4. OPERATING HISTORY

Shippingport LWBR was operated for about 29,000 EFPH[a] from September 1977 until October 1, 1982 (Budd 1986, WAPD-TM-1542, p. 1-9, and ICPP Fuel Receipt Criteria attached to WAPD-NRF(L)C-104, p.3). Average daily generator output as net electrical megawatts and reactor coolant temperature are presented in Figure 4-1 (Budd 1986, WAPD-TM-1542, Figure 1-1). The EFPH, number of hours the reactor was critical, and gross electrical output (in MWhr) are presented for the LWBR by quarter from 1977 to 1982 in Table 4-1.

During most of core life, the LWBR was operated as a base load station (Richardson et al. 1987, WAPD-TM-1606, p. 35). During the first two years of operation, the core was subjected to 204 planned swingload cycles to demonstrate the core transient capability and generating system load follow to simulate operation of a large commercial nuclear reactor (Richardson et al. 1987, WAPD-TM-1606, p. 35). A swing load cycle is defined as power reduction from about 90% to 35–60% for 4 to 8 hr, then back to 90% or higher power. Despite shutdowns and swing, the reactor achieved a high capacity factor of 65% and high availability factor of 86% (Richardson et al. 1987, WAPD-TM-1606, p. 35).

For its initial 18,000 EFPH, the maximum allowable reactor power was established as 72 MW gross (electric), and the average coolant temp was 531°F. Pressure was eventually reduced to 1,615 psia (Budd et al. 1986, WAPD-TM-1542, pp. 127-128). Table 4-2 identifies the operating temperatures and pressures for the LWBR operating life (Budd et al. 1986, WAPD-TM-1542, Table 4-1).

In the LWBR irradiation test program, two cladding defects occurred during planned power ramps. Both were hairline cracks attributed to stress corrosion cracking. Stress corrosion cracking was shown in laboratory tests on unfueled tubing specimens to occur at stress levels as low as 20,000 psi in the presence of controlled amounts of iodine gas at typical fuel rod operating temperatures (Campbell and Giovengo 1987, WAPD-TM-1387, p. 51).

The timeline for the LWBR reactor is presented in Table 4-3.

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[a] 1 EFPH is the equivalent of operating the core for one hour at rated power, namely, 236.6 MW (thermal).

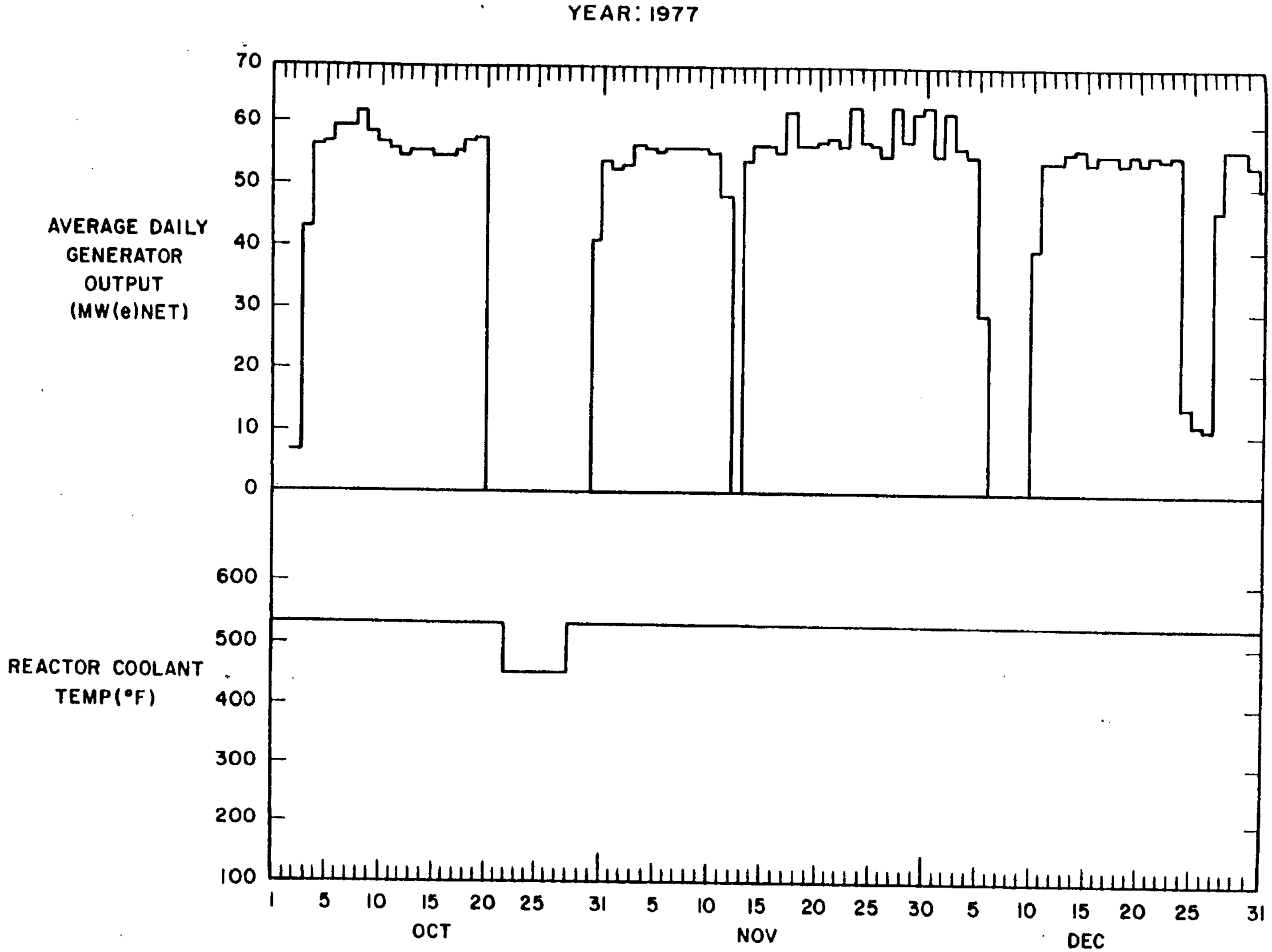


Figure 4-1. Light Water Breeder Reactor operational history, 1977 (Budd 1986, WAPD-TM-1542, Figure 1-1).

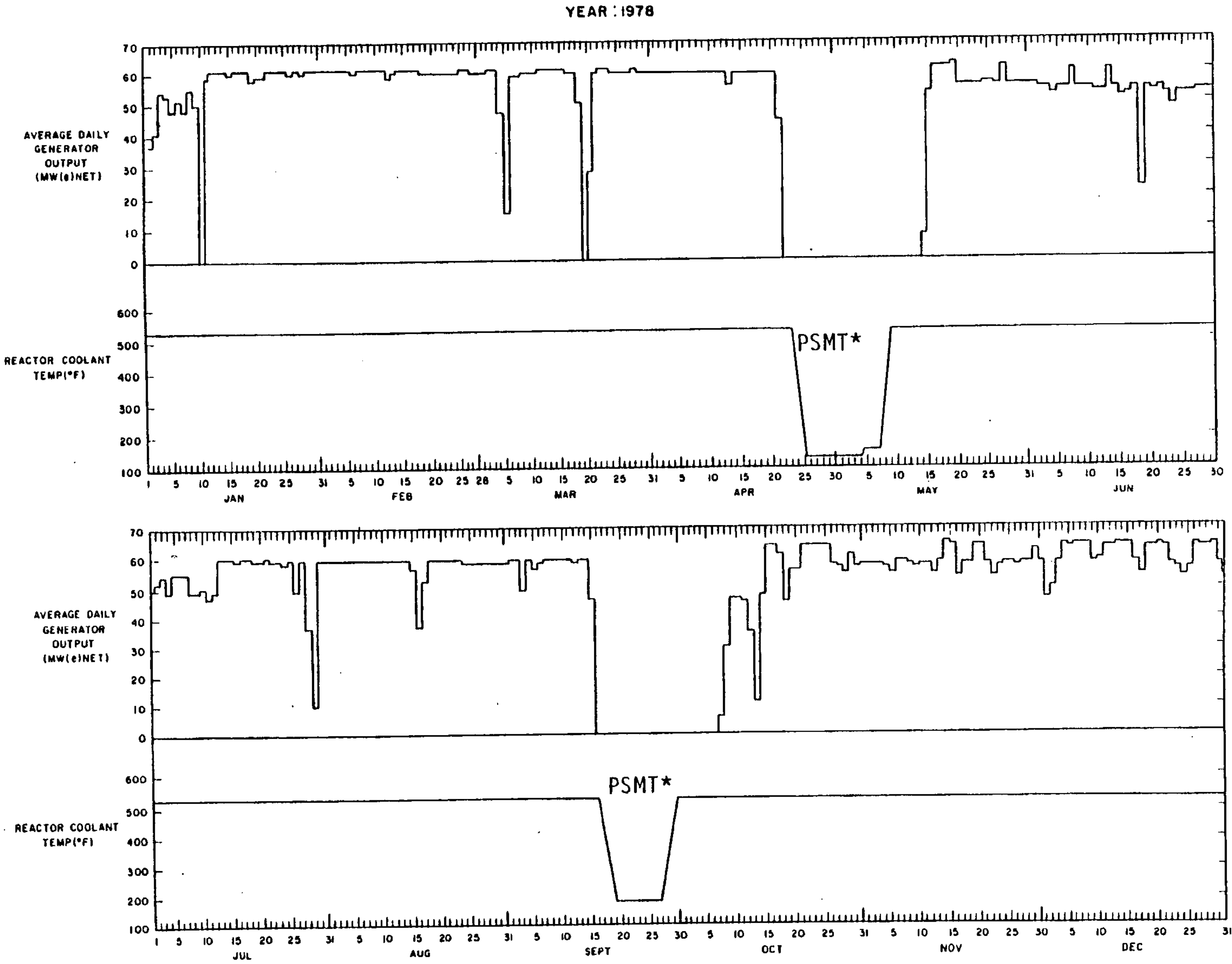


Figure 4-1. (continued.)

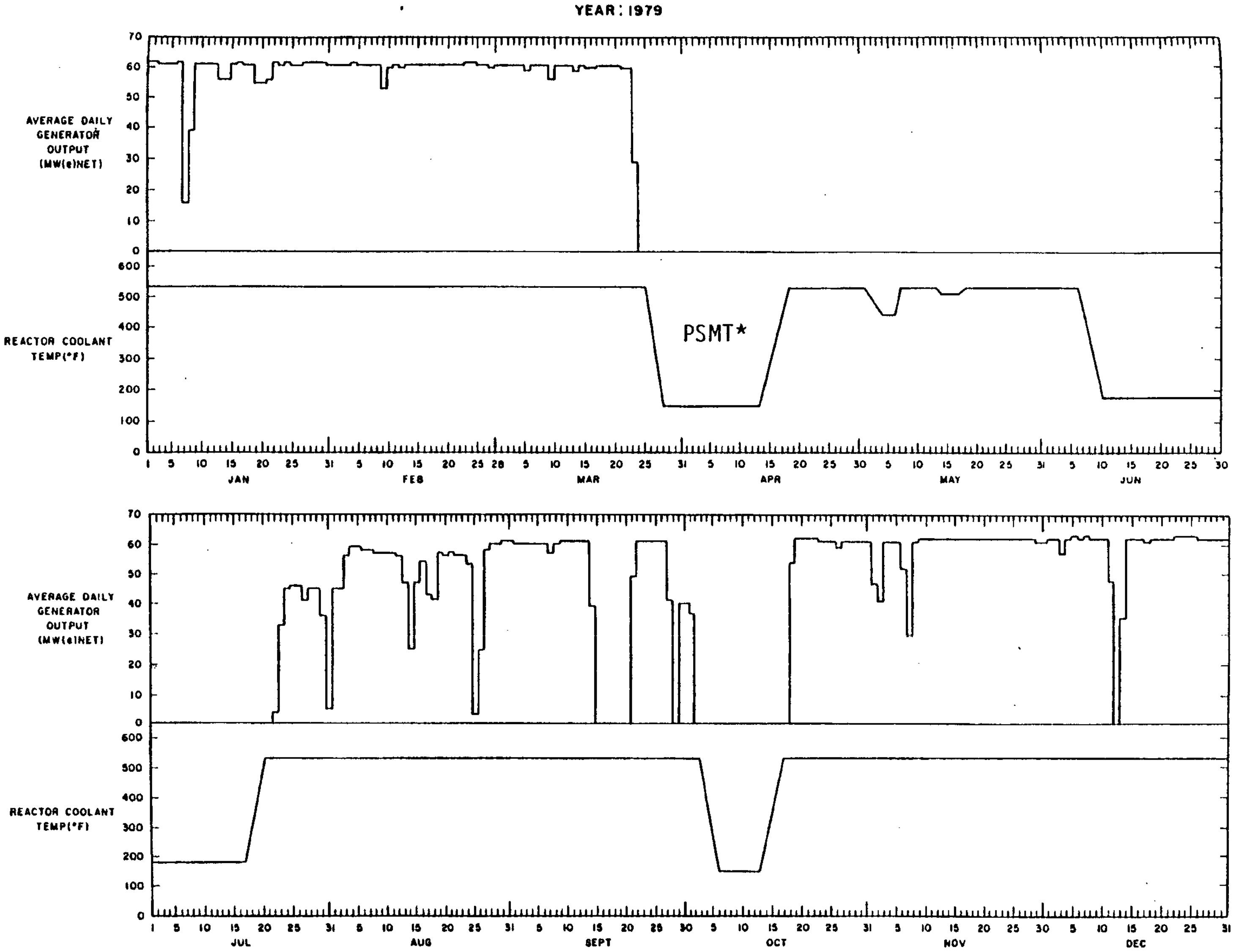


Figure 4-1. (continued).

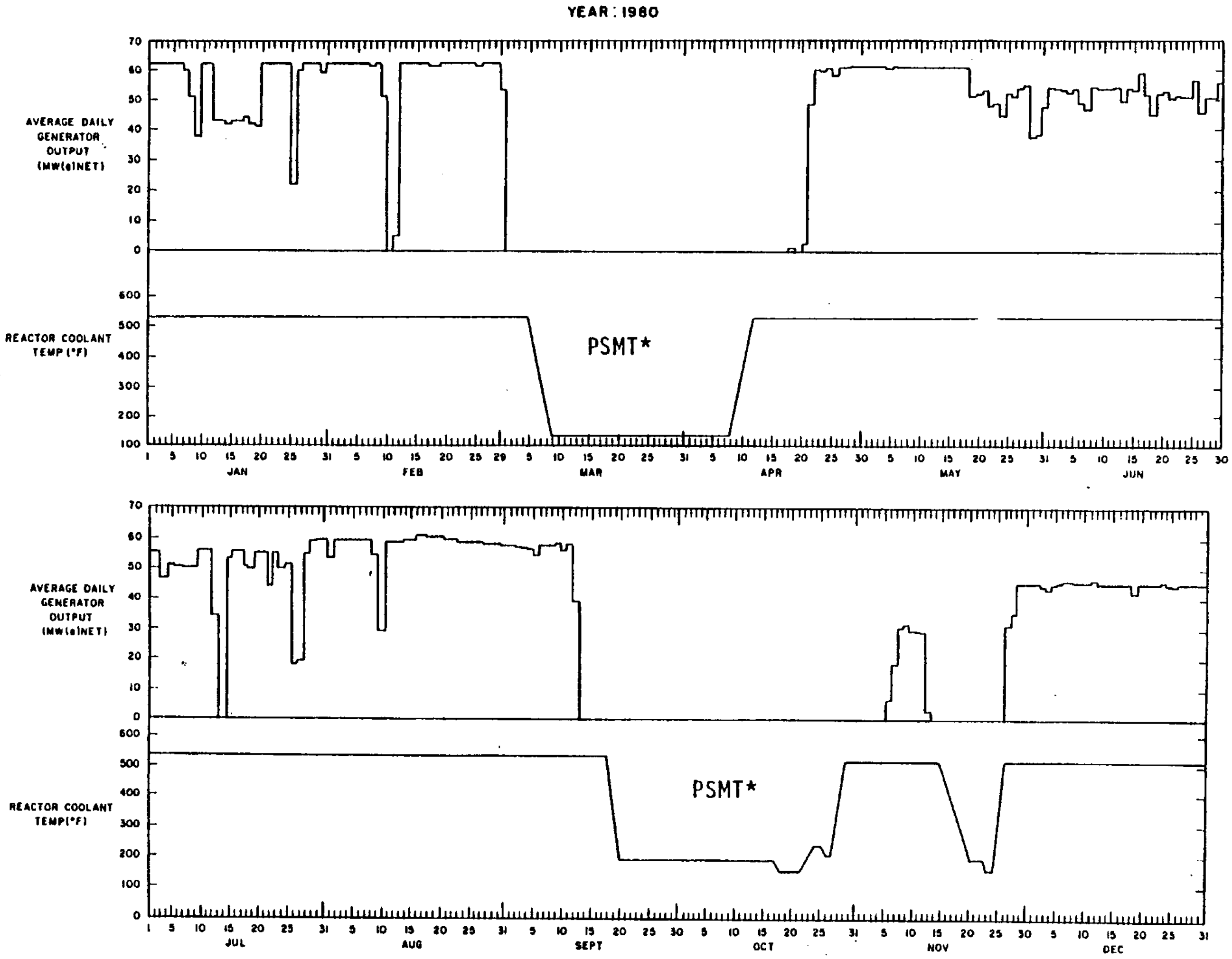


FIGURE I-1. LWBR OPERATIONAL HISTORY (SHEET 4 OF 6) - 1980

Figure 4-1. (continued).

