5300	96.08	93.93	2.000	U51	
67	17.6205	14.4836	.2454	0.4989	4.0720	10.5360	96.14	93.76	2.000	U51	
68	18.1163	14.9794	.2458	0.4958	4.0540	10.5267	96.00	93.92	2.000	U51	
69	18.6147	15.4778	.2456	0.4984	4.0720	10.5204	96.06	93.85	2.000	U51	
70	19.1133	15.9764	.2459	0.4986	4.0860	10.5356	96.14	94.13	2.000	U51	

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TABLE A-20
 PELLET LINEUP FOR PIN F3B-13

PELLET NO.	DIST. FROM BOTTOM OF PIN TO TOP OF THIS PELLET (INCHES)	DIST. FROM BOTTOM OF FUEL TO TOP OF THIS PELLET (INCHES)	PELLET DIAMETER (INCHES)	PELLET LENGTH (INCHES)	PELLET WEIGHT (GRAMS)	PELLET DENSITY (GMS/CC)	PELLET DENSITY (%T.P.)	PELLET DENSITY SMEARED	PELLET O/M	BATCH NO.	PELLET NUMBER IN BATCH
*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****
1	1.1408		.2455	0.5008	4.0930	10.5416	96.19	94.03	2.000	U51	
2	1.6378		.2455	0.4970	4.0630	10.5443	96.21	94.06	2.000	U51	
3	2.1349		.2459	0.4971	4.0790	10.5493	96.26	94.41	2.000	U51	
4	2.6312		.2457	0.4963	4.0600	10.5342	96.12	94.12	2.000	U51	
5	3.1306		.2457	0.4994	4.0860	10.5359	96.14	94.13	2.000	U51	
6	3.4099	0.2793	.2443	0.2793	2.1400	9.9799	90.72	87.82	1.980	B233	489
7	3.6837	0.5531	.2439	0.2738	2.1020	10.0324	91.20	88.00	1.980	B233	484
8	3.9619	0.8313	.2441	0.2782	2.1290	9.9842	90.76	87.72	1.980	B233	483
9	4.2554	1.1246	.2439	0.2935	2.2170	9.8711	89.73	86.58	1.980	B233	482
10	4.5390	1.4084	.2443	0.2836	2.1730	9.9802	90.72	87.82	1.980	B233	481
11	4.8176	1.6870	.2443	0.2786	2.1310	9.9629	90.57	87.67	1.980	B233	480
12	5.0983	1.9677	.2438	0.2807	2.1260	9.9057	90.05	86.81	1.980	B233	478
13	5.3779	2.2473	.2444	0.2796	2.1370	9.9471	90.42	87.61	1.980	B233	477
14	5.6571	2.5265	.2442	0.2792	2.1340	9.9637	90.57	87.61	1.980	B233	476
15	5.9347	2.8041	.2440	0.2776	2.1300	10.0167	91.07	87.95	1.980	B233	475
16	6.2283	3.0977	.2443	0.2936	2.2440	9.9552	90.50	87.61	1.980	B233	474
17	6.5086	3.3780	.2442	0.2803	2.1430	9.9664	90.60	87.63	1.980	B233	473
18	6.7858	3.6552	.2443	0.2772	2.1210	9.9662	90.60	87.70	1.980	B233	472
19	7.0818	3.9512	.2444	0.2960	2.2540	9.9104	90.09	87.28	1.980	B233	471
20	7.3809	4.2503	.2444	0.2991	2.2700	9.8773	89.79	86.99	1.980	B233	470
21	7.6728	4.5422	.2440	0.2919	2.2390	10.0155	91.05	87.92	1.980	B233	469
22	7.9675	4.8369	.2442	0.2947	2.2530	9.9660	90.60	87.63	1.980	B233	468
23	8.2626	5.1320	.2440	0.2951	2.2510	9.9600	90.54	87.43	1.980	B233	467
24	8.5613	5.4307	.2444	0.2967	2.2680	9.9818	89.83	87.03	1.980	B233	466
25	8.8519	5.7213	.2442	0.2906	2.2210	9.9631	90.57	87.60	1.980	B233	465
26	9.1471	6.0165	.2443	0.2952	2.2570	9.9586	90.53	87.64	1.980	B233	464
27	9.4410	6.3104	.2443	0.2930	2.2400	9.9273	90.24	87.36	1.980	B233	463
28	9.7349	6.6043	.2440	0.2939	2.2400	9.9518	90.47	87.36	1.980	B233	462
29	1.0236	6.8930	.2443	0.2987	2.2070	9.9173	90.52	87.62	1.980	B233	461
30	10.3174	7.1868	.2444	0.2938	2.2540	9.9846	90.76	87.94	1.980	B233	460
31	10.6104	7.4798	.2441	0.2930	2.2380	9.9652	90.59	87.55	1.980	B233	459
32	10.9033	7.7727	.2440	0.2929	2.2440	10.0036	90.94	87.81	1.980	B233	458
33	11.1603	8.0627	.2439	0.2570	1.9550	9.9408	90.37	87.19	1.980	B233	508
34	11.4112	8.2806	.2444	0.2509	1.9170	9.9437	90.39	87.58	1.980	B233	507
35	11.7002	8.5696	.2442	0.2890	2.1980	9.9145	90.13	87.16	1.980	B233	487
36	11.9502	8.8196	.2443	0.2500	1.9070	9.9356	90.32	87.43	1.980	B233	505
37	12.2066	9.0702	.2444	0.2566	1.9640	9.9612	90.55	87.73	1.980	B233	504
38	12.4633	9.3327	.2441	0.2565	1.9440	9.8879	89.89	86.87	1.980	B233	503
39	12.7170	9.5864	.2441	0.2537	1.9100	9.8222	89.29	86.29	1.980	B233	502
40	12.9745	9.8439	.2442	0.2575	1.9490	9.8668	89.69	86.70	1.980	B233	501

TABLE A-20 continued (F3B-13)

PELLET NO.	DIST. FROM BOTTOM OF PIN TO TOP OF THIS PELLET (INCHES)	DIST. FROM BOTTOM OF FUEL TO TOP OF THIS PELLET (INCHES)	PELLET DIAMETER (INCHES)	PELLET LENGTH (INCHES)	PELLET WEIGHT (GRAMS)	PELLET DENSITY (GMS/CC)	PELLET DENSITY (%T.D.)	PELLET DENSITY SMEARED	PELLET C/M	BATCH NO.	PELLET NUMBER IN BATCH
*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****
41	13.2598	10.1892	.2444	0.2853	2.1800	9.9445	90.40	67.58	1.983	8233	508
42	13.5568	10.4262	.2443	0.2970	2.2660	9.9377	90.34	67.45	1.983	8233	499
43	13.8628	10.7322	.2441	0.3060	2.3110	9.8531	89.57	66.57	1.983	8233	496
44	14.1719	11.0413	.2442	0.3091	2.3370	9.8560	89.60	66.66	1.983	8233	495
45	14.4693	11.3587	.2442	0.3174	2.3940	9.8323	89.38	66.45	1.983	8233	494
46	14.7655	11.6549	.2444	0.2962	2.2410	9.8466	89.51	66.72	1.983	8233	493
47	15.0836	11.9530	.2441	0.2981	2.2500	9.8473	89.92	66.51	1.983	8233	492
48	15.3928	12.2622	.2441	0.3092	2.3400	9.8735	89.75	66.74	1.983	8233	491
49	15.6826	12.5520	.2440	0.2858	2.1860	9.8492	89.53	66.46	1.983	8233	490
50	15.9769	12.8463	.2442	0.2943	2.2300	9.8777	89.79	66.65	1.983	8233	489
51	16.2718	13.1412	.2443	0.2949	2.2380	9.8848	89.86	66.99	1.983	8233	488
52	16.6408	13.5102	.2441	0.3690	2.7700	9.7937	89.03	66.04	1.983	8233	509
53	17.1386	14.0080	.2458	0.4978	4.0810	10.5482	96.25	94.32	2.000	U51	
54	17.6387	14.5881	.2459	0.5001	4.0840	10.4989	95.80	93.96	2.000	U51	
55	18.1402	15.0096	.2457	0.5015	4.1000	10.5277	96.06	94.06	2.000	U51	
56	18.6366	15.5060	.2457	0.4964	4.0590	10.5295	96.08	94.08	2.000	U51	
57	19.1328	16.0022	.2456	0.4962	4.0530	10.5267	96.05	93.96	2.000	U51	

TABLE A-21
 PELLET LINEUP FOR PIN F3B-14

PELLET NO.	DIST. FROM BOTTOM OF PIN TO TOP OF THIS PELLET (INCHES)	DIST. FROM BOTTOM OF FUEL TO TOP OF THIS PELLET (INCHES)	PELLET DIAMETER (INCHES)	PELLET LENGTH (INCHES)	PELLET HEIGHT (GRAMS)	PELLET DENSITY (GMS/CC)	PELLET DENSITY (XT,U,)	PELLET DENSITY SMEARED	PELLET O/H	BATCH NO.	PELLET NUMBER IN BATCH
*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****
1	1.1378		.2457	0.4978	4.0130	10.3809	94.72	98.75	2.000	U51	
2	1.6356		.2454	0.4978	4.0790	10.5774	96.92	94.28	2.000	U51	
3	2.1334		.2457	0.4978	4.0990	10.6034	95.75	94.74	2.000	U51	
4	2.6312		.2459	0.4978	4.0850	10.5500	96.27	94.41	2.000	U51	
5	3.1290		.2460	0.4978	4.0830	10.5362	96.14	94.37	2.000	U51	
6	3.3412	0.2122	.2439	0.2122	1.6100	10.2484	93.13	86.93	1.999	B237	380
7	3.5543	0.4853	.2442	0.2131	1.6190	10.2361	93.02	87.05	1.999	B237	379
8	3.7698	0.6408	.2442	0.2155	1.6180	10.1159	91.92	86.03	1.999	B237	378
9	3.9815	0.8525	.2443	0.2117	1.6210	10.3078	93.67	87.73	1.999	B237	377
10	4.1947	1.0657	.2442	0.2132	1.6220	10.2503	93.14	87.17	1.999	B237	376
11	4.4095	1.2805	.2441	0.2148	1.6330	10.2516	93.16	87.11	1.999	B237	375
12	4.6219	1.4929	.2443	0.2124	1.6180	10.2548	93.19	87.28	1.999	B237	374
13	4.8345	1.7055	.2443	0.2126	1.6230	10.2769	93.39	87.47	1.999	B237	372
14	5.0483	1.9193	.2443	0.2138	1.6400	10.3262	93.83	87.89	1.999	B237	371
15	5.2670	2.1380	.2443	0.2187	1.6720	10.2918	93.52	87.60	1.999	B237	370
16	5.4825	2.3535	.2439	0.2155	1.6260	10.2264	92.93	86.45	1.999	B237	368
17	5.6995	2.5705	.2442	0.2170	1.6570	10.2881	93.49	87.49	1.999	B237	365
18	5.9149	2.7859	.2440	0.2154	1.6220	10.1628	92.35	86.28	1.999	B237	364
19	6.1321	3.0031	.2444	0.2172	1.6600	10.2798	93.41	87.57	1.999	B237	363
20	6.3571	3.2281	.2439	0.2250	1.7080	10.2537	93.17	86.98	1.999	B237	494
21	6.5712	3.4422	.2441	0.2141	1.6320	10.2788	93.40	87.34	1.999	B237	498
22	6.7967	3.6677	.2441	0.2255	1.7200	10.2854	93.46	87.39	1.999	B237	492
23	7.0182	3.8892	.2441	0.2215	1.6860	10.2642	93.27	87.21	1.999	B237	491
24	7.2387	4.1097	.2443	0.2205	1.6820	10.2689	93.31	87.40	1.999	B237	490
25	7.4691	4.3401	.2444	0.2304	1.7670	10.3155	93.74	87.87	1.999	B237	489
26	7.6909	4.5619	.2441	0.2218	1.6870	10.2544	93.20	87.15	1.999	B237	488
27	7.9109	4.7819	.2438	0.2200	1.6820	10.3359	93.92	87.60	1.999	B237	485
28	8.1345	5.0055	.2442	0.2236	1.7090	10.2978	93.58	87.57	1.999	B237	484
29	8.3670	5.2300	.2443	0.2325	1.7750	10.2773	93.39	87.47	1.999	B237	483
30	8.5966	5.4676	.2439	0.2296	1.7550	10.3248	93.82	87.58	1.999	B237	482
31	8.8169	5.6879	.2440	0.2203	1.6780	10.2798	93.41	87.27	1.999	B237	481
32	9.0451	5.9161	.2444	0.2282	1.7500	10.3148	93.73	87.87	1.999	B237	480
33	9.2681	6.1391	.2444	0.2230	1.7020	10.2658	93.28	87.45	1.999	B237	479
34	9.4926	6.3636	.2444	0.2245	1.7200	10.3050	93.64	87.78	1.999	B237	469
35	9.7118	6.5828	.2443	0.2192	1.6730	10.2745	93.36	87.45	1.999	B237	478
36	9.9001	6.7711	.2443	0.1863	1.4370	10.2733	93.35	87.44	1.999	B237	467
37	10.1233	6.9943	.2444	0.2232	1.7000	10.2445	93.09	87.27	1.999	B237	468
38	10.3457	7.2167	.2443	0.2224	1.7000	10.2901	93.31	87.58	1.999	B237	474
39	10.5731	7.4441	.2444	0.2274	1.7350	10.2624	93.25	87.42	1.999	B237	475
40	10.8049	7.6759	.2438	0.2318	1.7600	10.2646	93.27	86.99	1.999	B237	476

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TABLE A-21 continued (F3B-14)

PELLET NO.	DIST. FROM BOTTOM OF PIN TO TOP OF THIS PELLET (INCHES)	DIST. FROM BOTTOM OF FUEL TO TOP OF THIS PELLET (INCHES)	PELLET DIAMETER (INCHES)	PELLET LENGTH (INCHES)	PELLET WEIGHT (GRAMS)	PELLET DENSITY (GMS/CC)	PELLET DENSITY (%T,P.)	PELLET DENSITY SMEARED	PELLET O/M	BATCH NO.	PELLET NUMBER IN BATCH
*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****
41	11.0230	7.8940	,2439	0.2181	1.6550	10,2499	93,14	86,94	1,999	8237	471
42	11.2420	8.1130	,2438	0.2190	1.6700	10,3090	93,68	87,37	1,999	8237	477
43	11.4276	8.2786	,2439	0.1856	1.4120	10,2762	93,38	87,17	1,999	8237	472
44	11.6474	8.5184	,2439	0.2198	1.6700	10,2698	93,26	87,05	1,999	8237	473
45	11.8467	8.7177	,2435	0.1993	1.5200	10,3368	93,93	87,38	1,999	8237	476
46	12.0277	8.8987	,2437	0.1910	1.3800	10,3161	93,74	87,36	2,000	8237	419
47	12.2397	9.1107	,2433	0.2120	1.6150	10,3425	93,98	87,26	2,000	8237	398
48	12.4534	9.3244	,2442	0.2137	1.6240	10,2389	93,04	87,07	2,000	8237	397
49	12.6680	9.5390	,2438	0.2146	1.6280	10,2558	93,19	86,92	2,000	8237	396
50	12.8810	9.7920	,2442	0.2130	1.6300	10,3105	93,69	87,68	2,000	8237	395
51	13.0950	9.9660	,2441	0.2140	1.6340	10,2962	93,56	87,48	2,000	8237	398
52	13.3070	10.1780	,2442	0.2120	1.6170	10,2765	93,38	87,39	2,000	8237	391
53	13.5204	10.3914	,2437	0.2134	1.6190	10,2652	93,28	86,93	2,000	8237	390
54	13.7342	10.6052	,2443	0.2138	1.6330	10,2821	93,43	87,51	2,000	8237	389
55	13.9482	10.8192	,2442	0.2140	1.6310	10,2686	93,31	87,32	2,000	8237	388
56	14.1620	11.0330	,2441	0.2138	1.6310	10,2870	93,48	87,41	2,000	8237	387
57	14.3772	11.2482	,2439	0.2152	1.6300	10,2311	92,97	86,78	2,000	8237	386
58	14.5922	11.4632	,2433	0.2150	1.6340	10,3181	93,76	87,06	2,000	8237	385
59	14.8060	11.6770	,2444	0.2138	1.6300	10,2546	93,18	87,35	2,000	8237	384
60	15.0196	11.8906	,2443	0.2136	1.6250	10,2414	93,06	87,17	2,000	8237	383
61	15.2324	12.1034	,2443	0.2128	1.6300	10,3115	93,70	87,76	2,000	8237	382
62	15.4450	12.3160	,2441	0.2126	1.6240	10,3076	93,60	87,52	2,000	8237	381
63	15.6009	12.4719	,2440	0.1559	1.1800	10,2151	92,82	86,72	2,000	8237	380
64	15.8186	12.6896	,2442	0.2177	1.6640	10,2984	93,58	87,58	1,999	8237	496
65	16.0109	12.8819	,2440	0.1923	1.4370	10,0852	91,64	85,62	1,999	8237	356
66	16.2329	13.1039	,2444	0.2220	1.6820	10,1969	92,60	86,81	2,000	8237	428
67	16.4439	13.3149	,2439	0.2110	1.6000	10,2427	93,07	86,88	1,999	8237	276
68	16.6553	13.5263	,2441	0.2114	1.6080	10,2570	93,20	87,15	2,000	8237	405
69	17.1527	14.0237	,2458	0.4974	4.0790	10,5515	96,28	94,35	2,000	U51	
70	17.6501	14.5211	,2460	0.4974	4.0800	10,5370	96,15	94,37	2,000	U51	
71	18.1475	15.0185	,2459	0.4974	4.0380	10,4370	95,24	93,40	2,000	U51	
72	18.6449	15.5159	,2455	0.4974	4.0830	10,5677	96,61	94,44	2,000	U51	
73	19.1423	16.0133	,2458	0.4974	4.0790	10,5515	96,28	94,35	2,000	U51	