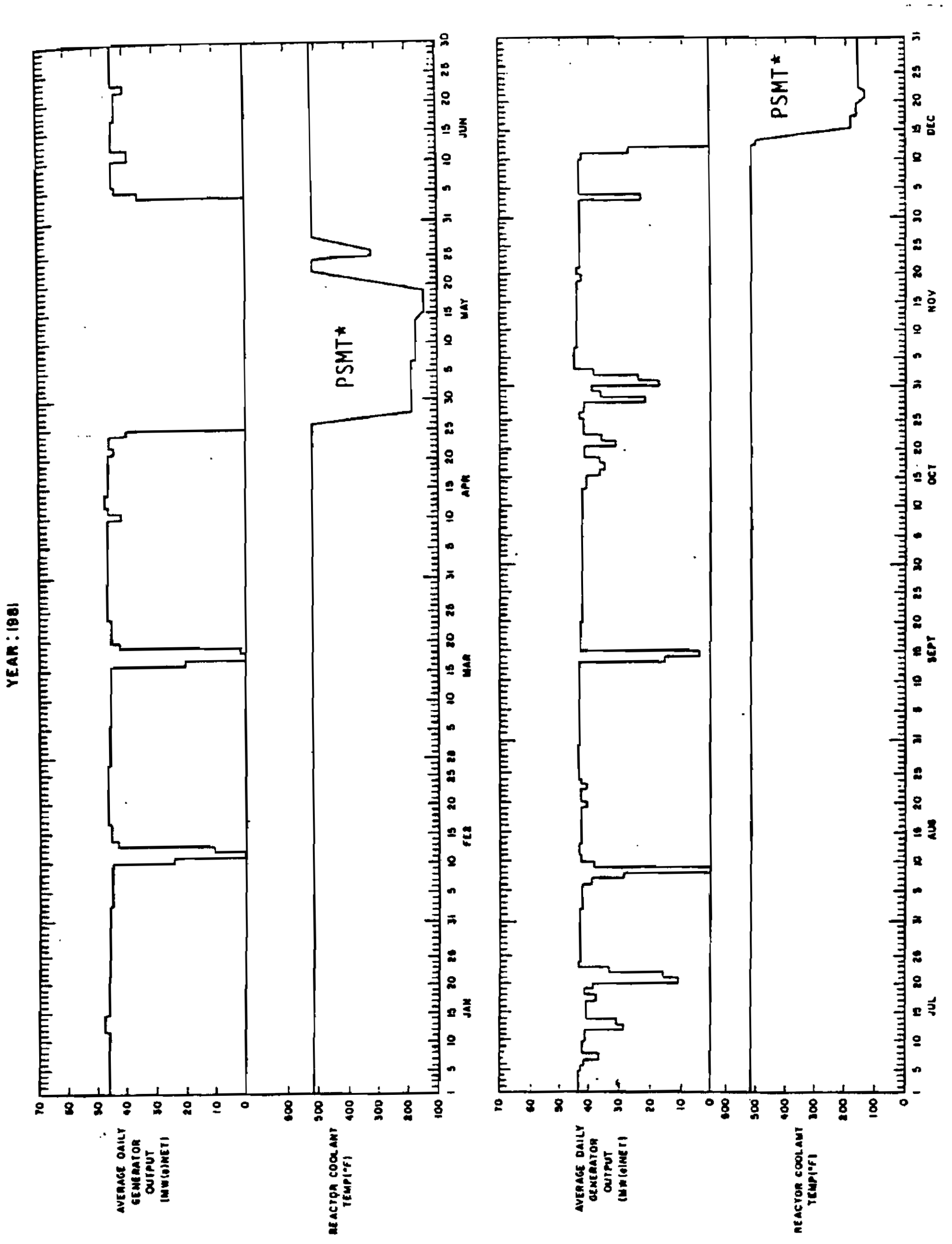
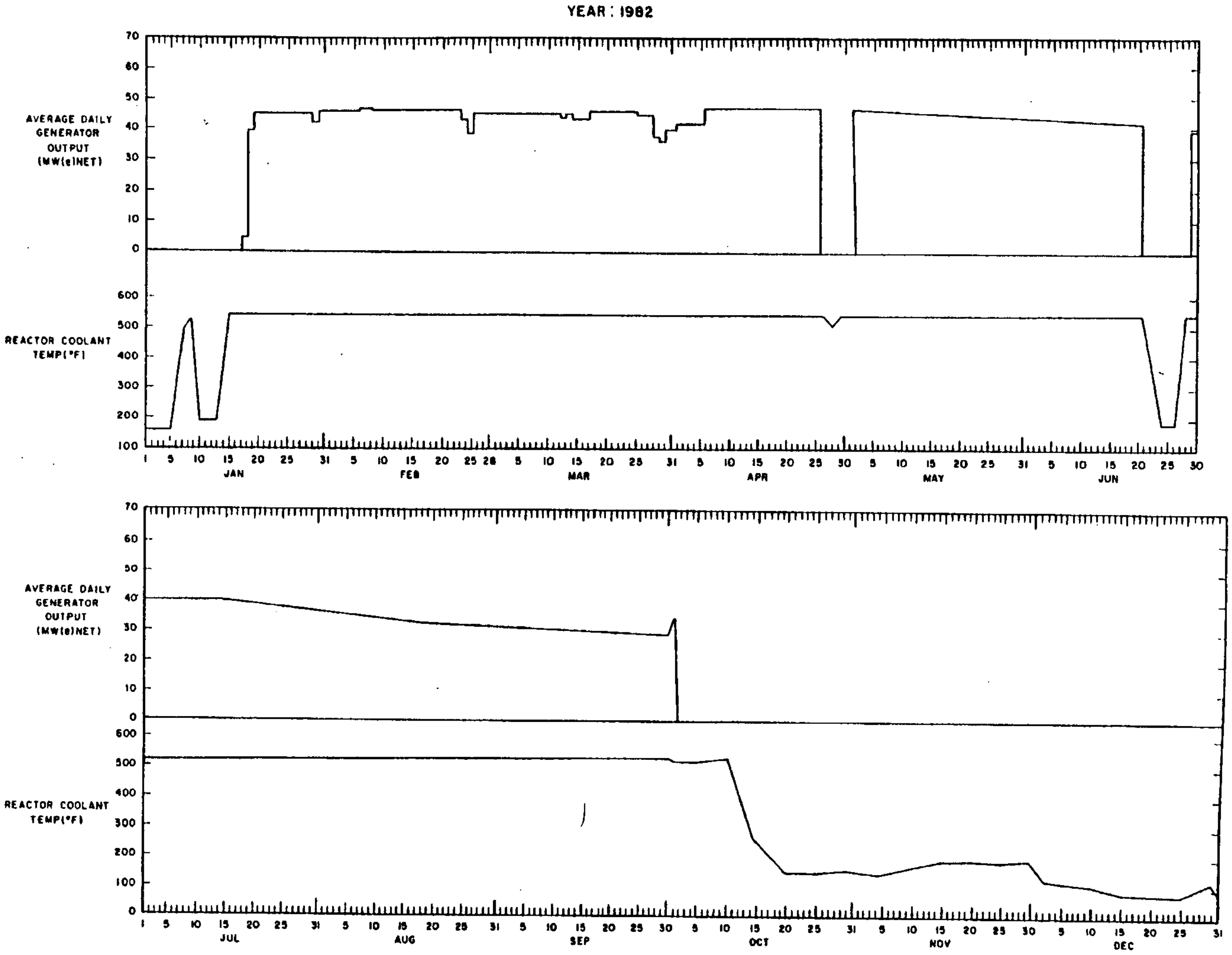


Figure 4-1. (continued).



*PSMT = planned shutdown for maintenance and testing.

Figure 4-1. (continued).

Table 4-1. Summary of Light Water Breeder Reactor station performance (Budd 1986, WAPD-TM-1542, Table 1-1).

Year	Quarter	EFPH*		Hrs Reactor Critical		Gross Electrical Output Mwhr
		This Quarter	To Date	This Quarter	To Date	To Date
1977	3	270.4	270.4	641.9	641.9	17899
	4	1553.9	1824.3	1814.2	2456.1	134232
1978	1	2010.4	3834.7	2137.9	4594.0	283947
	2	1536.6	5371.3	1695.6	6289.6	396929
	3	1761.0	7132.3	1859.3	8148.9	523279
	4	1878.1	9010.4	2111.6	10260.5	662675
1979	1	1921.9	10932.3	1945.5	12206.0	805655
	2	0	10932.3	346.9	12552.9	805655
	3	1353.9	12286.2	1574.7	14127.6	903425
	4	1734.9	14021.1	1802.3	15929.9	1034503
1980	1	1304.6	15325.7	1415.4	17345.3	1133200
	2	1544.2	16869.9	1815.4	19160.7	1248104
	3	1636.8	18506.7	1782.1	20942.8	1366698
	4	757.7	19264.4	1213.3	22156.1	1423380
1981	1	1617.6	20882.0	2090.3	24246.4	1545038
	2	960.6	21842.6	1462.6	25713.0	1615465
	3	1649.5	23492.1	2151.9	27864.9	1731032
	4	1311.4	24803.5	1715.8	29580.7	1824592
1982	1	1355.7	26159.2	1807.6	31388.3	1923224
	2	1459.7	27618.9	1911.7	33300.0	2029313
	3	1422.8	29041.7	2208.0	35508.0	2128542
	4	5.7	29047.4	293.1	35801.1	2128943

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*EFPH - Equivalent Full Power Hours [where full power is defined as 236.6 Megawatts thermal, Mw(t)]

Table 4-2. Summary of Light Water Breeder Reactor operating conditions (Budd 1986, WAPD-TM-1542, Table 4-1).

LWBR POWER OPERATING CONDITIONS

Effective Date	Reactor Lifetime	Reactor Power Gross Electric	System Pressure	Average Coolant Temperature
September 1977	0	72 MW	2000 psia	531°F
May 1978	4325 EFPH	72 MW	1940 psia	531°F
October 1978	7132 EFPH	72 MW	1870 psia	531°F
July 1979	10932 EFPH	72 MW	1815 psia	531°F
November 1980	18507 EFPH	58 MW	1615 psia	521°F
June to October 1982	27419 to 29047 EFPH	54 to 43 MW (in 12 steps)	1615 psia	521°F

Table 4-3. Timeline of events for the Light Water Breeder Reactor.

Reactor loading	1977
Initial criticality of core	Aug. 26, 1977 (Sarber 1983, WAPD-TM-1455 addendum, p. 3)
Full power operation	Sept. 21, 1977 (Sarber 1983, WAPD-TM-1455 addendum, p. 3)
Achieved depletion to 18,298 EFPH	Sept. 12, 1980 (Sarber 1983, WAPD-TM-1455 addendum, p. 3)
Operated at 80% of maximum, reduced temperature and pressure	Sept. 12, 1980 through Dec. 11, 1981 (18,298–24,451 EFPH) (Sarber 1983, WAPD-TM-1455 addendum, p. 3)
Maintenance and testing	21,094–24,541 EFPH
Reactor operation to 29,047 EFPH	1977–82
Reactor disassembly	Dec. 1982-Aug. 1984 (Selsley 1987c, WAPD-TM-1552, p. 7–9)
Shipping from Shippingport (10 shipments)	Sept. 1984 (Selsley 1987c, WAPD-TM-1552, p. 9)
Water pits S4-39 and N4-43 at Expended Core Facility for the majority of fuel disposal operations (Hodges 1987, WAPD-TM-1601, p. 1-4)	
Dismantling at Expended Core Facility 17 rods to Argonne National Lab-East 12 rods to Argonne National Lab-West	1984
Testing: Production Irradiated Fuel Assay Gauge	June 1984–May 1987 (Tessler et al. 1987, WAPD-TM-1614, p. 2).
Chronology of assay operations are provided in Table 24 (Tessler et al. 1987, WAPD-TM-1614, Table 4, p. 81)	
Repackaging at Expended Core Facility	
Shipping to Idaho Nuclear Technology and Engineering Center	1986–1987
Dry Storage at Idaho Nuclear Technology and Engineering Center	Current

5. FUEL EVALUATION

In order to verify both fuel and reactor performance, measured data were required to validate analytical models used to evaluate the LWBR burnup and breeding characteristics, as well as the reactor's physics parameters. A calculational model was developed to analyze the as-built core and predict the nuclear performance of the core prior to operation. The use of the U-233/Th fuel system led to the need for an extensive analysis of available cross section data and other basic nuclear data for U-233 and thorium, which had previously been given less attention than U-235 and U-238. The U-233 cross-section dependence on energy is particularly complex with broad resonances and strong multilevel effects. In addition, the U-233 cross section interferes with the thorium resonances and with the resonances of its own precursor Pa-233 (Freeman 1978, WAPD-TM-1314).

EOL destructive and nondestructive measurement data were used to compare with the calculational model results in order to verify and validate calculated breeding and burnup predictions.

5.1 End-of-Life Nondestructive and Destructive Examinations

The LWBR modules and rods were examined destructively and nondestructively to assess reactor and breeding performance. Examinations started in 1982 when the core was being removed from the reactor. At Shippingport, the modules were visually examined using an underwater closed circuit television camera, which verified that no indications of rough handling or other unusual conditions were present (WAPD-NRF(L)C-104 Fuel Receipt Criteria Part B 1987, p. 4). Following initial examination and loading, the modules were sent to ECF.

At ECF, 12 of the 39 core fuel modules were prepared for fuel rod removal: four seeds (SI-1, SII-3, SIII-1, and SIII-2), four blankets (BI-3, BII-2, BIII-2, and BIII-6) and four reflectors (RIV-3, RIV-4, RIV-9, and RV-4). Refer to Figure 5-1 for the locations of the removed modules in relation to the rest of the core. Both power-flattening and standard-type blanket rods were removed from the blanket modules. In all, more than 1000 rods were removed for testing and proof of breeding experiments. Of the 1,000+ rods, 524 were nondestructively evaluated at ECF using the Production Irradiated Fuel Assay Gauge (PIFAG) to measure rod EOL fertile and fissile thorium and uranium isotopic mass. To corroborate PIFAG measurements and obtain accurate data for the proof of breeding, 17 of the 524 PIFAG-analyzed rods were completely dissolved and assayed by ANL-E (Graczyk et al. 1987, ANL-87-2). Uranium isotopic data for each rod type are presented in Table 5-1, including destructive examination data (shaded), nondestructive examination data from the PIFAG (maximum assay results) and modeled beginning of life fissile content data. Information about the calculational model used to obtain the modeled data is presented in Freeman (1978)(WAPD-TM-1314). Information about nondestructive and destructive testing follows. An additional 12 PIFAG rods were destructively examined at ANL-W for fission gases.

5.1.1 Nondestructive Examinations

Nondestructive examinations were performed to confirm breeding, assess support structure and fuel rod performance, and provide a database for evaluation of design procedures (Table 5-2). The EOL examination program included examinations of entire modules as well as individual components (rods, grids, bolts, etc.) and crud examination (Table 5-3).