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TABLE A-22
 PELLET LINEUP FOR PIN F3B-15

PELLET NO.	DIST. FROM BOTTOM OF PIN TO TOP OF THIS PELLET (INCHES)	DIST. FROM BOTTOM OF FUEL TO TOP OF THIS PELLET (INCHES)	PELLET DIAMETER (INCHES)	PELLET LENGTH (INCHES)	PELLET WEIGHT (GRAMS)	PELLET DENSITY (GMS/CC)	PELLET DENSITY (%T.D.)	PELLET DENSITY SMEARED	PELLET O/M	BATCH NO.	PELLET NUMBER IN BATCH
*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****
1	1.1362		.2459	0.4962	4.0560	10.5088	95.89	94.05	2.000	U51	
2	1.6324		.2459	0.4962	4.0540	10.5037	95.84	94.00	2.000	U51	
3	2.1286		.2459	0.4962	4.0530	10.5011	95.82	93.96	2.000	U51	
4	2.6248		.2458	0.4962	4.0670	10.5459	96.23	94.30	2.000	U51	
5	3.1210		.2459	0.4962	4.0250	10.4285	95.16	93.33	2.000	U51	
6	3.3780	0.2970	.2439	0.2970	1.9370	9.8493	89.50	86.36	2.000	8237	518
7	3.6298	0.5088	.2443	0.2518	1.8960	9.8077	89.12	86.27	2.000	8237	519
8	3.8836	0.7626	.2441	0.2538	1.9080	9.8080	89.12	86.14	2.000	8237	520
9	4.1337	1.0127	.2443	0.2501	1.8710	9.7442	88.54	85.71	2.000	8237	521
10	4.3947	1.2737	.2441	0.2610	1.9700	9.8474	89.46	86.46	2.000	8237	522
11	4.6458	1.5248	.2441	0.2511	1.8840	9.7888	88.95	85.97	2.000	8237	523
12	4.9183	1.7973	.2437	0.2725	2.0440	9.8183	89.22	85.94	2.000	8237	524
13	5.1839	2.0629	.2443	0.2656	2.0000	9.8081	89.13	86.28	2.000	8237	525
14	5.4439	2.3229	.2438	0.2600	1.9450	9.7838	88.91	85.71	2.000	8237	526
15	5.7177	2.5967	.2443	0.2738	2.0500	9.7522	88.62	85.79	2.000	8237	527
16	5.9821	2.8611	.2443	0.2644	1.9880	9.7935	88.99	86.15	2.000	8237	528
17	6.2479	3.1269	.2441	0.2658	1.9950	9.7923	88.98	86.00	2.000	8237	529
18	6.5118	3.3908	.2442	0.2639	1.9810	9.7855	88.92	86.01	2.000	8237	530
19	6.7766	3.6556	.2440	0.2648	1.9900	9.8127	89.17	86.11	2.000	8237	531
20	7.0463	3.9253	.2443	0.2697	2.0260	9.7846	88.91	86.07	2.000	8237	532
21	7.3134	4.1924	.2438	0.2671	2.0000	9.7931	88.99	85.79	2.000	8237	533
22	7.5766	4.4556	.2438	0.2632	1.9780	9.8289	89.31	86.11	2.000	8237	534
23	7.8333	4.7123	.2433	0.2567	1.9700	10.0783	91.58	87.93	2.000	8237	535
24	8.0926	4.9716	.2443	0.2593	1.9540	9.8154	89.19	86.34	2.000	8237	536
25	8.3586	5.2476	.2440	0.2700	2.0720	9.8024	89.07	86.02	2.000	8237	537
26	8.6299	5.5089	.2438	0.2613	1.9580	9.8082	89.05	85.86	2.000	8237	538
27	8.8707	5.7497	.2439	0.2408	1.8020	9.7793	88.86	85.74	1.999	8237	539
28	9.1348	6.0138	.2443	0.2641	2.0030	9.8786	89.77	86.96	1.999	8237	540
29	9.4094	6.2884	.2441	0.2746	2.0810	9.8871	89.84	86.83	1.999	8237	541
30	9.6704	6.5494	.2441	0.2610	1.9710	9.8524	89.53	86.52	1.999	8237	542
31	9.9282	6.8072	.2441	0.2578	1.9500	9.8684	89.67	86.67	1.999	8237	543
32	10.1878	7.0668	.2442	0.2596	1.9530	9.8070	89.12	86.20	1.999	8237	544
33	10.3820	7.2610	.2436	0.1942	1.4550	9.8150	89.19	85.84	1.999	8237	545
34	10.6461	7.5251	.2442	0.2641	1.9900	9.8225	89.26	86.33	1.999	8237	546
35	10.9073	7.7863	.2443	0.2612	1.9580	9.7639	88.72	85.89	1.999	8237	547
36	11.1646	8.0436	.2441	0.2573	1.9340	9.8465	89.11	86.12	1.999	8237	548
37	11.4262	8.3052	.2441	0.2616	1.9680	9.8148	89.19	86.20	1.999	8237	549
38	11.6542	8.5532	.2442	0.2580	1.9490	9.8476	89.46	86.55	1.999	8237	550
39	11.9408	8.8198	.2439	0.2566	1.9130	9.7424	88.53	85.42	1.999	8237	551
40	12.2009	9.0799	.2440	0.2631	1.9560	9.8193	89.23	86.10	1.999	8237	552

TABLE A-22 continued (F3B-15)