PIFAG. The PIFAG, discussed in Tessler et al. 1987 (WAPD-TM-1614), was used to nondestructively measure the fissile fuel content of 524 spent fuel rods from the modules. Cell locations of the 524 rods are shown in Figures 5-2 through 5-13. The 524 rods were selected using a statistical

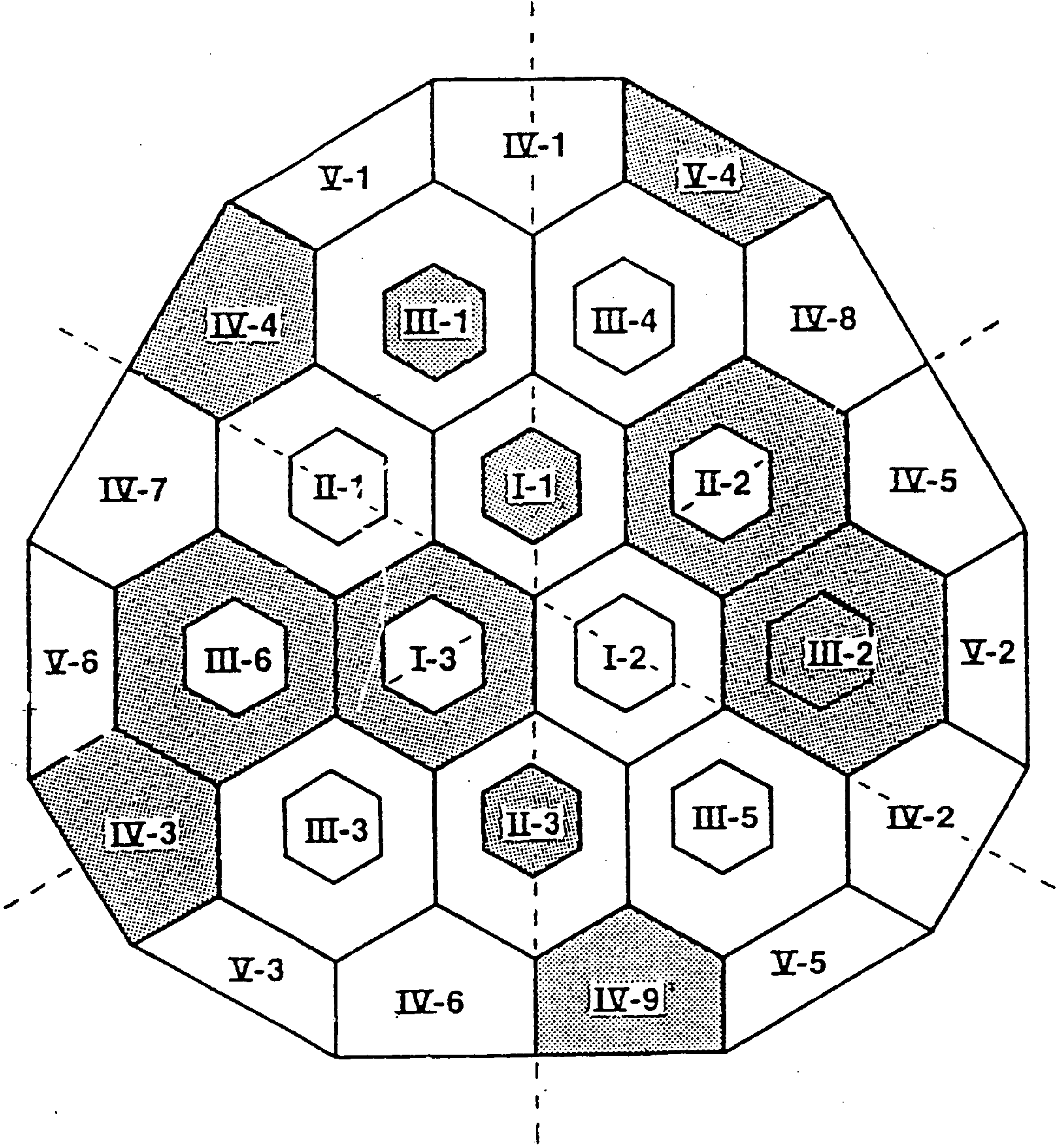

Figure 5-1. Diagram of Light Water Breeder Reactor core, showing locations of Proof-of-Breeding modules (shaded) and boundaries of Sixth-Core Sectors (dashed) (Schick et al. 1987, WAPD-TM-1612, Figure V-1).

Table 5-1. Modeled and measured end-of-life (EOL) isotopic content of Light Water Breeder Reactor fuel rods (from Fuel Receipt Criteria Part B information and ANL-E unpublished data).

Rod Type	Module Type (cell)	Th-232[a] (g)	U-232[a] (g)	U-233[a] (g)	U-234[a] (g)	U-235[a] (g)	U-236[a] (g)	U-238[a] (g)	Maximum BOL Fissile[b] (Modeled) (g)	Maximum EOL Fissile (Measured)[c] (g)
1,2,7,8	SI-1	0.7	0.03	13.69	1.67	0.29	0.03	0.03	14.35	14.23
	SI-1 (P39)[d]		0.02	13.57	1.69	0.29	0.03	0.04	14.22	13.99
	SII-3	0.71	0.02	13.75	1.48	0.23	0.02	0.03	14.37	14.27
	SIII-1	0.71	0.02	13.82	1.32	0.19	0.02	0.03	14.33	14.32
	SIII-2	0.71	0.02	13.82	1.32	0.19	0.02	0.03	14.45	14.38
3	SI-1	0.7	0.03	15.29	1.89	0.33	0.03	0.04	19.18	15.68
	SI-1 (N63)[d]		0.02	15.3	1.88	0.34	0.04	0.05	19.18	15.68
	SII-3	0.7	0.03	15.6	1.7	0.28	0.02	0.04	19.15	15.77
	SIII-1	0.7	0.02	15.88	1.53	0.23	0.02	0.04	19.14	15.98
	SIII-2	0.7	0.02	15.88	1.53	0.23	0.02	0.04	19.19	16.44
4	SI-1	0.69	0.03	17.17	2.13	0.38	0.04	0.05	23.90	17.52
	SI-1 (M49)[d]		0.02	17.06	2.12	0.37	0.03	0.07	23.70	17.52
	SII-3	0.69	0.03	17.72	1.93	0.31	0.03	0.05	24.03	18.06
	SIII-1	0.69	0.02	18.24	1.76	0.26	0.02	0.05	23.90	18.77
	SIII-2	0.69	0.02	18.24	1.76	0.26	0.02	0.05	23.98	18.92
5,6	SI-1	0.68	0.03	24.34	2.54	0.41	0.03	0.07	34.74	25.71
	SI-1 (L29)[d]		0.02	22.33	2.74	0.46	0.04	0.08	34.60	22.96
	SI-1 (C10)[d]		0.02	25.15	2.51	0.4	0.03	0.08	34.68	25.67
	SII-3	0.68	0.03	25.37	2.31	0.35	0.03	0.07	34.87	26.88
	SIII-1	0.68	0.02	26.28	2.1	0.29	0.02	0.07	34.74	27.67
	SIII-2	0.68	0.02	26.28	2.1	0.29	0.02	0.07	34.84	27.58
11,12	BI-3	2.9	0.1	35.4	3.25	0.54	0.05	0.03	16.50	36.88
	BI-3 (A49)[d]		0.08	35.9	3.87	0.7	0.07	0.04	16.45	36.88
	BII-2	2.9	0.09	34.3	2.98	0.47	0.04	0.03	16.48	36.10
	BIII-2	2.91	0.08	33.3	2.73	0.41	0.03	0.03	16.48	34.11
	BIII-6	2.91	0.08	33.3	2.73	0.41	0.03	0.03	16.51	34.72
13	BI-3	2.87	0.1	47.2	4.42	0.74	0.06	0.08	45.53	47.75
	BI-3 (D24)[d]		0.06	46.43	4.35	0.73	0.07	0.1	45.46	47.38
	BII-2	2.87	0.09	46.87	4.22	0.68	0.06	0.08	45.52	47.68
	BIII-2	2.87	0.08	46.59	4.02	0.63	0.05	0.08	45.56	47.25
	BIII-6	2.87	0.08	46.59	4.02	0.63	0.05	0.08	45.58	47.07

Table 5-1. (continued).

Rod Type	Module Type (cell)	Th-232[a] (g)	U-232[a] (g)	U-233[a] (g)	U-234[a] (g)	U-235[a] (g)	U-236[a] (g)	U-238[a] (g)	Maximum BOL Fissile[b] (Modeled) (g)	Maximum EOL Fissile (Measured)[c] (g)
14	BI-3	2.92	0.09	40.74	3.63	0.61	0.05	0.06	30.67	41.35
	BI-3 (C3)[d]		0.06	40.03	3.59	0.58	0.04	0.07	30.67	40.76
	BII-2	2.92	0.09	40.74	3.63	0.61	0.05	0.06	30.61	40.96
	BIII-2	2.92	0.08	39.4	3.21	0.5	0.04	0.06	30.64	39.89
	BIII-6	2.92	0.08	39.4	3.21	0.5	0.04	0.06	30.71	39.89
15	BI-3	2.88	0.1	47.04	4.66	0.76	0.07	0.09	45.84	48.78
	BII-2	2.88	0.1	46.88	4.5	0.72	0.06	0.09	45.75	48.45
	BIII-2	2.88	0.09	46.71	4.29	0.67	0.06	0.09	45.74	48.23
	BIII-6	2.88	0.09	46.71	4.29	0.67	0.06	0.09	45.76	48.21
16	BI-3	2.89	0.1	52.19	4.92	0.8	0.07	0.1	54.75	52.81
	BI-3 (E56)[d]		0.07	51.41	5.23	0.88	0.08	0.12	54.55	52.51
	BII-2	2.89	0.09	52.1	4.74	0.75	0.07	0.1	54.86	52.88
	BIII-2	2.9	0.09	52.06	4.53	0.7	0.06	0.1	54.67	52.74
	BIII-6	2.9	0.09	52.06	4.53	0.7	0.06	0.1	54.70	52.64
21,22	BII-2	2.45	0.06	30.09	2.67	0.4	0.03	0.04	19.00	31.14
	BIII-2	2.45	0.05	28.98	2.29	0.31	0.02	0.04	18.99	30.55
	BIII-6	2.45	0.05	28.98	2.29	0.31	0.02	0.04	19.00	30.39
	BIII-6 (B62)[d]		0.04	28.91	2.27	0.32	0.03	0.05	19.00	29.37
23	BII-2	2.42	0.06	45.57	3.95	0.57	0.05	0.22	52.79	46.03
	BIII-2	2.42	0.05	46.13	3.53	0.47	0.04	0.22	52.77	46.86
	BIII-6	2.42	0.05	46.13	3.53	0.47	0.04	0.22	52.55	46.71
	BIII-6 (D29)[d]		0.05	44.45	4.4	0.71	0.08	0.12	52.51	45.36
24	BII-2	2.46	0.06	34.68	2.98	0.45	0.04	0.06	30.77	35.29
	BIII-2	2.46	0.05	34.11	2.62	0.37	0.03	0.06	30.88	34.49
	BIII-6	2.46	0.05	34.11	2.62	0.37	0.03	0.06	30.80	34.89
	BIII-6 (C13)[d]		0.02	33.61	2.21	0.28	0.02	0.08	30.78	34.02
25,26	BII-2	2.43	0.05	53.87	3.78	0.47	0.04	0.26	63.39	56.60
	BIII-2	2.43	0.03	55.13	3.3	0.38	0.03	0.26	63.18	57.41
	BIII-6	2.43	0.03	55.13	3.3	0.38	0.03	0.26	63.45	57.53
	BIII-6 (F73)[d]		0.04	53.07	4.27	0.62	0.07	0.15	63.27	53.75
	BIII-6 (H1)[d]		0.01	57.1	2.51	0.23	0.01	0.46	63.00	57.44
	BIII-6 (E31)[d]		0.05	50.7	4.94	0.78	0.09	0.15	63.12	51.62

Table 5-1. (continued).

Rod Type	Module Type (cell)	Th-232[a] (g)	U-232[a] (g)	U-233[a] (g)	U-234[a] (g)	U-235[a] (g)	U-236[a] (g)	U-238[a] (g)	Maximum BOL Fissile[b] (Modeled) (g)	Maximum EOL Fissile (Measured)[c] (g)
27	BII-2	2.42	0.07	41.72	4.14	0.64	0.06	0.09	46.53	42.75
	BIII-2	2.42	0.07	41.78	4.04	0.62	0.06	0.09	46.37	43.14
	BIII-6	2.42	0.07	41.78	4.04	0.62	0.06	0.09	46.56	42.88
Reflector POB Cat 43[e]	RIV-3	6.09	0.00	4.54	0.03	0.00	0.00	0.00	0.00	37.45
POB Cat 44[e]	RIV-3	6.09	0.00	9.36	0.10	0.00	0.00	0.00	0.00	
POB Cat 45[e]	RIV-3	6.08	0.01	15.31	0.28	0.01	0.00	0.00	0.00	
POB Cat 46[e]	RIV-3	6.08	0.02	22.42	0.59	0.04	0.00	0.00	0.00	
POB Cat 47[e]	RIV-3	6.04	0.04	30.97	1.12	0.09	0.00	0.00	0.00	
	RIV-3 (B1)[c]		0.04	34.63	1.49	0.14	0.005	0.002	0.00	34.93
	RIV-3 (E3)[c]		0.01	23.68	0.68	0.04	0.001	0.002	0.00	23.87
POB Cat 38[e]	RIV-4, RIV-9	6.09	0.00	4.99	0.03	0.00	0.00	0.00	0.00	39.34
POB Cat 39[e]	RIV-4, RIV-9	6.09	0.00	10.34	0.13	0.00	0.00	0.00	0.00	39.69
POB Cat 40[e]	RIV-4, RIV-9	6.08	0.01	16.57	0.32	0.01	0.00	0.00	0.00	
POB Cat 41[e]	RIV-4, RIV-9	6.07	0.02	23.53	0.65	0.04	0.00	0.00	0.00	
POB Cat 42[e]	RIV-4, RIV-9	6.04	0.04	32.39	1.22	0.10	0.00	0.00	0.00	
POB Cat 48[e]	RV-4	6.09	0.00	4.80	0.03	0.00	0.00	0.00	0.00	24.20
POB Cat 49[e]	RV-4	6.09	0.00	10.46	0.12	0.00	0.00	0.00	0.00	
POB Cat 50[e]	RV-4	6.07	0.01	19.14	0.42	0.02	0.00	0.00	0.00	

a. Isotopic data taken from Part B Fuel Receipt Criteria EOL fuel loading data for the rod storage liners. Shaded cells contain results from the unpublished ANL-E destructive examinations.

b. Maximum as-built loading (modeled) for the rod type as reported in Tessler et al. (1987) WAPD-TM-1614, Tables 26–40.

c. Maximum EOL fissile for the rod type measured with the PIFAG, as reported in Tessler et al. (1987) WAPD-TM-1614, Tables 26–40.

d. The number in parentheses is the location of the cell within the module, which held the rod that was destructively examined by ANL-E.

e. POB Cat is the Proof of Breeding category assigned to the fuel rods within the reflector modules.

Table 5-2. Summary of nondestructive examinations.

Test	Purpose	Number of Samples	Results	Location of Test
Fuel module visual examinations	Assess module condition immediately after being removed from reactor (crud, corrosion, damage, deformation of modules)	All before shipping from Shippingport 5 seed, 5 blanket, 3 reflector modules at Expended Core Facility (ECF)	Seal blocks and stub tubes clean, crud on reflector modules, but otherwise in excellent condition (Wargo 1987, WAPD-TM-1602, pp. 18-27)	Shippingport APS, ECF
Fuel module bow and growth	Measure module bow and growth	Seed: 5 modules Blanket: 5 modules Reflector: 3 modules	Minimal growth and bow. Module bowing: Seed: 0.01 to 0.053 in. Blanket: 0.029 to 0.098 in. Reflector: 0.236 to 0.239 in. (Wargo 1987, WAPD-TM-1602, pp. 18-27)	ECF water pits
Production Irradiated Fuel Assay Gauge (PIFAG) (active neutron interrogation and delayed neutron counting)	Fissile fuel content, proof-of-breeding	524 rods from 12 modules (Figures 5-2 through 5-13)	Results are reproduced in Appendix A.	ECF hot cells
Gamma scan (PIFAG)	Measure in-stack gaps, binary fuel stack lengths, and axial profiles	24 rods: 9 seed 8 standard blanket 4 power-flattening blanket 3 reflector	No in-stack gaps between pellets noted with gamma scan (Gorscak, Campbell, and Clayton 1987, WAPD-TM-1605, p. 182). Resolution 0.2 in. Maximum binary fuel elongation: Seed: 0.722 in. Blanket: 0.541 in. (Gorscak, Campbell, and Clayton 1987, WAPD-TM-1605, Table 27).	ECF hot cells

Table 5-2. (continued).

Test	Purpose	Number of Samples	Results	Location of Test
Rod pull force measurements (Rod Removal System [RRS])	Prevent overstressing a rod during disassembly, measure residual spring forces in support grids	1072 (test rods and rods for accessing test rods)	Upper 95% tolerance limit and maximum pull forces: Seed: 29 lb/90 lb Blanket: 52 lb/96 lb Reflector: 56 lb/145 lb (Gorscak, Campbell, and Clayton 1987, WAPD-TM-1605, Figures 14–16, Table 9).	ECF
In-bundle bow and gap measurements (Vertical Inspection Gage Inspection Package) underwater	For Nuclear Regulatory Commission core certification safety analysis, standard deviations of percent gap closure required (Campbell, and Clayton 1987, p. 39). Fuel rod performance	1 seed 5 blankets 1 reflector (see Gorscak, Campbell, and Clayton 1987, WAPD-TM-1605, Figure 7)	Module bowing: SII-3: 0.03 in. BIII-2: 0.095 in. RIV-4: 0.160 in. (Gorscak, Campbell, and Clayton 1987, WAPD-TM-1605, p. 72). Other results in App. A4 and A5, Figures 21-30 in Gorscak, Campbell, and Clayton 1987, WAPD-TM-1605.	Bettis
Rod length (Rod Examination [REX] Gauge)	Evaluate in-reactor length increases from thermal expansion, system pressure, irradiation growth of zircaloy cladding, and pellet-cladding interaction.	6 seed 5 standard blanket 5 power-flattening blanket 3 reflector	Elongation about 0.3–0.6 inches for all types (Gorscak, Campbell, and Clayton 1987, WAPD-TM-1605, Table 10).	ECF
Visual inspections (REX, underwater camera)	Cladding cracking and collapse	Almost 1100 from 12 modules	Usual wear. No evidence of gross cladding deformation, cracked cladding, excessive wear, or any other unusual conditions (Gorscak, Campbell, and Clayton 1987, WAPD-TM-1605, pp. 98-99). Negligible post-transition oxide.	ECF

Table 5-2. (continued).