PELLET NO.	DIST. FROM BOTTOM OF PIN TO TOP OF THIS PELLET (INCHES)	DIST. FROM BOTTOM OF FUEL TO TOP OF THIS PELLET (INCHES)	PELLET DIAMETER (INCHES)	PELLET LENGTH (INCHES)	PELLET WEIGHT (GRAMS)	PELLET DENSITY (GMS/CC)	PELLET DENSITY (%T.D.)	PELLET DENSITY SMEARED	PELLET O/M	BATCH NO.	PELLET NUMBER IN BATCH
*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****
41	12.4651	9.3441	.2439	0.2642	1.9900	9.8430	89.44	86.30	1.999	8237	547
42	12.7261	9.6851	.2440	0.2610	1.9660	9.8355	89.37	86.31	1.999	8237	548
43	12.9860	9.8650	.2438	0.2599	1.9520	9.8228	89.26	86.05	1.999	8237	549
44	13.2465	10.1255	.2433	0.2605	1.9710	9.9363	90.29	86.69	1.999	8237	579
45	13.5075	10.3865	.2432	0.2610	1.9810	9.9758	90.65	86.96	1.999	8237	574
46	13.7672	10.6462	.2433	0.2597	1.9770	9.9973	90.84	87.22	1.999	8237	575
47	14.0252	10.9042	.2433	0.2580	1.9540	9.9461	90.38	86.78	1.999	8237	572
48	14.2875	11.1665	.2433	0.2623	1.9900	9.9633	90.54	86.93	1.999	8237	571
49	14.5473	11.4263	.2431	0.2598	1.9690	9.9694	90.59	86.84	1.999	8237	570
50	14.7906	11.6896	.2431	0.2433	1.8410	9.9534	90.45	86.70	1.999	8237	568
51	15.0531	11.9821	.2432	0.2625	1.9930	9.9789	90.68	86.99	1.999	8237	567
52	15.3095	12.1885	.2434	0.2564	1.9400	9.9283	90.22	86.69	1.999	8237	566
53	15.5645	12.4435	.2440	0.2550	1.9090	9.7750	88.82	85.77	2.000	8237	517
54	15.8286	12.7076	.2440	0.2641	1.9730	9.7546	88.64	85.60	2.000	8237	548
55	16.1006	12.9996	.2431	0.2720	2.0280	9.8075	89.12	85.43	2.000	8237	542
56	16.3738	13.2828	.2439	0.2732	2.0360	9.7388	88.50	85.39	2.000	8237	541
57	16.6422	13.5212	.2430	0.2684	2.0130	9.8737	89.72	85.93	2.000	8237	540
58	17.1364	14.0154	.2460	0.4942	4.0660	10.5688	96.44	94.66	2.000	U51	
59	17.6306	14.5096	.2459	0.4942	4.0930	10.6476	97.16	95.29	2.000	U51	
60	18.1248	15.0038	.2457	0.4942	4.0720	10.6102	96.82	94.80	2.000	U51	
61	18.6190	15.4980	.2459	0.4942	3.9290	10.2210	93.26	91.47	2.000	U51	
62	19.1132	15.9922	.2460	0.4942	4.0380	10.4960	95.77	94.01	2.000	U51	

TABLE A-23
 PELLET LINEUP FOR PIN F3B-16

PELLET NO.	DIST. FROM BOTTOM OF PIN TO TOP OF THIS PELLET (INCHES)	DIST. FROM BOTTOM OF FUEL TO TOP OF THIS PELLET (INCHES)	PELLET DIAMETER (INCHES)	PELLET LENGTH (INCHES)	PELLET WEIGHT (GRAMS)	PELLET DENSITY (GMS/CC)	PELLET DENSITY (%T.D.)	PELLET DENSITY SMEARED	PELLET O/M	BATCH NO.	PELLET NUMBER IN BATCH
*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****
1	1.1373		.2458	0.4973	4.0630	10.5122	95.92	94.00	2.000	U51	
2	1.6357		.2458	0.4984	4.0810	10.5355	96.13	94.21	2.000	U91	
3	2.1319		.2460	0.4962	4.0610	10.5132	95.93	94.16	2.000	U91	
4	2.6315		.2459	0.4996	4.0940	10.5351	96.13	94.28	2.000	U51	
5	3.1311		.2456	0.4996	4.0810	10.5273	96.06	93.96	2.000	U91	
6	3.4054	0.2743	.2440	0.2743	1.9838	9.4395	85.81	82.86	1.977	8233	68
7	3.6794	0.5483	.2440	0.2740	1.9808	9.4355	85.77	82.83	1.977	8233	67
8	3.9541	0.8230	.2443	0.2747	1.9828	9.3979	85.43	82.70	1.977	8233	66
9	4.2287	1.0976	.2442	0.2744	1.9808	9.3995	85.45	82.65	1.977	8233	65
10	4.5042	1.3731	.2433	0.2755	1.9430	9.2619	84.19	80.84	1.977	8233	64
11	4.7785	1.6474	.2444	0.2743	1.9830	9.4086	85.53	82.86	1.977	8233	64
12	5.0528	1.9217	.2444	0.2743	1.9900	9.4418	85.83	83.16	1.979	8233	59
13	5.3279	2.1968	.2442	0.2751	1.9928	9.4393	85.81	83.00	1.979	8233	46
14	5.6013	2.4702	.2443	0.2734	1.9838	9.4473	85.88	83.14	1.979	8233	43
15	5.8737	2.7426	.2443	0.2724	1.9738	9.4342	85.76	83.02	1.977	8233	37
16	6.1457	3.0146	.2440	0.2720	1.9700	9.4569	85.97	83.02	1.977	8233	36
17	6.4218	3.2907	.2442	0.2761	1.9788	9.3390	84.90	82.12	1.977	8233	35
18	6.6966	3.5655	.2444	0.2748	1.9708	9.3299	84.81	82.17	1.977	8233	34
19	6.9714	3.8403	.2443	0.2748	1.9798	9.3802	85.27	82.55	1.977	8233	33
20	7.2461	4.1150	.2444	0.2747	1.9808	9.3807	85.27	82.62	1.977	8233	32
21	7.5204	4.3893	.2442	0.2743	1.9878	9.4430	85.84	83.03	1.977	8233	31
22	7.7969	4.6658	.2431	0.2765	1.9748	9.3910	85.37	81.83	1.977	8233	30
23	8.0709	4.9398	.2442	0.2740	1.9808	9.4201	85.63	82.83	1.977	8233	29
24	8.3402	5.2091	.2435	0.2693	1.9508	9.4936	86.30	83.00	1.983	8233	184
25	8.6143	5.4832	.2444	0.2741	1.9738	9.3680	85.16	82.51	1.977	8233	183
26	8.9113	5.7802	.2433	0.2970	2.1170	9.3608	85.09	81.70	1.977	8233	182
27	9.1796	6.0485	.2439	0.2683	1.9508	9.4978	86.34	83.31	1.983	8233	181
28	9.4493	6.3182	.2439	0.2697	1.9408	9.4000	85.45	82.45	1.983	8233	180
29	9.7174	6.5863	.2439	0.2681	1.9410	9.4610	86.00	82.96	1.977	8233	179
30	9.9922	6.8611	.2439	0.2748	1.9790	9.4110	85.55	82.55	1.977	8233	178
31	10.2671	7.1360	.2440	0.2749	1.9450	9.2384	83.96	81.10	1.977	8233	177
32	10.5348	7.4037	.2439	0.2677	1.9460	9.4995	86.36	83.32	1.983	8233	176
33	10.8106	7.6795	.2438	0.2758	1.9378	9.1854	83.50	80.50	1.977	8233	175
34	11.0846	7.9535	.2430	0.2740	1.9800	9.5133	86.48	82.83	1.979	8233	174
35	11.3574	8.2263	.2433	0.2728	1.9818	9.5365	86.69	83.23	1.979	8233	173
36	11.6310	8.4999	.2435	0.2736	1.9888	9.2265	86.60	83.26	1.979	8233	172
37	11.9057	9.7746	.2437	0.2747	1.9930	9.4966	86.33	83.16	1.979	8233	171
38	12.1782	9.0471	.2436	0.2725	1.9810	9.5234	86.57	83.33	1.979	8233	170
39	12.4522	9.3211	.2435	0.2740	1.9888	9.5126	86.47	83.16	1.979	8233	169
40	12.7302	9.5991	.2442	0.2780	2.0100	9.4252	85.68	82.87	1.983	8233	168

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TABLE A-23 continued (F3B-16)