Test	Purpose	Number of Samples	Results	Location of Test
Free hanging bow (REX, 5X video recordings at 0, 45, 90, and 135-degree orientations)	Calculate seeding force and beginning-of-life bow of each rod	5 seed 4 standard blanket 3 power-flattening blanket 3 reflector	Free hanging bow measurements indicate an EOL maximum of 0.291 in. in a reflector rod (Gorscak, Campbell and Clayton 1987, WAPD-TM-1605, p. 109, Table 13). Calculated end-of-life in-bundle span bows from free hanging bow data were significantly smaller than worst-case bow predictions except for span 7 of seed rod 1606710 (Gorscak, Campbell, and Clayton 1987, WAPD-TM-1605, p. 110, data in Table 14).	ECF
Cladding diameter and in-stack ovality measurements (REX axial profilometer; cladding outside diameters measured at 0, 45, 90 and 135-degree orientation)	Evaluate fuel rod ridging, grooving, ovality	19 rods	Diameter shrinkage and ovality less than predicted (see Gorscak, Campbell, and Clayton 1987, WAPD-TM-1605, Figures 44–46 and Table 15). Shrinkage 1–6 mils.	ECF
Plenum ovality (REX)	To confirm stability of the freestanding recrystallization annealed cladding in the seeds and confirm predictions of cladding deformation for nonfreestanding stress relief annealed blanket cladding (p. 47)	4 seed 7 standard blanket 3 power-flattening blanket	Ovalities <2 mils for seed rods and <4 mils for blanket rods (Gorscak, Campbell, and Clayton 1987, WAPD-TM-1605, Table 17).	ECF

Table 5-2. (continued).

Test	Purpose	Number of Samples	Results	Location of Test
Wear mark depth volume and location (REX orbiting profilometer)	Confirm fuel rod design analysis procedure for rod wear; overall view of rod wear for grid support system	4 seed 7 standard blanket 3 power-flattening blanket	Wear marks virtually nonexistent (Gorscak, Campbell, and Clayton 1987, WAPD-TM-1605, p. 128).	ECF
Oxide thickness (Nortec 5 MHZ eddy current oxide thickness, EDCOT, gauge in the axial profilometer)	Axial variations of oxide thickness	12 destructive examination rods + 4 others	Oxide thickness <0.2 mil over the bottom 30 in. of each rod. Peak of 1.46 mils near the seventh grid level in rod 400736, which coincides with top of binary stack; peak of 1.56 mils between 6th and 7th levels in 606773 (Gorscak, Campbell, and Clayton 1987, WAPD-TM-1605, Table 19).	ECF
Cladding defects (REX ultrasonic gauge)	Determine if cracks formed as a result of core operation and to locate defect indications (Gorscak, Campbell, and Clayton 1987, WAPD-TM-1605, p. 54)	12 destructive examination (Gorscak, Campbell, and Clayton 1987, WAPD-TM-1605, p. 147)	No indications of significant defects through-cladding cracks or other unusual conditions in 9 of the 12 rods. 1 standard blanket and 2 power-flattening blanket rods had strong ultrasonic examination indications (>10 mils) that were not surface marks and not confirmable with metallo-graphic analysis (Gorscak, Campbell, and Clayton 1987, WAPD-TM-1605, p. 147).	ECF
Crud measurements (decrud with four solutions then quantitative analysis)	Characterize crud deposits on the external surface including elements and radioisotopes in crud.	Seed 0504502 Standard blanket 1605629 Reflector 3220018	Characteristics of crud shown in Table 5-3. Local smudge-like areas of crud were frequently observed on the rods. Descaling was largely effective (Gorscak, Campbell, and Clayton 1987, WAPD-TM-1605, p. 152).	Argonne National Laboratory - West

Table 5-2. (continued).

Test	Purpose	Number of Samples	Results	Location of Test
Neutron radiography	For proper cutting of rods, examining fuel pellet integrity, and determining fuel stack and plenum dimensions in the intact fuel rods.	12 destructive examination rods: 4 seed (2 with 84-in. binary stack length, 1 with 70-in. binary stack length, 1 with 42-in. binary stack length). 4 standard blanket (2 with 42-in. binary stack length, 1 with 84-in. binary stack and high enrichment, and 1 with 84-in. binary stack length and medium enrichment) 3 power-flattening blanket (84 in. with high enrichment) 1 reflector	None of the radiographs gave an indication of defected cladding or massive hydriding. (Gorscak, Campbell, and Clayton 1987, WAPD-TM-1605, p. 164). Pellet stacks were generally stable and continuous. Most pellet cracks were hairline; few indicate fuel separation.	Argonne National Laboratory-West Neutron Radiography Facility

Table 5-3. Fuel rod crud characterization (Gorscak, Campbell, and Clayton 1987, WAPD-TM-1605, Table 21).

Seed Rod 0504502

Elements (mg/dm^2)

Increment	Fe	Ni	Cr	Co	Cu
First	0.38	0.45	0.10	nd*	nd*
Second	0.26	0.26	0.03	nd*	nd*
Third	0.54	0.88	0.08	nd*	nd*

Radioisotopes (µCi/dm^2)

Increment	^{55}Fe	^{63}Ni	^{60}Co	^{54}Mn	^{125}Sb
First	3.87	3.45	10.21	7.74	nd*
Second	3.54	1.70	15.21	5.76	nd*
Third	5.23	1.95	26.87	6.54	trace

Blanket Rod 1605629

Elements (mg/dm^2)

Increment	Fe	Ni	Cr	Co	Cu
First	0.48	0.39	0.08	nd*	nd*
Second	0.73	0.56	0.04	nd*	nd*
Third	2.02	0.86	0.09	nd*	nd*

Radioisotopes (µCi/dm^2)

Increment	^{55}Fe	^{63}Ni	^{60}Co	^{54}Mn	^{125}Sb
First	3.02	1.91	12.68	3.30	nd*
Second	8.52	5.57	42.61	7.10	nd*
Third	13.83	4.18	62.76	5.81	trace

Reflector Rod 3220018

Elements (mg/dm^2)

Increment	Fe	Ni	Cr	Co	Cu
First	0.49	0.47	0.04	nd*	nd*
Second	0.34	0.86	0.04	nd*	nd*
Third	0.40	0.04	0.04	nd*	nd*

Radioisotopes (µCi/dm^2)

Increment	^{55}Fe	^{63}Ni	^{60}Co	^{54}Mn	^{125}Sb
First	2.03	1.48	2.61	3.47	nd*
Second	4.58	5.08	9.66	2.69	nd*
Third	2.16	0.73	5.13	nd*	nd*

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*nd - not discernible

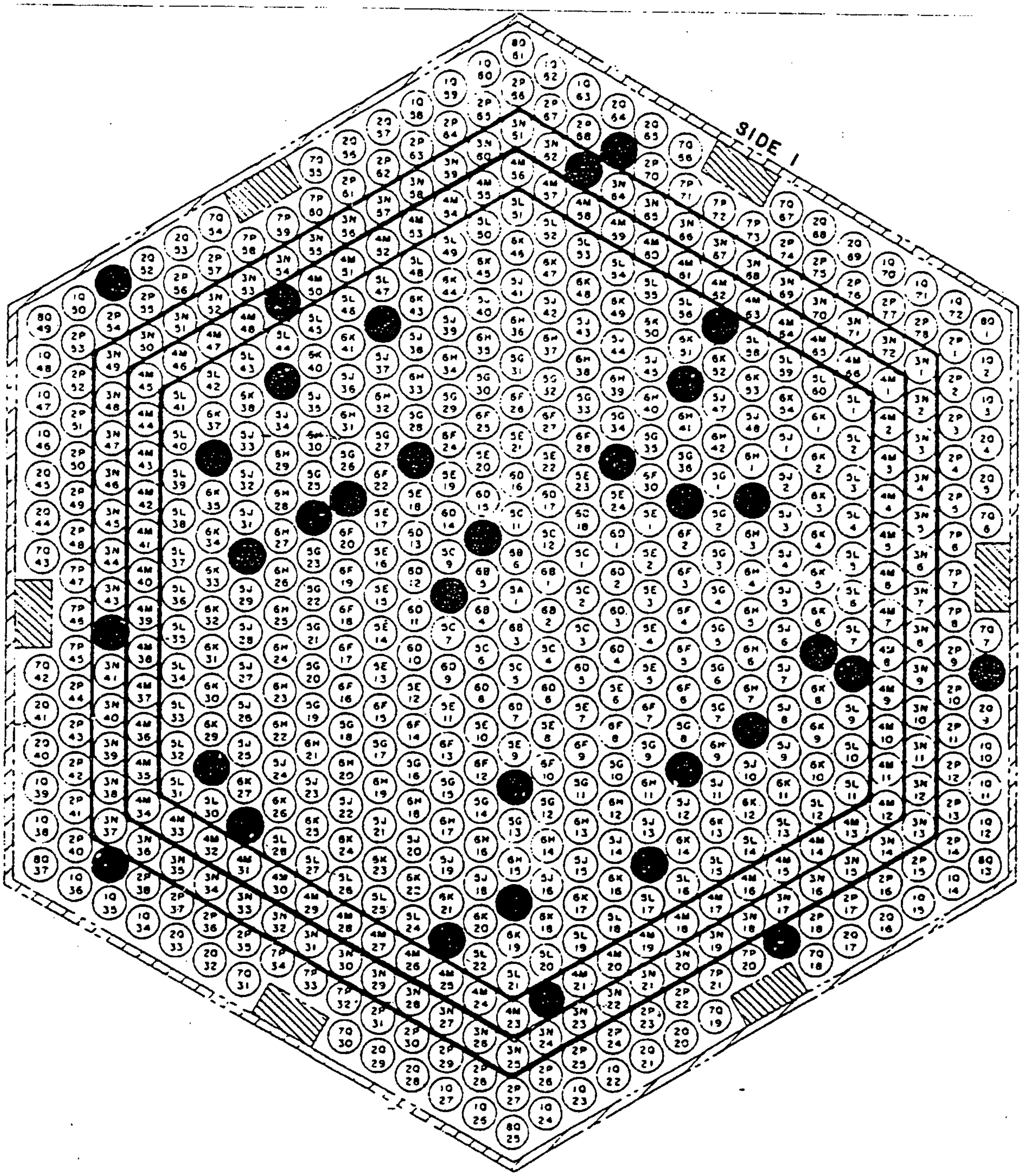


Figure 5-2. Location of proof-of-breeding rods in Seed Module I-1 (Schick et al. 1987, WAPD-TM-1612, Figure V-2).

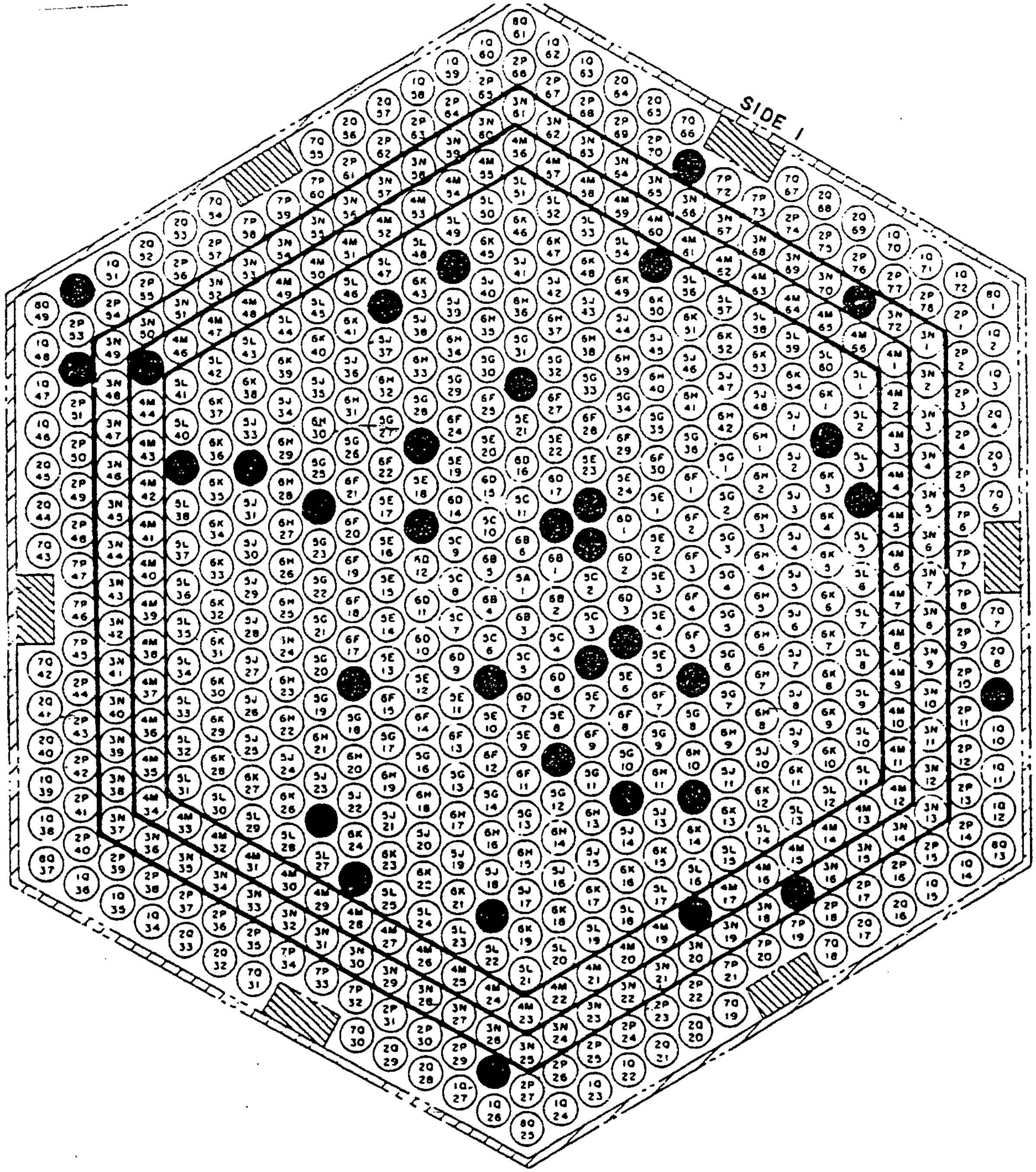


Figure 5-3. Location of proof-of-breeding rods in Seed Module II-3 (Schick et al. 1987, WAPD-TM-1612, Figure V-3).

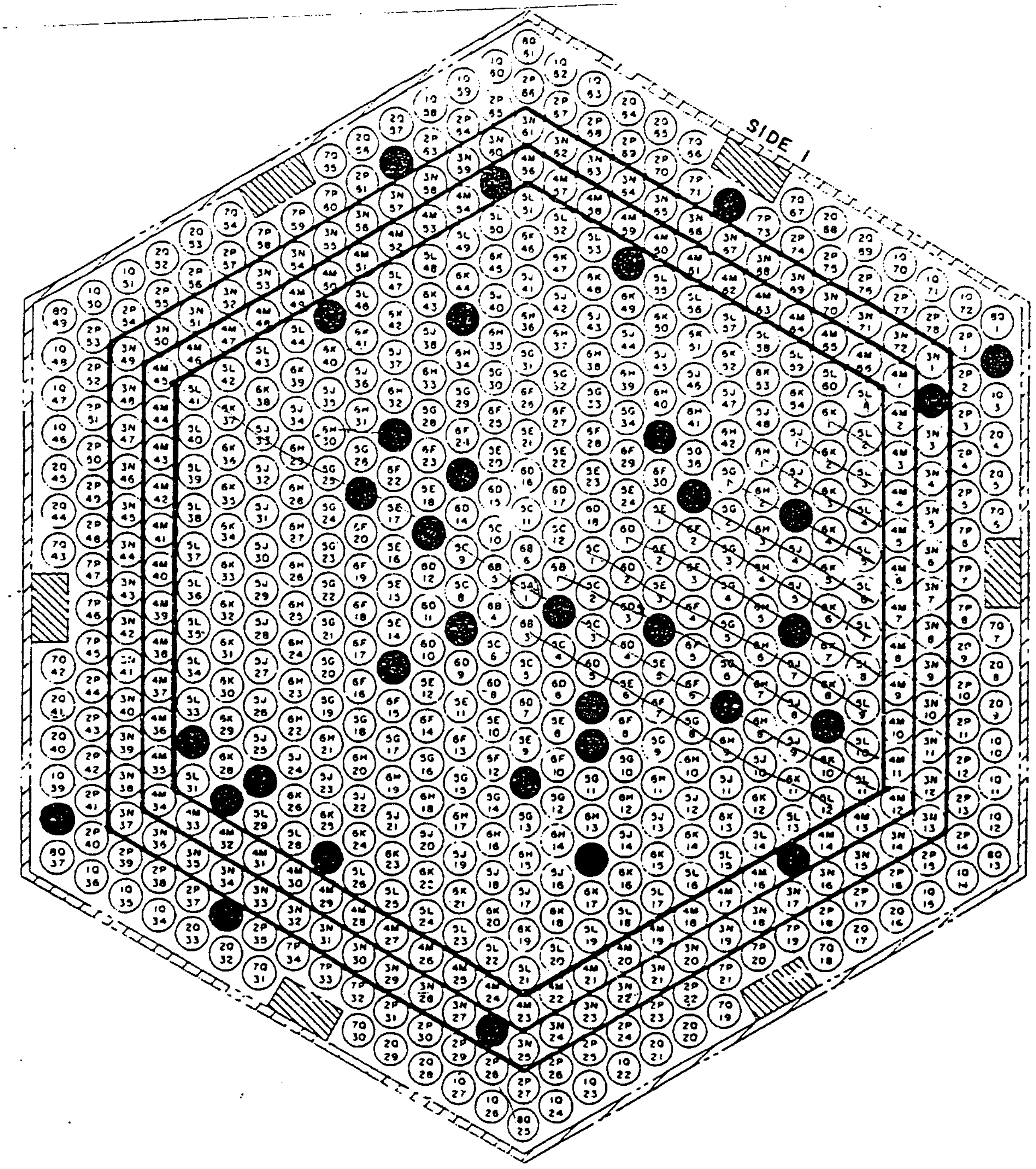


Figure 5-4. Location of proof-of-breeding rods in Seed Module III-1 (Schick et al. 1987, WAPD-TM-1612, Figure V-4).

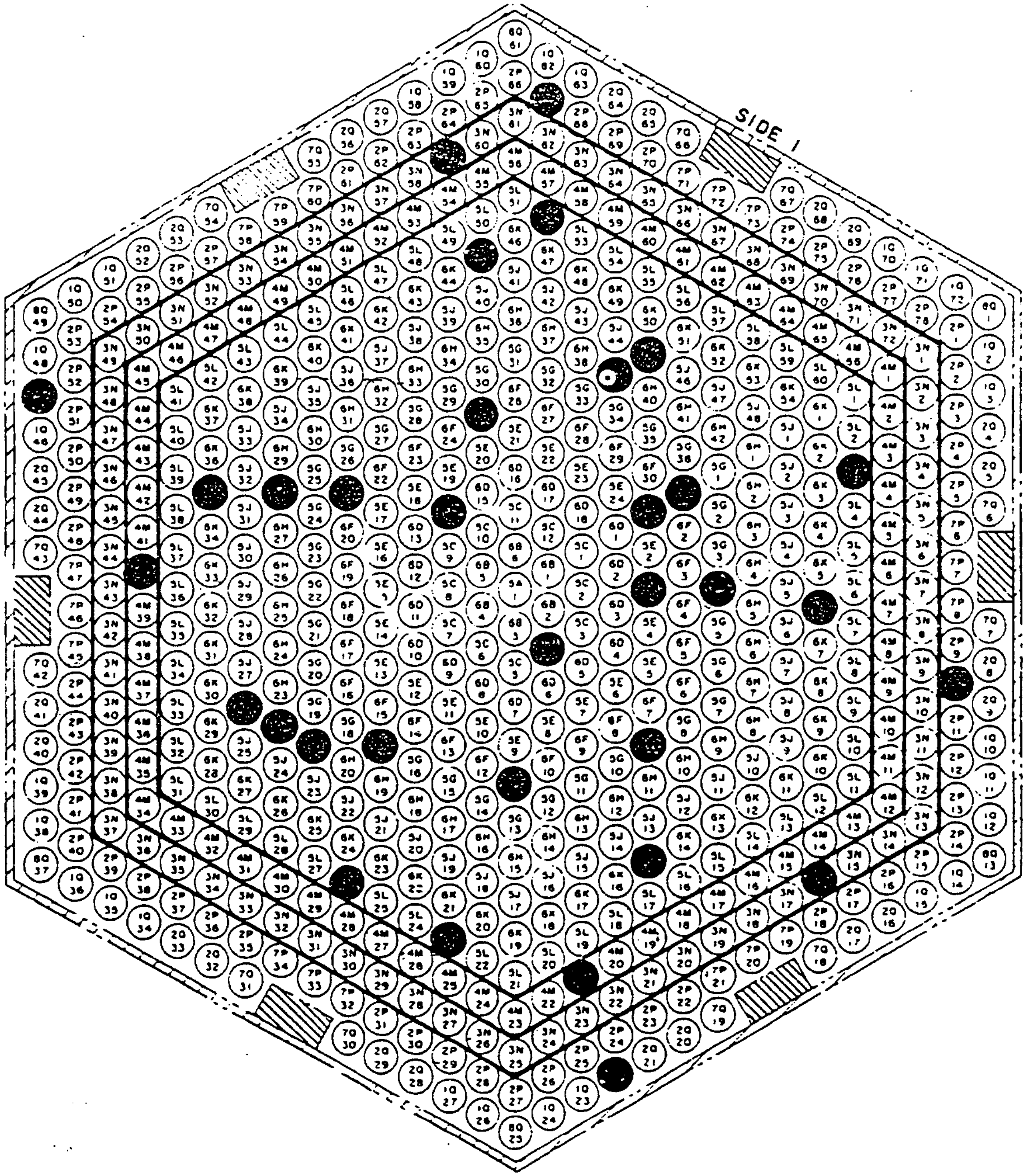


Figure 5-5. Location of proof-of-breeding rods in Seed Module III-2 (Schick et al. 1987, WAPD-TM-1612, Figure V-5).

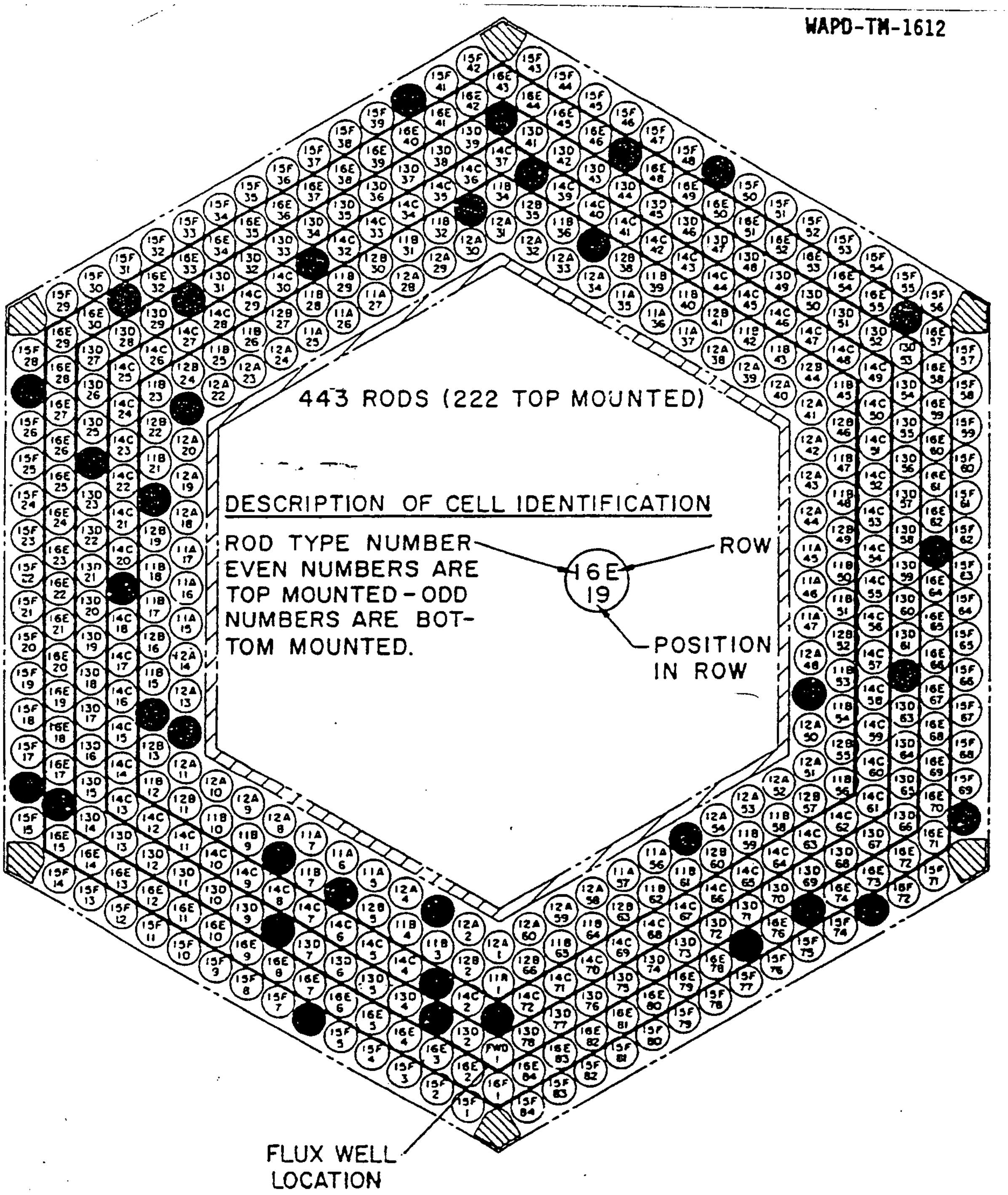


Figure 5-6. Location of proof-of-breeding rods in Blanket Module I-3 (Schick et al. 1987, WAPD-TM-1612, Figure V-6).

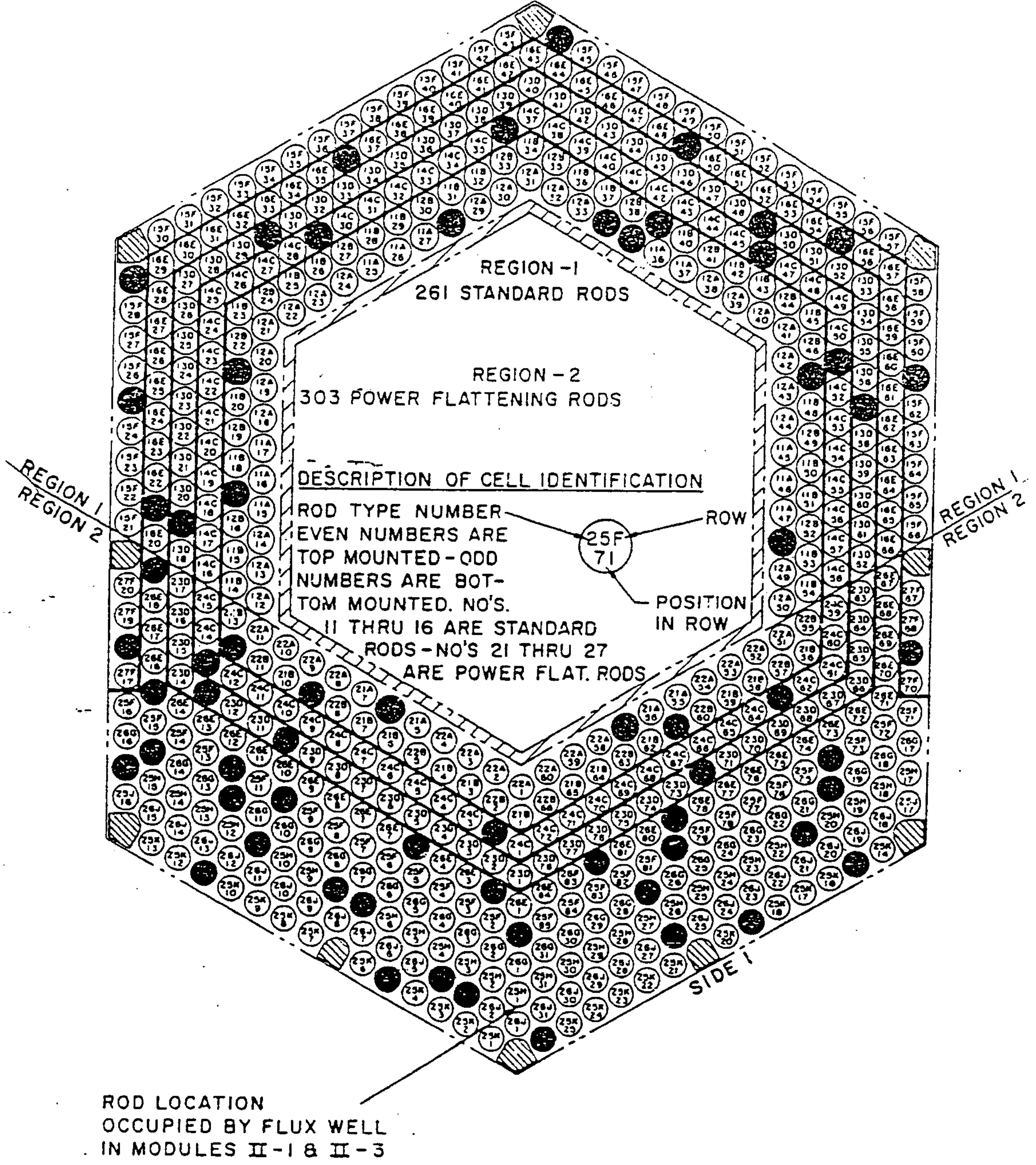


Figure 5-7. Location of proof-of-breeding rods in Blanket Module II-2 (Schick et al. 1987, WAPD-TM-1612, Figure V-7).

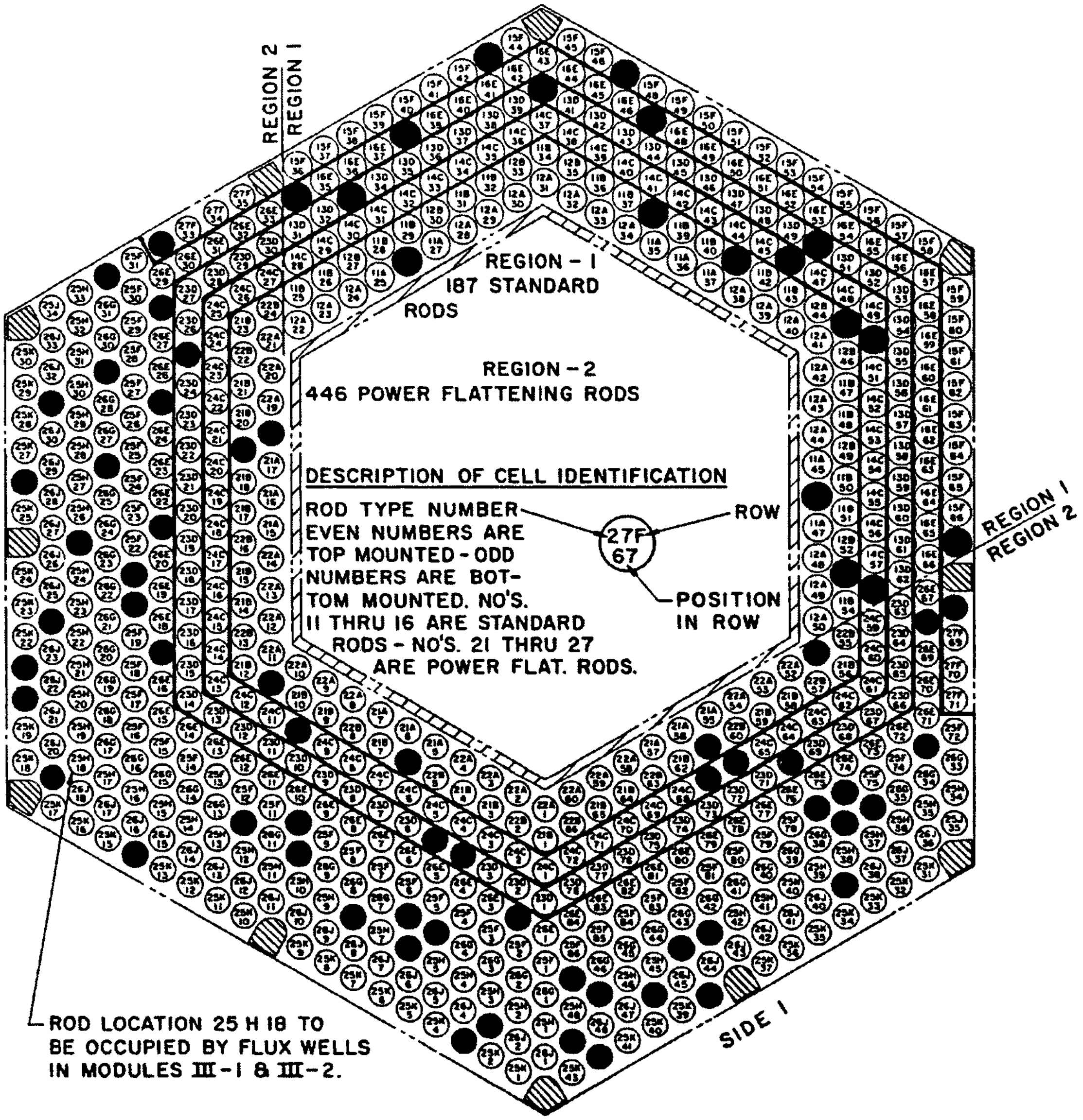


Figure 5-8. Location of proof-of-breeding rods in Blanket Module III-2 (Schick et al. 1987, WAPD-TM-1612, Figure V-8).