PELLET NO.	DIST. FROM BOTTOM OF PIN TO TOP OF THIS PELLET (INCHES)	DIST. FROM BOTTOM OF FUEL TO TOP OF THIS PELLET (INCHES)	PELLET DIAMETER (INCHES)	PELLET LENGTH (INCHES)	PELLET WEIGHT (GRAMS)	PELLET DENSITY (GMS/CC)	PELLET DENSITY (%T,P,)	PELLET DENSITY SMEARED	PELLET O/M	BATCH NO.	PELLET NUMBER IN BATCH
*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****
41	12.9997	9.8686	.2443	0.2695	1.9560	9.4535	85.94	83.19	1.983	8233	178
42	13.2687	10.1376	.2440	0.2690	1.9320	9.3779	85.25	82.32	1.983	8233	177
43	13.5377	10.4066	.2444	0.2690	1.9540	9.4537	85.94	88.20	1.983	8233	176
44	13.8068	10.6757	.2433	0.2691	1.9150	9.3455	84.95	81.57	1.983	8233	175
45	14.0760	10.9449	.2439	0.2692	1.9450	9.4417	85.83	82.81	1.983	8233	174
46	14.3448	11.2137	.2444	0.2688	1.9520	9.4510	85.91	83.24	1.983	8233	173
47	14.6140	11.4829	.2442	0.2692	1.9470	9.4282	85.71	82.90	1.983	8233	172
48	14.8855	11.7544	.2444	0.2715	1.9560	9.3762	85.23	82.58	1.983	8233	171
49	15.1530	12.0219	.2441	0.2675	1.9470	9.4959	86.32	83.43	1.983	8233	170
50	15.4207	12.2896	.2442	0.2677	1.9590	9.5395	86.72	83.88	1.983	8233	169
51	15.6927	12.5616	.2443	0.2720	1.9390	9.2852	84.41	81.71	1.983	8233	168
52	15.9644	12.8333	.2431	0.2717	1.9150	9.2713	84.28	80.79	1.983	8233	167
53	16.2347	13.1036	.2439	0.2703	1.9560	9.4565	85.96	82.94	1.983	8233	166
54	16.5033	13.3722	.2440	0.2686	1.9460	9.4599	86.00	83.04	1.983	8233	165
55	16.7740	13.6429	.2442	0.2707	1.9570	9.4241	85.67	82.86	1.983	8233	164
56	16.8858	13.7847	.2441	0.1118	0.7980	9.3123	84.65	81.81	1.983	8233	163
57	17.3847	14.2836	.2457	0.4969	4.0820	10.5361	96.14	94.14	2.000	U51	
58	17.8868	14.7557	.2459	0.5021	4.1080	10.5185	95.98	94.13	2.000	U51	
59	18.3847	15.2836	.2459	0.4979	4.0770	10.5272	96.06	94.21	2.000	U51	
60	18.8841	15.7530	.2459	0.4994	4.0910	10.5316	96.10	94.25	2.000	U51	
61	19.3825	16.2514	.2460	0.4984	4.0810	10.5184	95.98	94.21	2.000	U51	

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Table A-24

**SPECTROCHEMICAL ANALYSIS OF MIXED OXIDE FUEL PELLETS
FROM BATCHES B-233 AND B-237^(a) (F3A SERIES PINS)**

Element	ppm	Element	ppm
Ag	< 0.1	Mo	< 3
Al	< 4	Ni	< 15
B	< 1	Pb	< 1
Be	< 0.5	Si	< 10
Ca	< 25	Sn	< 1
Cd	< 2	V	< 3
Co	< 1	Zn	< 10
Cr	8	P	< 50
Cu	< 1	Li	< 10
Fe	150	Na	< 15
Mg	< 2	Bi	< 1
Mn	< 1		

(a) The analysis from one batch was indistinguishable from that of the other.

Table A-25

RESULTS OF GAS ANALYSIS FROM MIXED OXIDE FUEL BATCH B-237 PERFORMED IN JULY 1971

Total Gas Evolved: 134 $\mu\text{l/gm}$

Species	Percent
He	2.4
H ₂	76.4
O ₂	0.0
N ₂	2.7
CH ₄	1.0
CO	<u>17.5</u>
	100.0

Sample (1 gm) was outgassed at 1700°C and 10⁻⁶ torr. Resulting gas was chromatographically analyzed.

Table A-26
CARBON AND HALOGEN CONTENT OF F3A SERIES FUEL

Batch	B-233	B-237
Used in Pins F3B-	2, 4, 5, 6, 8, 10, ^(a) 11	1, 3, 7, 9, 10, ^(a) 12, 14, 15
Carbon, ppm	1120	420
Chlorine, ppm	< 1 ^(b)	Not Analyzed
Fluorine, ppm	2 ^(b)	Not Analyzed

(a) F3B-10 had batch B-237 in top 0.606 inch and in bottom 1.894 inch; remainder was B-233.

(b) Retest values are given in the table; previous analysis on B-233 gave <10 ppm Cl and <5 ppm F.

Figure A-1. Axial Temperature Distribution F3B1 Coolant and Cladding

Figure A-2. Axial Temperature Distribution F3B1 Fuel

Figure A-3. Axial Temperature Distribution F3B2 Coolant and Cladding

Figure A-4. Axial Distribution F3B2 Fuel

Figure A-5. Axial Temperature Distribution F3B3 Coolant and Cladding

Figure A-6. Axial Temperature Distribution F3B3 Fuel

Figure A-7. Axial Temperature Distribution F3B5 Coolant and Cladding

Figure A-8. Axial Temperature Distribution F3B5 Fuel

Figure A-9. Axial Temperature Distribution F3B7 Coolant and Cladding

Figure A-10. Axial Temperature Distribution F3B7 Fuel

Figure A-11. Axial Temperature Distribution F3B10 Coolant and Cladding

Figure A-12. Axial Temperature Distribution F3B10

APPENDIX B

CLADDING PROPERTIES AND POST-IRRADIATION SECTION DIAGRAMS

Table B-1

**CHEMICAL COMPOSITION AND PROPERTIES OF GROUP F3A FUEL CLADDING
IN THE PRE-IRRADIATION CONDITION (SUPPLIERS CERTIFICATION)^(a)**

	Heat Number 46533 316 Clad Fuel Pins	Heat Number Armco 840505 304L Clad Fuel Pins
Carbon wt %	0.06, 0.07	0.030, 0.021
Manganese wt %	1.66, 1.71	1.37
Phosphorous wt %	0.023, 0.018	0.010
Sulphur wt %	0.012, 0.014	0.007
Silicon wt %	0.67, 0.67	0.62
Nickel wt %	13.50, 13.53	9.26
Chromium wt %	17.17, 17.31	18.29
Molybdenum wt %	2.75, 2.93	0.02
Yield Strength, ksi	36.3, 36.3	
Ultimate Strength, ksi	84.8, 85.7	-
Elongation, %	58, 60	-
Hardness, Rockwell B	58/59	60/62
ASTM Grain Size Number ^(a)	5	-
Hydrostatic, psi	2200	-
Inclusion Count, ASTM ^(a)	C-1 Thin	C-2 Thin

(a) Inclusion count by GE. Pre-irradiation grain size measurements by GE:

ASTM 5-1/2 on F3B-1 cladding (316),
ASTM 5 on F3B-2 cladding (316),
ASTM 5-1/2 on F3B-7 cladding (304L),
ASTM 5 on F3B-10 cladding (304L).

Reference: GE Breeder Reactor Development Operation memorandum,
W. K. Appleby to W. E. Boily, "F3A Series Fuel Pins--Archive Metallography,"
February 3, 1971.

Table B-2

**BIAXIAL STRESS-RUPTURE TEST RESULTS IN ARGON at 1300°F
(INTERNAL PRESSURIZATION)**

Alloy	Hoop Stress (ksi)	Time to Rupture (hr)	Percent $\Delta D/D$	Failure Location
304L	12	503 to 667	7.2	Weld
304L	15	< 171	5.2	Weld
304L	18	< 171	-	Weld
316	14	> 1322	5.0	None
316	17	831 to 993	17.6	Parent Metal
316	20	667	11.7	-

Reference: GE Advanced Products Operation Memorandum, G. P. Wozadlo
to K. J. Perry, *Short-Time Biaxial Stress-Rupture Testing of the
Task F-3A (3B) Pressure Tubing*, February 14, 1968.