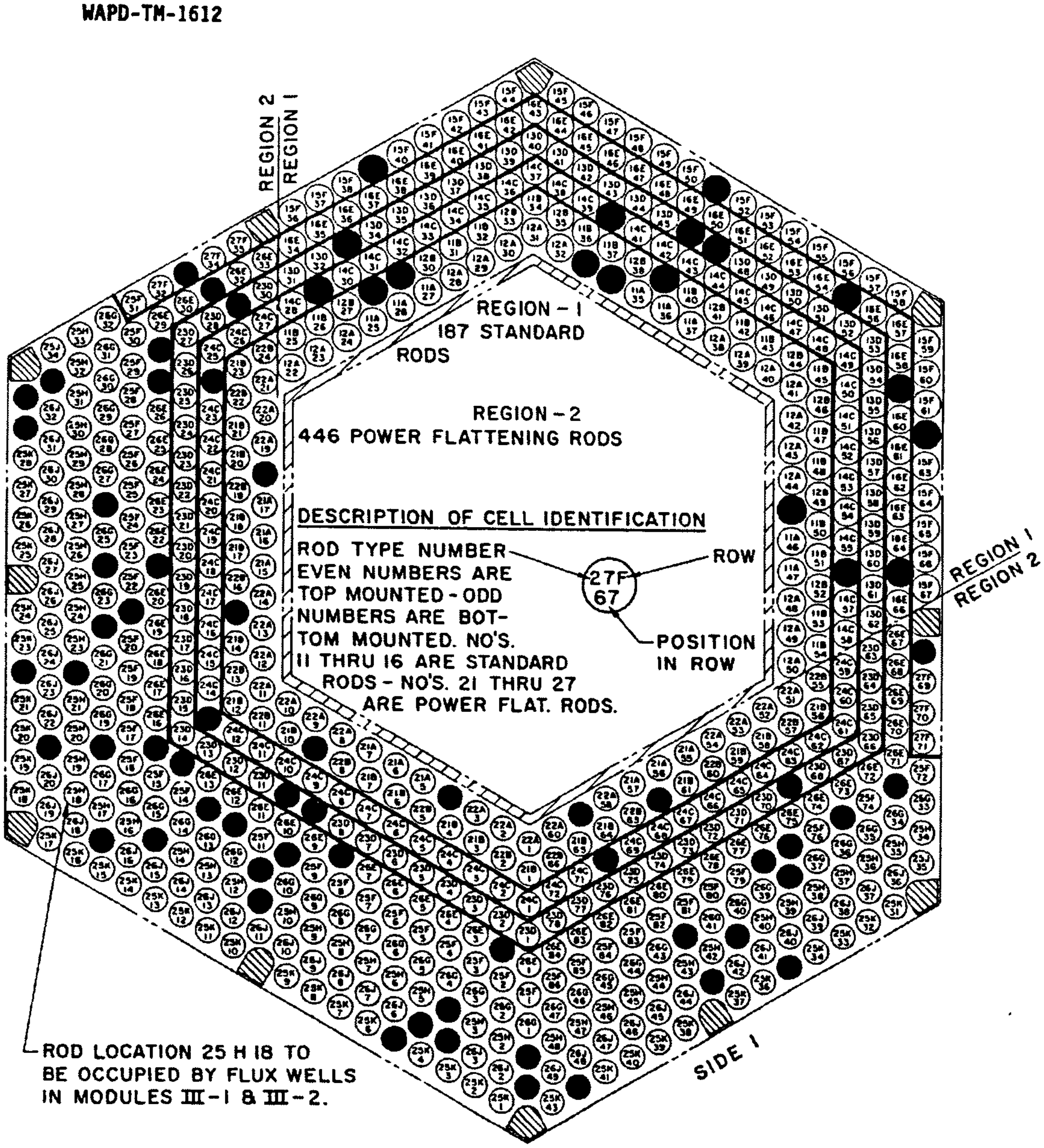
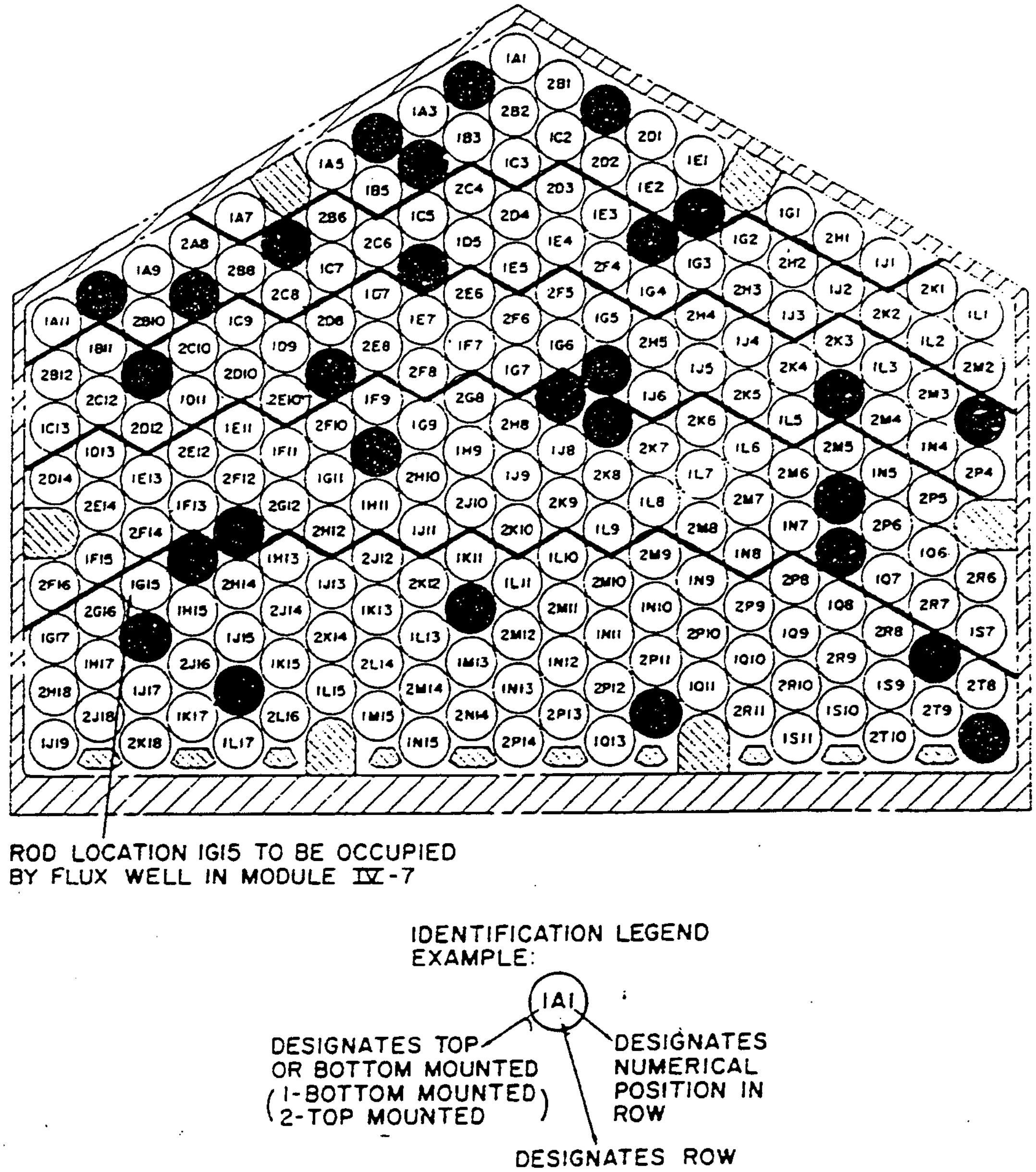


Figure 5-9. Location of proof-of-breeding rods in Blanket Module III-6 (Schick et al. 1987, WAPD-TM-1612, Figure V-9).



ROD LOCATION 1G15 TO BE OCCUPIED BY FLUX WELL IN MODULE IV-7

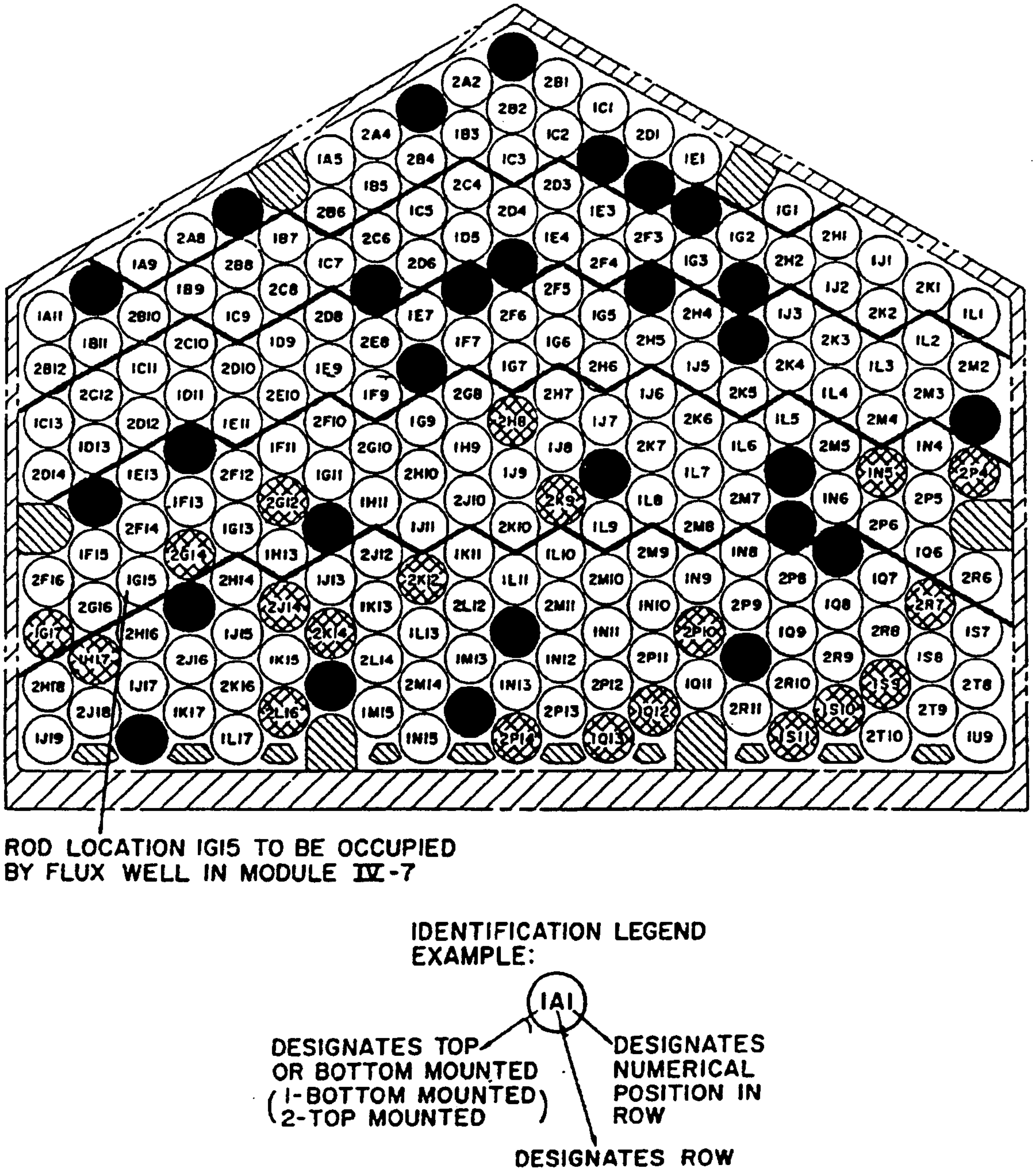
IDENTIFICATION LEGEND EXAMPLE:

DESIGNATES TOP OR BOTTOM MOUNTED (1-BOTTOM MOUNTED 2-TOP MOUNTED)

DESIGNATES NUMERICAL POSITION IN ROW

DESIGNATES ROW

Figure 5-10. Location of proof-of-breeding rods in Reflector Module IV-4 (Schick et al. 1987, WAPD-TM-1612, Figure V-10).



ROD LOCATION IGI5 TO BE OCCUPIED
BY FLUX WELL IN MODULE IV-7

IDENTIFICATION LEGEND
EXAMPLE:

DESIGNATES TOP OR BOTTOM MOUNTED
(1-BOTTOM MOUNTED
2-TOP MOUNTED)

DESIGNATES NUMERICAL POSITION IN ROW

DESIGNATES ROW

Figure 5-11. Location of proof-of-breeding (POB) rods in Reflector Module IV-9. Twenty additional rods that are not part of the original POB sample are indicated by cross hatching (Schick et al. 1987, WAPD-TM-1612, Figure V-11).

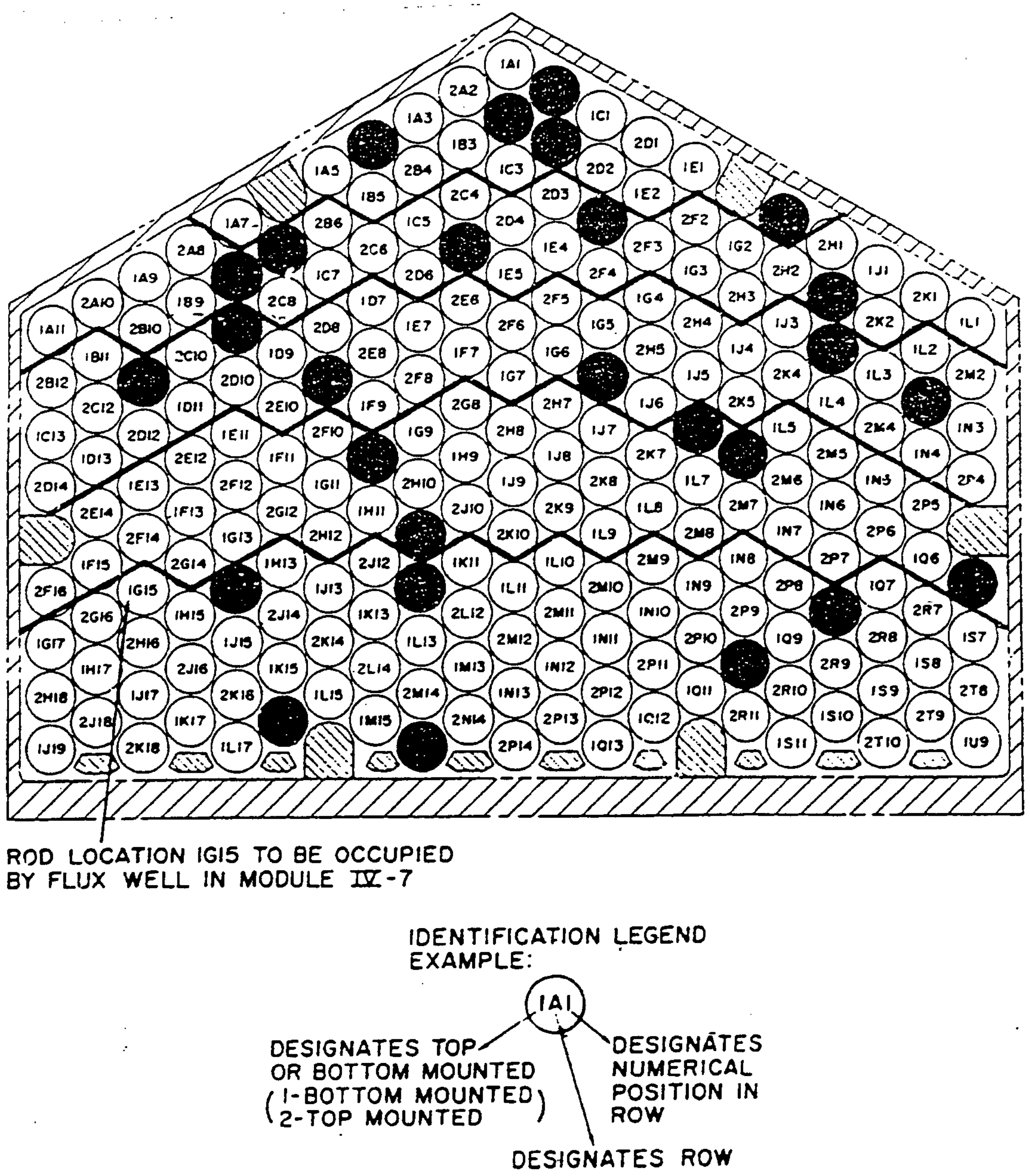


Figure 5-12. Location of proof-of-breeding rods in Reflector Module IV-3 (Schick et al. 1987, WAPD-TM-1612, Figure V-12).