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Figure B-1. Sectioning Diagram for Fuel Pin F3B-1

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Figure B-2. Sectioning Diagram for Fuel Pin F3B-2

Figure B-3. Sectioning Diagram for Fuel Pin F3B-3

Figure B-4. Sectioning Diagram for Fuel Pin F3B-5

Figure B-5. Sectioning Diagram for Fuel Pin F3B-7

Figure B-6. Sectioning Diagram for Fuel Pin F3B-10

TYPE 304L (F3B-7)

TYPE 316 (F3B-1)

Figure B-7. Transverse Microsections of As-Received Tubing. Grain Size is ASTM ~5-1/2 for Each Sample. Etchant HCL + H₂O₂, 100X

TYPE 304L

(F3B-7)

TYPE 316

(F3B-1)

Figure B-8. Transverse Microsections Through Welds in As-Received Tubing. Etchant HCL + H₂O₂, 80X

TYPE 304L (F3B-7) ASTM INCLUSION COUNT: C-2 THIN

TYPE 316 (F3B-1) ASTM INCLUSION COUNT: C-1 THIN

Figure B-9. Longitudinal Microsections of As-Received Tubing. As Polished, 100X

APPENDIX C

**PROFILOMETER TRACES, PELLET LINEUP HISTOGRAMS, GAMMA SCANS
(WITH POINT COUNT DATA), NEUTROGRAPHS AND AUTORADIOGRAPHS**

Figure C-1. Profilometer Traces of Type 316 Clad Group F3A Fuel Pin F3B-1 Compared to Pre-Irradiation Fuel Pellet Lengths and Diameters

Figure C-2. Profilometer Traces of Type 316 Clad Group F3A Fuel Pin F3B-2 Compared to Pre-Irradiation Fuel Pellet Lengths and Diameters

Figure C-3. Profilometer Traces of Type 316 Clad Group F3A Fuel Pin F3B-3 Compared to Pre-Irradiation Fuel Pellet Lengths and Diameters

Figure C-4. Profilometer Traces of Type 316 Clad Group F3A Fuel Pin F3B-4 Compared to Pre-Irradiation Fuel Pellet Lengths and Diameters

Figure C-5. Profilometer Traces of Type 316 Clad Group F3A Fuel Pin F3B-5 Compared to Pre-Irradiation Fuel Pellet Lengths and Diameters

Figure C-6. Profilometer Traces of Type 316 Clad Group F3A Fuel Pin F3B-6 Compared to Pre-Irradiation Fuel Pellet Lengths and Diameters

Figure C-7. Profilometer Traces of Type 304L Clad Group F3A Fuel Pin F3B-7 Compared to Pre-Irradiation Fuel Pellet Lengths and Diameters

Figure C-8. Profilometer Traces of Type 304L Clad Group F3A Fuel Pin F3B-8 Compared to Pre-Irradiation Fuel Pellet Lengths and Diameters

Figure C-9. Profilometer Traces of Type 304L Clad Group F3A Fuel Pin F3B-9 Compared to Pre-Irradiation Fuel Pellet Lengths and Diameters

Figure C-10. Profilometer Traces of Type 304L Clad Group F3A Fuel Pin F3B-10 Compared to Pre-Irradiation Fuel Pellet Lengths and Diameters

Figure C-11. Profilometer Traces of Type 304L Clad Group F3A Fuel Pin F3B-11 Compared to Pre-Irradiation Fuel Pellet Lengths and Diameters

Figure C-12. Profilometer Traces of Type 316 Clad Group F3A Fuel Pin F3B-12 Compared to Pre-Irradiation Fuel Pellet Lengths and Diameters

Figure C-13. Profilometer Traces of Type 316 Clad Group F3A Fuel Pin F3B-13 Compared to Pre-Irradiation Fuel Pellet Lengths and Diameters

Figure C-14. Profilometer Traces of Type 316 Clad Group F3A Fuel Pin F3B-14 Compared to Pre-Irradiation Fuel Pellet Lengths and Diameters

Figure C-15. Profilometer Traces of Type 316 Clad Group F3A Fuel Pin F3B-15 Compared to Pre-Irradiation Fuel Pellet Lengths and Diameters

Figure C-16. Profilometer Traces of Type 316 Clad Group F3A Fuel Pin F3B-16 Compared to Pre-Irradiation Fuel Pellet Lengths and Diameters

Figure C-17. Gross Gamma Activity Profile of F3B-1 and F3B-2

Figure C-18. Gross Gamma Activity Profile of F3B-3 and F3B-4

Figure C-19. Gross Gamma Activity Profile of F3B-5 and F3B-6

Figure C-20. Gross Gamma Activity Profile of F3B-7 and F3B-8

Figure C-21. Gross Gamma Activity Profile of F3B-9 and F3B-10

Figure C-22. Gross Gamma Activity Profile of F3B-11 and F3B-12

Figure C-23. Gross Gamma Activity Profile of F3B-13 and F3B-14

Figure C-24. Gross Gamma Activity Profile of F3B-15 and F3B-16

Table C-1
LOCAL GAMMA ACTIVITY IN FCR F3A SERIES FUEL RODS(a)

Rod No. (F3B)	Position No. (b)	Ce-144 (0.134 MeV)	Ru-103 (0.497 MeV)	Ru-106 (0.512 MeV)	Cs-137 (0.662 MeV)	Zr-95 (0.724 MeV)	Nb-95 (0.765 MeV)	Cs-134 (0.796 MeV)	Co-58 (0.811 MeV)	Mn-54 (0.835 MeV)	La-140 (1.60 MeV)	Pr-144 (2.19 MeV)
1	1	1,000	4,000	1,000	500	4,000	20,000	<100	600	200	150	70
	2		3,000	700	1,000	3,500	15,000		300	100	100	40
2	1		3,000	500	1,500	5,000	35,000		300	200	200	60
	2		3,500	500	1,000	6,000	30,000		700	400	600	60
	3		3,500	800	1,000	6,000	17,000		700	300	150	70
	4	<1,000	3,000	600	800	6,000	40,000		600	200	500	70
	5	15,000	4,000	600	700	4,000	25,000		400	150	500	40
3	1	<1,000	4,000	1,000	700	6,000	20,000	<100	800	300	200	70
	2	1,000	2,500	500	2,000	2,500	70,000	300	400	200	300	40
	3	<1,000	200	150	< 200	150	600	<100	200	100	<10	<10
4	1		3,500	700	1,000	7,000	30,000		600	200	250	60
	2		4,000	1,000	1,000	7,000	20,000		800	300	200	70
	3		3,000	1,000	1,500	5,000	25,000		600	300	200	80
5	1		300	150	< 200	300	800		250	100	<10	<10
	2		3,000	1,000	800	4,500	20,000		700	200	200	50
	3		4,000	500	1,100	4,500	28,000		800	300	300	60
	4		2,500	500	400	3,500	25,000		300	100	200	30
6	1		3,000	1,000	700	5,000	15,000	<100	500	300	200	80
	2		3,000	800	1,500	4,000	13,000	100	300	150	100	40
7	1		2,500	500	1,500	5,000	17,000	<100	250	200	150	50
	2		4,000	700	1,000	5,000	30,000		500	300	400	70
	3		2,000	800	800	4,000	15,000		200	100	100	60
8	1		4,000	500	1,500	6,000	30,000		500	300	700	60
	2		4,000	1,000	500	6,000	25,000		500	300	400	60
	3		3,000	700	500	4,000	25,000		150	100	300	50
9	1	<1,000	<1,000	1,000	1,000	6,000		<100	<100	< 20	<10	<10
	2	<1,000	<1,000	500	1,000	5,000		<100	<100	< 20	<10	<10
10	1		4,000	1,000	700	5,000	20,000		500	300	200	70
	2		3,000	600	400	3,000	30,000		200	100	300	40
11	1		2,000	<1,000	800	1,500	9,000		100	100	20	15
	2		1,500	<1,000	700	2,500	9,000		100	200	20	15
	3		1,500	<1,000	600	1,500	7,000		100	100	<20	<10
12	1		2,000	1,500	600	1,500	7,000		200	100	<20	<10
13	1	<1,000	<1,000	500	1,000	5,000			100	<100	<20	< 10
	2	<1,000	<1,000	400	1,000	7,000			150	100	20	10
	3	<1,000	<1,000	400	1,000	10,000	<100	<100	<100	<100	20	10
14	1		4,000	1,500	800	4,000	13,000	<100	300	300	20	20
	2		1,000	<1,000	1,000	1,500	20,000	200	200	100	25	<10
15	1		4,000	1,500	800	3,500	15,000	<100	500	200	20	20
	2		2,000	1,000	2,000	2,500	20,000	100	200	100	20	15
16	1		3,000	1,000	1,000	3,000	10,000	<100	400	200	20	15
	2		2,000	<1,000	500	2,000	8,000	<100	200	100	<20	<10

a) In counts per minute

b) Positions as labeled on gross gamma scans, Figures C-17 through C-24.

Figure C-25. Neutron Radiographs of Group F3A Fuel Pins

Figure C-26. Neutron Radiographs of Group F3A Fuel Pins

Figure C-27. Neutron Radiographs of Group F3A Fuel Pins

Figure C-28. Neutron Radiographs of Group F3A Fuel Pins

Figure C-29. Neutron Radiographs of Group F3A Fuel Pins

PHOTOGRAPH
(AS SECTIONED)

A599-01

ALPHA

A599-02

BETA-GAMMA

A599-03

MICROGRAPHIC
MONTAGE
(AS POLISHED)

A599-05

13.9 in.

13.5 in.

12.9 in.

A598-22

A598-02

A598-03

A598-31

12.7 in.

Figure C-30. Photographs and Autoradiographs of Pin F3B-3 Near Top of Fuel Column - 5X

PHOTOGRAPH
(AS SECTIONED)

A597-01

ALPHA

A597-02

BETA-GAMMA

A597-03

MICROGRAPHIC
MONTAGE
(AS POLISHED)

12.2 in.

A597-04

11.2 in.

Figure C-31. Photographs and Autoradiographs of Pin F3B-3 at about 11.7 Inches from Bottom of Fuel Column - 5X

PHOTOGRAPH
(AS SECTIONED)

A596-01

ALPHA

A596-02

BETA-GAMMA

A596-03

MICROGRAPHIC
MONTAGE

A596-04

A595-01

A595-02

A595-03

+0.4 in.

FUEL

BOTTOM
OF FUEL
COLUMN

INSULATOR

-0.6 in.

Figure C-32. Photographs and Autoradiographs of Pin F3B-3 at about the Center and at the Bottom of the Fuel Column - 5X

Figure C-33. Alpha and Beta-Gamma Autoradiographs for Pins F3B-1, -2, -3, -5, -7, -10
Near the Center of Each Pin - 5X

APPENDIX D
SUBASSEMBLY ENVIRONMENT

APPENDIX D SUBASSEMBLY ENVIRONMENT

Several of the experimental observations, made during post-irradiation examination, appeared to conflict with the nominally calculated linear powers for the F3A Series. These included substantially greater than usual cladding attack, larger than expected equiaxed and columnar grain limits in the fuel, somewhat more than normal fission gas release and substantially higher than calculated cladding temperatures, as indicated by the Kr^{85} method. For this reason, the X040 and X040A irradiation histories were examined in greater detail than has been usual in earlier post-irradiation examinations. It was hoped that this would allow a differentiation between those effects of the reactor environment (neutron flux, sodium temperature, etc.) and those due to the fuel (large diameter, carbon content, etc.).

Table D-1 is a compilation of nearest-neighbor and next-nearest-neighbor subassemblies to X040 and X040A. Figures D-1 through D-7 show the reactor loading pattern for each of the applicable runs. It is noted that the only nearby subassemblies having greater fissile loading than a normal driver were the 70% enriched drivers* at location 4B1, which were immediately adjacent to X040(A) at 5B2. These were inserted for approximately 29% of the F3A exposure as shown in Figures D-1 through D-7 and listed in Table 4. This was also the rationale for Figure 9 which plots experimental burnup as a function of distance from the extra worth driver and which suggests that there may have been a fission rate enhancement toward that location. A detailed calculation by the EBR-II project^{D-1} indicates, however, that the high-worth driver could have elevated the fission rate by no more than 2%.

Attempts were made to use the burnup distribution of Figure 9 to calculate a perturbed peak linear power for each of the X040 pins. However, the powers so obtained were equivalent to cladding temperature rises of only 50-100F° which are considered insufficient to account for the excessive cladding attack that was observed. This correlation work is continuing and the more detailed calculations being performed at EBR-II, together with new experimental evidence (particularly that from X027, series E1H), may well resolve the apparent anomalies of the X040(A) irradiation.

The X040(A) subassemblies containing the F3A series fuel pins also contained 19 to 18 mixed oxide pins prepared by Argonne National Laboratories (see Figure 2). Instead of matching the 13.5-inch core length and the F3A pins, however, the ANL pins had fueled lengths of only eleven inches. The ANL fuel was not axially centered, but the bottom of this fuel was reported to be 0.85 inch above the bottom of the core. The short fuel had some fission rate and temperature effects on the adjacent F3A pins and, in fact, the central void in pin F3B-3 was smaller than the as-fabricated inside diameter of the annular pellets at axial locations corresponding to the upper ends of the adjacent ANL fuel columns. See Table 14 and Subsection 5.3.2.1.

The effect of the adjacent short fuel on the F3A pins was estimated by calculation. The results are given in Table D-2 and Figure D-8. The thermal results were generated using standard methods.^{D-2} A computer performs the steady-state calculation of average temperatures for each fuel rod and coolant flow subchannel in the bundle at an arbitrary number of axial planes (here at every integral inch and at the top of each pin). Flow splits between subchannels are calculated from bundle dimensions assuming no radial gradients. Interchannel turbulent mixing is assumed equal to one-half of the flow area cut by the wire wrap being swept into the adjacent subchannel.**

Two sets of cases were run using the computer codes: (A) the normal set in which the true peak linear power calculated for each pin is used as input, and (B) a set in which a peak linear power corresponding to the total power produced by the pin according to an integration of the axial fission rate distribution given in the EBR-II guide^{D-3} is used. The codes are incapable of handling power generation which starts at more than one axial location (as in X040(A)), although they can take account of the axial variation in fission rates, provided that the fueled lengths of all pins are substantially identical. Thus, set (A) will involve accurate local power generation in the ANL pins, but it assumes that the 0.85 inch below the fuel and the 1.65 inch above it (18-1/2%) are fully fueled. Therefore, the total heat generated by the ANL pin will be overestimated and some of this heat will be transferred to coolant channels in the F3A half of the subassembly. In cases (B), however, the total energy produced by the ANL pins will be correct, but the linear power at any point will be underestimated. The coolant channel temperatures, then, will be accurate only at the top of the F3A fuel. Neither calculation precisely represents conditions in X040(A), but the difference between the two should provide a reasonable measure of the effect of interchannel mixing and hence it should give a reliable, order-of-magnitude estimate of the possible effect of the short ANL fuel on the F3A temperatures. The inside cladding temperatures at the top of the F3A fuel are listed in Table D-2 for each F3A pin and for selected ANL pins

*Normal drivers are 52% enriched in U^{235} .

** This value is consistent with the limited experimental data available for wire-wrapped bundles.^{D-4, D-5}

representative of the range of conditions. Temperature differences between the two calculations are also given and these differences are plotted on Figure D-8. The principal effect is on the central pin, F3B-3, which has four adjacent ANL elements. The influence on cladding temperature here was 26°F . The six F3A pins in the first row from the F3A/ANL interface row had one or two adjacent ANL pins and the temperature effect was 9 to 13°F . Pins more distant than one row from the interface row were negligibly affected by the ANL pins.