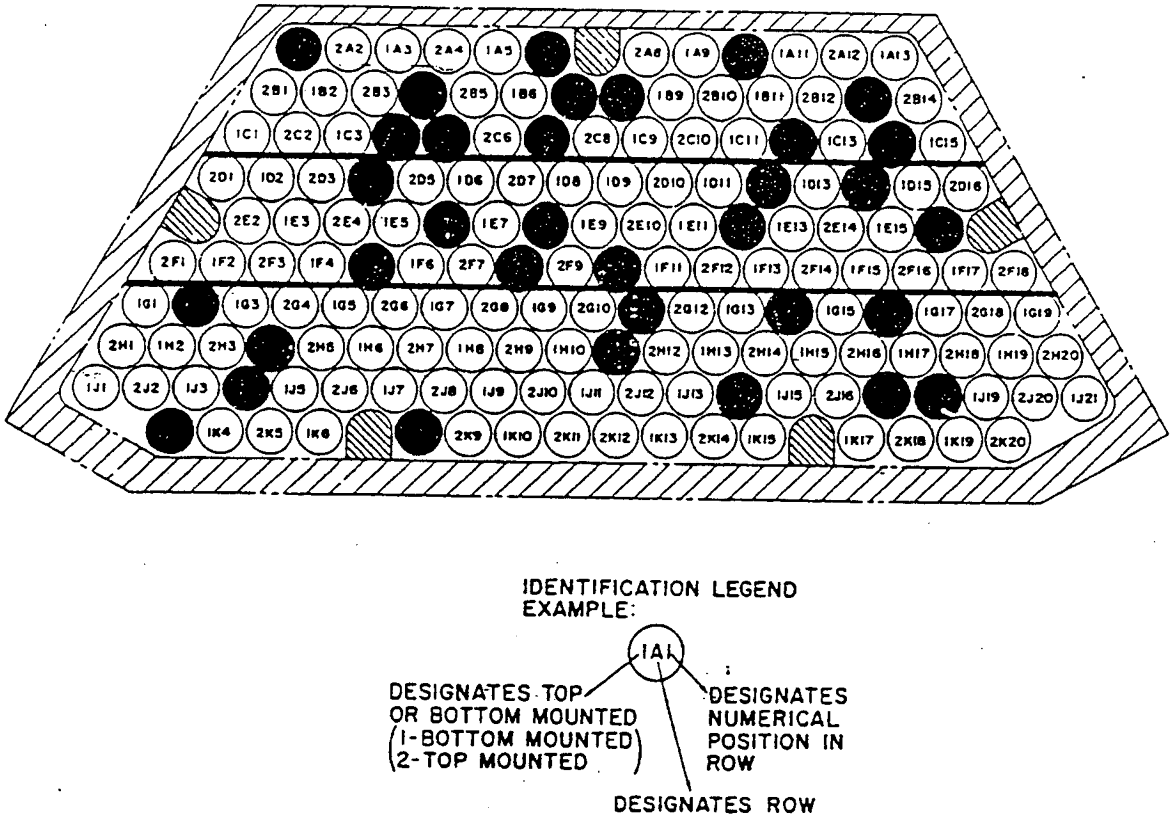


Figure 5-13. Location of proof-of-breeding rods in Reflector Module V-4 (Schick et al. 1987, WAPD-TM-1612, Figure V-13).

sampling plan, and the resulting data were used to estimate the EOL fissile inventory for the whole core. Data from the PIFAG are provided in Appendix A. EOL fissile data from PIFAG were compared with data from extensive destructive evaluations to assess the accuracy of the PIFAG. EOL and beginning-of-life data were compared to determine if breeding had occurred (Tessler et al. 1987, WAPD-TM-1614, p. 1).

The PIFAG used the method of active neutron interrogation and delayed neutron counting (see Tessler et al. 1987, WAPD-TM-1614) to determine the fissile uranium loading of each rod. The PIFAG was assembled in a hot cell at Naval Reactors ECF. As-fabricated (unirradiated) rods were used to calibrate the PIFAG. Isotopic loadings for individual unirradiated seed, standard blanket, power-flattening and reflector rods are presented in Table 5-4. Core rod testing was conducted from June 1984 to May 1987 (Tessler et al. 1987, WAPD-TM-1614).

Rods were irradiated by neutrons from four Cf-252 sources, then delayed neutrons resulting from the fissions occurring from the source were counted as the rod passed through the detector region. The indium-cadmium liner in the PIFAG could be positioned to provide thermal or epithermal neutron interrogation spectrum. After an epithermal mode foreground pass, the rods were gamma scanned, and a cumulative gamma ray spectrum was recorded (Tessler et al. 1987, WAPD-TM-1614, p. 25). The PIFAG performance was closely monitored. The accuracy of the PIFAG was determined by comparing PIFAG results with destructive analysis results for 17 of the rods (Tessler et al. 1987, WAPD-TM-1614, p.74).

Table 5-4. Calibration rod isotopic loadings. All values are in grams (Tessler et al. 1987, WAPD-TM-1614, Table 24).

a. Seed Rods

Rod ID	^{232}U*	^{233}U	^{234}U	^{235}U	^{236}U	^{238}U	^{232}Th
05001	0.0	0.0	0.0	0.0	0.0	0.0	745.5
05004	0.0	0.0	0.0	0.0	0.00	0.0	746.2
05061	2.05E-5	3.401	0.0400	2.92E-3	4.18E-4	0.0351	728.2
05062	2.05E-5	3.402	0.0400	2.92E-3	4.18E-4	0.0352	728.4
05121	4.91E-5	8.131	0.0957	6.99E-3	9.98E-4	0.0840	721.1
05122	4.91E-5	8.132	0.0957	6.99E-3	9.98E-4	0.0840	721.5
05273	1.11E-4	18.308	0.215	0.0157	2.25E-3	0.189	712.1
0100500	9.97E-5	14.196	0.194	0.0176	3.90E-3	0.0448	716.5
0301754	1.55E-4	19.110	0.233	4.47E-3	1.94E-4	0.0697	708.1
0401863	1.67E-4	23.698	0.323	0.0294	6.52E-3	0.0743	698.0
0414466	1.67E-4	24.077	0.321	0.0201	4.65E-3	0.0705	702.6
05431	2.25E-4	28.709	0.350	6.71E-3	2.92E-4	0.104	695.8
05432	2.25E-4	28.709	0.350	6.71E-3	2.92E-4	0.104	695.6
0511165	2.49E-4	34.548	0.431	0.0133	1.75E-3	0.0782	691.9
0527674	2.48E-4	34.797	0.457	0.0269	6.37E-3	0.1005	691.6

b. Regular Blanket Rods

Rod ID	^{232}U	^{233}U	^{234}U	^{235}U	^{236}U	^{238}U	^{232}Th
15002	0.0	0.0	0.0	0.0	0.0	0.0	2954.3
15004	0.0	0.0	0.0	0.0	0.0	0.0	2959.0
15061	8.35E-5	13.838	0.163	0.0119	1.70E-3	0.143	2949.5
15064	8.35E-5	13.828	0.163	0.0119	1.70E-3	0.143	2949.0
1103425	1.41E-4	16.445	0.221	0.0135	3.51E-3	0.0452	2931.2
1104780	1.40E-4	16.431	0.221	0.0135	3.51E-3	0.0451	2936.2
15122	2.57E-4	32.814	0.475	0.0478	0.0154	0.0823	2910.7
15124	2.58E-4	32.829	0.475	0.0478	0.0154	0.0823	2912.2
1412359	2.54E-4	30.094	0.392	0.0190	3.98E-3	0.0826	2953.6
1501827	3.89E-4	45.577	0.612	0.0380	9.74E-3	0.124	2915.2
1512019	3.89E-4	45.528	0.611	0.0380	9.73E-3	0.124	2914.9
1300545	3.83E-4	45.399	0.604	0.0362	9.15E-3	0.119	2904.0
1613659	4.59E-4	54.397	0.719	0.0431	0.0111	0.143	2923.6
1613834	4.59E-4	54.380	0.719	0.0431	0.0111	0.143	2922.3

c. Power Flattening Blanket Rods

Rod ID	^{232}U	^{233}U	^{234}U	^{235}U	^{236}U	^{238}U	^{232}Th
25001	0.0	0.0	0.0	0.0	0.0	0.0	2488.9
25004	0.0	0.0	0.0	0.0	0.0	0.0	2493.2
25063	7.04E-5	11.660	0.137	0.0100	1.43E-3	0.120	2489.8
25064	7.03E-5	11.646	0.137	0.0100	1.43E-3	0.120	2486.5
25122	1.69E-4	27.930	0.329	0.0240	3.43E-3	0.289	2473.8
25123	1.69E-4	27.940	0.329	0.0240	3.43E-3	0.289	2474.7
2100153	1.60E-4	18.910	0.250	0.0144	3.46E-3	0.0496	2477.8
2103140	1.58E-4	18.972	0.257	0.0180	4.83E-3	0.0521	2471.2
25161	3.19E-4	37.813	0.500	0.0292	6.92E-3	0.0984	2459.3
25163	3.22E-4	38.168	0.505	0.0295	6.99E-3	0.0993	2459.2
2402626	2.43E-4	30.601	0.424	0.0343	9.97E-3	0.0826	2472.6
2700468	3.82E-4	46.313	0.636	0.0519	0.0146	0.126	2452.6
2701624	3.56E-4	46.523	0.683	0.0749	0.0237	0.124	2455.7
2303222	3.76E-4	52.579	0.639	0.0440	8.59E-3	0.415	2433.6
2500452	4.43E-4	62.959	0.732	0.0398	7.71E-3	0.482	2427.1
2502616	4.51E-4	63.139	0.747	0.0464	0.0122	0.439	2431.0

d. Reflector Rods

Rod ID	^{232}U	^{233}U	^{234}U	^{235}U	^{236}U	^{238}U	^{232}Th
3106718	0.0	0.0	0.0	0.0	0.0	0.0	6089.4
3108707	0.0	0.0	0.0	0.0	0.0	0.0	6028.1
3102143	0.0	0.0	0.0	0.0	0.0	0.0	6036.7
31062	1.75E-4	29.048	0.342	0.0250	3.57E-3	0.300	6033.9
31063	1.75E-4	29.052	0.342	0.0250	3.57E-3	0.300	6037.6
31123	4.19E-4	69.363	0.816	0.0596	8.52E-3	0.717	5978.9
31124	4.19E-4	69.401	0.817	0.0596	8.52E-3	0.717	5976.9

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* Notation n.nnE-n ≡ n.nn x 10^{-n}

Paired t-test analysis of the differences in results by rod type indicates a small statistically insignificant bias at the 5% significance levels (Tessler et al., WAPD-TM-1614, pp. 60–61). Table 5-1 shows the comparative results of the PIFAG and the destructively evaluated rods.

REX. The Rod Examination (REX) gauge measured fuel rod length, diameter, oxide thickness, ovality, wear mark depth, and volume and provided a 5X visual examination and video recording capabilities. The gauge also had the capability of ultrasonic screening of the fuel rod cladding for defects.

Nineteen rods were removed for nondestructive examinations in the REX gauge (12 of those were also destructively examined at ANL-W). The 19 were selected to evaluate the effects of a broad range of parameters on fuel rod performance and included: 6 seed rods, 7 standard blanket rods, 3 power-flattening rods, and 3 reflector rods. Their approximate locations are shown in Figure 5-14.

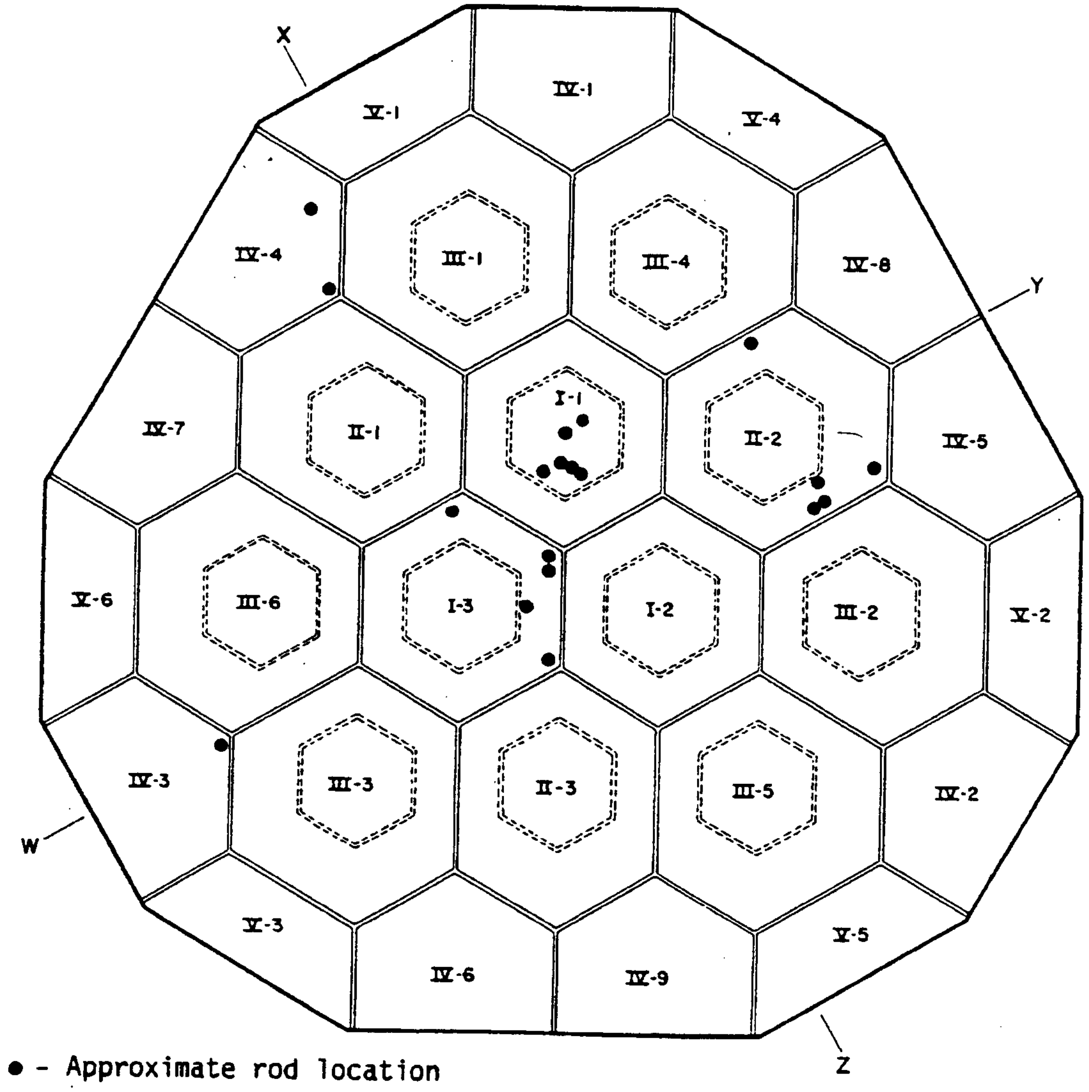

Figure 5-14. Rod examination (REX) fuel rod locations (Gorscak, Campbell, and Clayton 1987, WAPD-TM-1605, Figure 9).

5.1.2 Destructive Examination

Twelve of the 19 rods examined using the REX gauge were shipped to ANL-W for nondestructive neutron radiography, then were punctured to obtain fission gases. Seventeen of the 524 rods examined for fissile content with the PIFAG were shipped to ANL-E for destructive examination for the isotopic content. Destructive examinations conducted on both the 12 rods and the 17 rods are summarized in Table 5-5 and discussed briefly below.

5.1.2.1 Fission Gas Release at End-of-Life. Twenty-nine rods were selected for fission gas (xenon and krypton) analysis, 12 were sent to ANL-W and 17 to ANL-E. Rods were chosen to represent a broad range of as-built and core operating characteristics and to cover a broad range of power density, fuel burnup, and rod neutron fluence. Operating characteristics of the 12 rods selected for analysis by ANL-W are presented in Table 5-6.

Only fission gas released from the plenum was measured at ANL-W. In contrast, ANL-E measured fission gas from the plenum as well as fission gas released during rod shearing and rod dissolution. The method for fission gas sampling of the plenum involved puncturing the rod cladding with a laser, collecting the released gases in a sample collection tube, and analyzing by mass spectrometry for xenon and krypton (Richardson et al.1987, WAPD-TM-1606, pp. 39–40). Results from the plenum tap from both sets of samples are presented in Table 5-7. Results from the plenum puncture, shearing, and dissolution samples for the 16 rods are presented in Table 5-8.

Plenum gas analyses were only obtained for 11 of the 12 sampled rods at ANL-W (the twelfth sample was lost during plenum tap) and from 16 of the 17 rods from ANL-E (one sample was contaminated with nitrogen and oxygen from the room). Results from the 11 ANL-W samples and all 17 ANL-E samples are presented in Table 5-7.[b] Core locations of the 28 rods can be determined using the cell numbers presented in Table 5-7 along with the cell maps presented in Section 3. All rods were shown to have gas release levels below the low-temperature prediction line. Because fuel rods from peak temperature and peak depletion locations were included in the samples, all fuel was considered to have operated at temperatures below 2580°F (Richardson et al. 1987, WAPD-TM-1606, pp. 49–50).

5.1.2.2 Isotopic Results. The 17 rods shipped to ANL-E were analyzed for isotopic inventory. Total uranium and uranium isotopic (U-233, U-234, U-235, U-236, U-238) analyses were performed by thermal ionization mass spectrometry. Because of the interference of Th-232, U-232 was determined by alpha spectrometry (ANL-E data reports). Fission products Cs-137, Ce-144, and Nb-95 (Zr-95 daughter) were determined by gamma spectrometry (high purity germanium detector with associated automated multi-channel analyzer/data management system) on weighed aliquots of the samples. Cs-137 and Ce-144 were determined on a sample aliquot by direct counting. Zirconium-95 was obtained after processing the sample aliquot through a cleanup procedure to reduce interferences. The losses of Zr-95 were accounted for by using before and after values of the Ce-144. Error requirements for Zr-95 measurements that were made after October 1984 were waived due to the short half-life (64.02 days).