Table D-1

SUBASSEMBLIES NEAR X040 AND X040A (F3A) DURING IRRADIATION

Subassembly	EBR-II Location	Separation from X040 and X040A, (in.) (b)	Run Numbers from 29D-43	Description	Approximate Reactivity Equivalent gm U-235(c)	Approximate Power kW per Subassembly
X040, X040A	5B2 (5B4)	None	30A-D, 31A-35, 38B-42(a)	(16)F3A, (19)ANL 1-31, Oxide	2637	510
Control	5B1, 5B3	2.32 (2)	29D-43	(61) 52% U-235 Metal, 80-100% Insert	2240	2/3 Nominal
Driver	A1 Other	—	—	(91) 52% U-235 Metal (0.144-in. diameter)	3370	700(d) Nominal
70%	4B1	2.32	{ 30B, 31A, 31E-32B, 33A } { 34A, 38B—See Table 4 }	(91) 70% U-235 Metal Driver (vs. 52%)	4370	900
X012, X012A	4B2	2.32	29D-30D, 31A-37, 39A-40B	(19)NUMEC, C5 and D5, Oxide	< 2000	320
X027	4B3	4.18	29D-30D, 31A-42	(18)GE-F3B, Oxide	1126	260
X035	734, 7B3	4.64, 4.13	29D-43	ORNL Structural	None	None
X066	4A3	4.64	34	(2)Mk IA (Metal)	67	15
X067	4A3	4.64	35, 36	Structural and Al ₂ O ₃	None	None
EBU	6B1	4.18	36B	Extended Burnup Driver	3000	130
EBU	6A5	4.64	38A-37	Extended Burnup Driver	3000	130
X033	5B4	4.64	38B	(19) UNC Carbide	< 2000	380
Mk II	3B2	4.64	36B, 33B-40, 42, 43	(91) Mk II Driver (Metal)	~ 3370	Nominal
X020(a)	6B5	2.32	39B and C(a)	(9) GE-F8 oxide, (3) UNC Carbide	< 1000	150
X056(a)	5C2	4.18	39B and C(a)	(37) GE-F9C	2470	480
Mk II(a)	3C1	4.18	39B and C(a)	(91) Mk II Driver (Metal)	~ 3370	Nominal
X050(a)	4C2	4.64	39B and C(a)	(4)F7 and (4)F2, (7)W and ORNL Carbide	< 3000	280
X068	4A3	4.64	40-43	(61) Mk IA Driver (Metal)	~ 2240	2/3 Nominal
X072	6B2	2.32	40-43	(18)ANL, ASOPC Oxide	< 3000	—
X079	4B2	2.32	42-43	(19) UNC Carbide		570

(a) X040A S/A containing F3A pins at 5B4 only during runs 39B and C. X020, X056, and X050 data are given only for that exposure.

(b) Distance between Subassembly Centers.

(c) Assumes: (Fission Rate Pu-239) = 1.194 (Fission Rate U-235), per EBR-II Guide for Location 5N2.

(d) At Row 5.

Figure D-1. Loading for Runs 29D-30E

KEY:

- C# - CONTROL ROD
- S# - SAFETY ROD
- D - DRIVER FUEL
- P - 1/2 DRIVER FUEL, 1/2 SST
- B - DEPLETED URANIUM
- 70% - 70% ENRICHED DRIVER (91 PINS)

**RUNS 32B AND 33A ONLY

Figure D-2. Loading for Runs 31-33 ("B" Sextant)

KEY:

- C# - CONTROL ROD
- S# - SAFETY ROD
- D - DRIVER FUEL
- B - DEPLETED URANIUM
- R - SST REFLECTOR
- MK-II - MARK-II FUEL
- EBU - EXTENDED BURNUP
- CF - CONTROLLED FLOW
- 70% - 70% ENRICHED DRIVER (83 PINS)

Figure D-3. Loading for Runs 34-36

RUN 37

(RUN 38A WAS AT 62.5 MW AND CONTAINED VERY FEW
EXPERIMENTAL SUBASSEMBLIES—NOT INCLUDING X040A)

KEY:

- C# - CONTROL ROD
- S# - SAFETY ROD
- D - DRIVER FUEL
- P - 1/2 DRIVER FUEL, 1/2 SST
- B - DEPLETED URANIUM
- R - SST REFLECTOR
- MK-II - MARK-II FUEL
- EBU - EXTENDED BURNUP
- CF - CONTROLLED FLOW
- 70% - 70% ENRICHED DRIVER (70 PINS)

RUN 38B

RUN 39A

Figure D-4. Loading for Runs 37-39A

KEY:	SSTH - SST THIMBLE	P - 1/2 DRIVER FUEL, 1/2 SST
	BETH - BERYLLIUM THIMBLE	B - DEPLETED URANIUM
	SSCR - SST CONTROL ROD	R - SST REFLECTOR
	C# - CONTROL ROD	MK-II - MARK-II FUEL
	S# - SAFETY ROD	EBU - EXTENDED BURNUP
	D - DRIVER FUEL	CF - CONTROLLED FLOW
	Ni - NICKEL CORROSION	70% - 70% ENRICHED DRIVER (70 PINS)

Figure D-5. EBR-II Loading Pattern Run Number 39-C (39B Had Same "B" Sextant Loading)

KEY: Ssth - SST THIMBLE	P - 1/2 DRIVER FUEL, 1/2 SST
BETH - BERYLLIUM THIMBLE	B - DEPLETED URANIUM
SSCR - SST CONTROL ROD	R - SST REFLECTOR
C# - CONTROL ROD	70% - 70% ENRICHED DRIVER
S# - SAFETY ROD	MK-II - MARK-II FUEL
D - DRIVER FUEL	EBU - EXTENDED BURNUP
Ni - NICKEL CORROSION	CF - CONTROLLED FLOW

Figure D-6. EBR-II Loading Pattern Run Number 40-B (40-A Had Same "B" Sextant Loading)

KEY:

- C# - CONTROL ROD
- S# - SAFETY ROD
- D - DRIVER FUEL
- Ni - NICKEL CORROSION
- P - 1/2 DRIVER FUEL, 1/2 SST
- B - DEPLETED URANIUM
- R - SST REFLECTOR
- 70% - 70% ENRICHED DRIVER
- MK-II - MARK-II FUEL
- EBU - EXTENDED BURNUP
- CF - CONTROLLED FLOW

Figure D-7. Loading For Runs 41-43

Table D-2
EFFECT OF SHORT ANL PINS IN X040

Pin Number	Number of Rows from Interface (a)	Peak Linear Power (kW/ft)		Maximum Cladding Temperature (°F)		Probable Temperature Over-Estimate Due to Assuming ANL Pin is Fully Fueled (F°)
		Assumption A (b)	Assumption B (c)	Assumption A (b)	Assumption B (c)	
F3B-1	3		15.89	994	994	0
F3B-2	2		16.32	1099	1097	2
F3B-3	0(4)		17.00	1130	1104	26
F3B-4	2		16.29	1084	1082	2
F3B-5	3		15.04	1011	1011	0
F3B-6	2		14.91	1005	1003	2
F3B-7	1(1+D)		14.47	981	972	9
F3B-8	1(2)		16.55	1085	1072	13
F3B-9	1(1)		16.59	1116	1106	10
F3B-10	1(2)		16.84	1092	1079	13
F3B-11	2		15.62	1008	1006	2
F3B-12	3		16.14	999	999	0
F3B-13	2		16.36	1087	1085	2
F3B-14	1(1+D)		16.82	998	989	9
F3B-15	1(1)		16.47	1125	1115	10
F3B-16	3		15.04	1012	1012	0
ANL007(d)	-1(1)	15.33	12.71	1106	1046	60
ANL012(d)	-3	15.80	13.50	997	947	50
ANL023(d)	-1(0)	16.51	13.78	1093	1032	61
ANL029(d)	-2	16.54	13.63	1017	964	53

(a) Imaginary interface between F3A and ANL Pins is the row between the dummy pins at locations 4 and 34 and including the central pin, F3B-3. See Figure 2. The inscriptions in parentheses for the interface row, Number 0, and the rows next to the interface, Numbers 1 and -1, indicate the number of adjacent pins of the other kind with "D" indicating a dummy pin. For example, F3B-3 has 4 adjacent short-fueled ANL pins; F3B-7 has one adjacent ANL pin and one dummy, ANL 007 has one adjacent F3A pin.

(b) Assumption A is the normal calculation which assumes that the ANL pins are fueled for the entire 13.5-inch length of the core instead of approximately 11.00 inches beginning 0.85 inch from bottom of core. This involves somewhat more than 20 percent increase in the total power produced by an ANL pin and will overestimate the temperature near the top of the core.

(c) Assumption B considers that the energy is produced in the ANL pins from 0.85 inch from core bottom to the top of the pin (using the axial fission rate distribution given in the EBR-II guide); but the total power so obtained is distributed over the 13.5-inch core length. It will give approximately the correct temperature at the top of the core; but will underestimate it elsewhere.

(d) Temperatures at 11.00 inches for ANL pins.

Figure D-8. Effect of Assumptions about Loading of A.N.L. X040 Pins on Maximum Cladding Temperature in F3A Pins

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