Results from isotopic analyses were sent to Lockheed Martin Idaho Technologies Company by the former project manager (Don Graczyk, Analytical Chemistry Laboratory, Chemical Technology Division, ANL-E) of the destructive evaluation at ANL-E. These results are summarized in Table 5-9 and provided in detail in Appendix B.

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[b] According to the notes attached to the sample report for the contaminated sample (Rod "R" as referred to in Appendix B), ANL-E provided Bettis with sufficient data to calculate or compile fission data for Rod "R."

Table 5-5. Destructive examinations (Richardson et al. 1987, WAPD-TM-1606).

Test	Purpose	Number of Samples	Results	Testing Facility
Fission gas release (mass spectrometry)	Quantify fission gases, which are an indication of fuel temperatures achieved during reactor operation.	12 rods by Argonne National Laboratory-West (ANL-W) 17 rods by Argonne National Laboratory-East (ANL-E)	Estimated operating temperature of all the fuel was less than 2580°F (Richardson et al. 1987, WAPD-TM-1606, p. 49–50). Fission gas in the gap (plenum) comprises less than 1% of total fission gases measured from the rods (ANL-E data).	ANL-W ANL-E
Metallographic examination	Size and spatial distribution of pores, cracks, grain size, internal and external corrosion, fuel and cladding mechanical and chemical interaction, hydriding, hydrogen in cladding.	12 rods (or pellets from the rods) selected by Bettis	Low burnup thoria pellets were intact. Binary pellets often cracked but freestanding within the cladding. Fine porosity. No evidence of fuel bonding to zircaloy cladding in seed, but some in blanket region rods. No massive hydriding. (Richardson et al. 1987, WAPD-TM-1606, pp.50–123)	ANL-E
Cladding behavior	Detect cladding inadequacies.	Cladding of 12 rods checked	No through-cladding defects detected (Richardson et al. 1987, WAPD-TM-1606, p. 80)	Expended Core Facility (ECF)
Cladding oxide	Identify thickness of oxide layer on the cladding	12	Thickness of the oxide ranged from .05 to 1.95 mils (Table 10 of Richardson et al. 1987, WAPD-TM-1606)	ECF
Hydrogen analysis of the cladding	Assess hydriding of the cladding	12	Hydride size and distribution varied by rod type. Total H content: Seed: 50 to 100 ppm Blanket: 25 to 100 ppm Reflector: 25 to 50 ppm (Richardson et al. 1987, WAPD-TM-1606, pp. 87–88)	ECF

Table 5-5. (continued).

Test	Purpose	Number of Samples	Results	Testing Facility
Fuel depletion (fissions per cc of fuel). Isotopic dilution mass spec of HNO3-HF dissolved samples for total Th and U, isotopic U, and La-139 and Nd-148. La-139 and Nd-148 were burnup monitors (Richardson et al. 1987, WAPD-TM-1606, p. 124). Gamma spec for Cs-137 and Ce-144	Compare destructive examination to calculated burnup and qualify the calculational model (Richardson et al. 1987, WAPD-TM-1606, p. 44).	2 of the 12 destructive examination rods were analyzed for fuel burnup (from a seed and standard blanket). For each rod, one sample pellet was taken from top thoria region and second sample from adjacent top binary pellet.	Measured depletion and burnup values were consistently lower (about 10% or less) than calculated values for both rods (Richardson et al. 1987, WAPD-TM-1606 Table 15). Calculated values based on a 3.5-in. rod segment vs. measured values based on pellet analysis.	ANL-E
Iodine and cesium analysis of fuel and cladding	Iodine and cesium are possibly corrosive agents causing stress corrosion cracking. Tests to determine the fraction of these nuclides that migrate to the gap region and into the cladding.	2 sample locations per 2 seed rods 2 sample locations in 2 standard blanket rods	Minute quantities of I-129 in rod or pellet. Iodine confirmed to be in fuel, none in cladding. Cesium primarily dissolved in the fuel and small quantities in cladding (Richardson et al. 1987, WAPD-TM-1606, Tables 16 and 17).	ANL-E
Tensile testing of cladding	Assess strength of cladding after service.	At 77°F: 2 seed 1 standard blanket 1 reflector At 500°F: 2 seed 1 reflector	Mechanical properties of Light Water Breeder Reactor fuel adequate throughout core life (Richardson et al. 1987, WAPD-TM-1606 Table18 and Figure 71)	ANL-E

Table 5-6. Operating characteristics of the 12 Light Water Breeder Reactor destructive examination fuel rods at end-of-life (Richardson et al. 1987, WAPD-TM-1606, Table 6).

Module Type	Rod S/N	Peak Power (Kw/ft)	Peak Depletion (10^{20} f/cc)	Peak Burnup MWD/MTM*	Peak Fast Fluence (>1 Mev) (10^{20} n/cm^2)
Seed I-1	0400736	6.7	9.52	44,500	85.0
Seed I-1	0606773	4.4	8.81	41,200	96.5
Seed I-1	0205071	5.5	11.43	53,400	75.5
Seed I-1	0507672	4.2	10.12	47,300	87.9
Blanket I-3	1606710	8.7	5.07	22,300	73.0
Blanket I-3	1105717	8.6	5.18	22,800	71.4
Blanket I-3	1504272	7.4	4.37	19,200	64.2
Blanket II-2	1208823	6.9	4.25	18,700	55.4
Blanket II-2	2610746	8.7	5.70	25,200	57.7
Blanket II-2	2514164	8.3	5.05	22,300	38.6
Blanket II-2	2607600	8.4	5.53	24,400	58.6
Reflector IV-3	3102657	3.4	0.96	4,100	25.9

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* MWD/MTM = Megawatt days per metric ton of metal (uranium plus thorium)

Table 5-7. Light Water Breeder Reactor fuel rod fission gas release at end-of-life (Richardson et al. 1987, WAPD-TM-1606, Table 7).

				Fission Gas			
Rod S/N	Cell	Module	Rod-average Depletion (10^{20} f/cc)	Generated in Fuel* (mol)	Measured in Plenum Tap (10^{-5} mol)	Recovered Fraction**	Released (%)***
0606773	6B4	SI-1	5.4	0.02683	1.22	0.803	0.06
0507672	5L31	SI-1	6.4	0.03198	2.51	0.725	0.11
0504042	5L29	SI-1	6.0	0.03007	2.37	0.734	0.11
0507057	5C10	SI-1	5.1	0.02575	1.30	0.744	0.07
0400736	4M33	SI-1	5.3	0.02631	1.51	0.912	0.06
0401744	4M49	SI-1	4.8	0.02398	3.76	0.849	0.18
0307602	3N63	SI-1	4.2	0.02120	1.36	0.767	0.08
0205071	2Q41	SI-1	4.5	0.02266	1.02	0.782	0.06
0201562	2P39	SI-1	3.8	0.01890	1.06	0.816	0.07
1606710	16E57	BI-3	2.9	0.05723	3.10	0.662	0.08
1605519	16E56	BI-3	2.9	0.05693	2.76	0.659	0.07
1504272	15F11	BI-3	2.5	0.04831	1.90	0.726	0.05
1400544	14C3	BI-3	1.9	0.03791	1.77	0.959	0.05
1302864	13D24	BI-3	2.4	0.04582	1.49	0.675	0.05
1200830	12A49	BI-3	2.1	0.04051	1.37	0.695	0.05
1208823	12A12	BII-2	1.8	0.03436	0.89	0.788	0.03
1105717	11A46	BI-3	2.2	0.04304	2.27	0.722	0.07
2610746	26E68	BII-2	3.3	0.05531	3.22	0.646	0.09
2606481	26E31	BIII-6	3.1	0.05424	3.43	0.743	0.09
2514164	25K13	BII-2	2.9	0.04741	1.63	0.629	0.06
2513854	25F73	BIII-6	2.6	0.04345	1.46	0.655	0.05
2502102	25H1	BIII-6	1.3	0.02209	0.22	0.770	0.01
2400408	24C13	BIII-6	1.4	0.02319	0.38	0.725	0.02
2300711	23D29	BIII-6	2.8	0.04622	2.54	0.633	0.09
2102187	21B62	BIII-6	1.5	0.02380	0.44	0.729	0.03
3102657	1A1	RIV-3	0.5	0.01856	0.17	0.983	0.01
3211456	2B1	RIV-3	0.4	0.01659	0.12	0.788	0.01
3110505	1E3	RIV-3	0.2	0.00687	0.04	0.999	0.01

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* Calculated from rod-average depletion

** Ratio of helium recovered to calculated amount present from initial fill and {n,γ} reaction

*** Gas release = (Amount measured in plenum tap)/(Amount generated)/(Recovered fraction)

Table 5-8. Fission gases (Kr + Xe) released during processing of Light Water Breeder Reactor rods. (Source: Data packages from ANL-E).

Rod ID	Gas released in Plenum Puncture (g)	Gas Released in Shearing (g)	Gas Released in Dissolution (g)	Total Gas Released (g)	Percent Plenum Gas in Total
2606481	0.0037	0.0140	5.3379	5.3556	0.0691
2513854	0.0017	0.0138	4.9268	4.9423	0.0344
2502102	0.0003	0.0065	2.3256	2.3324	0.0129
2102187	0.0005	0.0065	2.8505	2.8575	0.0175
2400408	0.0005	0.0044	2.5041	2.5091	0.0199
2300711	0.0030	0.0192	4.9428	4.9650	0.0604
3211456	0.0001	0.0032	1.8676	1.8709	0.0053
1605519	0.0033	0.0151	6.6098	6.6283	0.0498
1200830	0.0016	0.0158	5.0025	5.0198	0.0319
1302864	0.0018	0.0091	5.3405	5.3514	0.0336
1400544	0.0022	0.0078	4.2974	4.3074	0.0511
0504042	0.0029	0.0183	3.6756	3.6968	0.0784
0507057	0.0016	0.0131	3.0711	3.0859	0.0518
0201562	0.0013	0.0161	2.4877	2.5051	0.0519
0307602	0.0012	0.0134	2.7539	2.7685	0.0433
0401744	0.0046	0.0181	3.0852	3.1079	0.1480

Table 5-9. Isotopic results from Argonne National Laboratory-East destructive examination of 17 Light Water Breeder Reactor rods.

Module and Cell Location	Length (in.)	U-232 (g)	U-233 (g)	U-234 (g)	U-235 (g)	U-236 (g)	U-238 (g)	Cs-137 (g)	Ce-144 (g)	Zr-95 (g)
PFB III-6 E31	118.19	0.048833	50.697	4.9377	0.77915	0.086475	0.15378	1.3314	0.068311	0.00029782
PFB III-6 F73	118.17	0.038269	53.065	4.2727	0.61827	0.069008	0.15432	1.0884	0.05748	0.00025527
PFB III-6 H1	118.07	0.011363	57.097	2.5111	0.22817	0.014398	0.45712	0.55456	0.030255	0.00014121
PFB III-6 B62	118.1	0.035986	28.912	2.2675	0.31601	0.025272	0.047159	0.62564	0.039853	0.00019086
PFB III-6 C13	118.14	0.02448	33.612	2.2119	0.28089	0.022936	0.077994	0.56341	0.033364	0.0001649
PFB III-6 D29	118.16	0.047229	44.4489	4.4039	0.71007	0.075831	0.12314	1.2045	0.062935	0.00029186
R IV-3 B1	111.17	0.03567	34.63	1.4876	0.1396	0.00497	0.002403	0.40327	0.031655	0.00016271
SB I-3 E56	118.17	0.072399	51.405	5.2338	0.88411	0.075202	0.11883	1.444	0.074399	0.00033378
SB I-3 A49	118.21	0.075275	35.902	3.8718	0.69573	0.065544	0.036364	1.124	0.070642	0.00034347
SB I-3 D24	118.16	0.060678	46.432	4.3487	0.73112	0.069634	0.09946	1.169	0.06352	0.0002886
SB I-3 C3	118.15	0.061431	40.025	3.5948	0.5826	0.044207	0.072962	0.98522	0.057713	0.00028351
S I-1 5L29	116.98	0.023971	22.331	2.7358	0.46199	0.040206	0.082102	0.78023	0.037911	0.00017893
S I-1 5C10	116.97	0.022944	25.151	2.5057	0.40467	0.030226	0.082867	0.66492	0.034177	0.00016321
S I-1 2P39	116.86	0.022106	13.568	1.689	0.29413	0.027545	0.044155	0.49799	0.031122	0.00017505
S I-1 3N63	117	0.021506	15.303	1.881	0.33739	0.035724	0.050802	0.54545	0.031287	0.00015271
S I-1 4M49	116.94	0.023016	17.058	2.124	0.37119	0.032009	0.072576	0.61732	0.032358	0.00016065
RIV-3 E3	111.21	0.014029	23.68	0.6758	0.044932	0.001001	0.001645	0.17928	0.014956	0.000087136

Data from the nondestructive (PIFAG) and destructive (ANL-E dissolution) examinations for fuel loading were compared to assess the accuracy of the PIFAG and to demonstrate breeding; results showed the Fissile Inventory Ratio (ratio of the fissile inventory at EOL versus beginning-of-life) was 1.01, which included fissile inventory gains in the reflector rods.

5.1.2.3 Isotopic and Heat Rate Validation Studies. Recent validation work has been performed in support of radionuclide inventory and heat rate predictions for the LWBR modules. One study (Sterbentz 1999) focused on the prediction of uranium, fission product, krypton, and xenon isotopic masses in a seed, a blanket and a reflector rod. A comparison of the results showed less than a 5% difference between the calculated and measured mass concentrations in the three rods for the two major uranium isotopes (U-233, U-234). Further discussion on the comparisons for the other isotopes is given in the reference.

Heat rate predictions (Sterbentz and Wahnschaffe 2001) were calculated for a single seed (Type I), standard blanket (Type I), standard/power-flattening blanket (Type II), standard/power-flattening blanket (Type III), Reflector IV, and Reflector V module. Module heat rates are given as a function of decay date (2000-2030). These calculated module heat rates were also compared to heat rates reported in WAPD-NRF(L)C-104, which were calculated values verified against actual LWBR module decay heat measurements. The Sterbentz and Wahnschaffe (2001) calculated values were 33% and 29% higher than the WAPD-NRF(L)C-104 values for a single seed module and a single standard blanket/power-flattening blanket module, respectively. The Sterbentz and Wahnschaffe (2001) Reflector IV decay heat value was about 29% lower than the WAPD value.

5.2 Fuel Burnup

Fuel burnup is defined in terms of fissions per cubic centimeter of fuel, or more often, given in terms of megawatt days per metric ton of initial heavy metal (Richardson et al. 1987, WAPD-TM-1606, p. 44). In the case of LWBR, the initial heavy metal includes both uranium and thorium. Calculated burnup data are provided in several places in Richardson 1987 (WAPD-TM-1606, p. 37) for the 12 rod samples that were destructively examined at ECF.

Only 2 of the 12 rods destructively evaluated by ANL-W were selected for burnup evaluation and model verification; those two rods were seed rod 0205071 and standard blanket rod 1606710 (Richardson et al. 1987, WAPD-TM-1606, p. 44). Two fuel pellets from each of the two rods were analyzed and compared with calculated burnup values to qualify the calculational model. For each of the two fuel rods examined for burnup, one of the pellets was taken from the top thoria region, and the second pellet was taken from the adjacent top binary pellet.

Pellets were removed from the cladding and dissolved in acid solution (HNO_3-HF) without comminution (pulverization). After decontamination of the analytes from interferences and radioactive fission products, total thorium and uranium, isotopic uranium, and stable fission products La-139 and Nd-148 were measured by isotopic dilution mass spectroscopy. (Note from Richardson et al. 1987, WAPD-TM-1606, p. 124: La-139 and Nd-148 were burnup monitors.) The mass spectrometer was calibrated with istopically pure ThO_2 and a National Institute of Standards and Technology uranium standard.

Calculated and measured burnup data for the two seed pellets (Rod No. 0205071 from location Q41) and the two blanket pellets (Rod No. 1606710 from location E57) are presented in Table 5-10. Calculated burnups for a larger variety of rods are presented in Table 5-6.

Table 5-10. Comparison of measured and calculated fuel depletion and burnup (Richardson et al. 1987, WAPD-TM-1606, Table 15).

		Measured at End of Life		Calculated	
Rod S/N	Type Fuel	Depletion (10^{20} f/cc)	Burnup (MWD/MT)	Depletion (10^{20} f/cc)	Burnup (MWD/MT)
Based on ^{139}La					
0205071	Thoria	3.85	17,720	4.27	19,670
	Binary	10.39	48,630	11.56	54,090
1606710	Thoria	0.13	560	0.14	630
	Binary	0.83	3,670	0.86	3,780
Based on ^{148}Nd					
0205071	Thoria	4.04	18,610	4.27	19,670
	Binary	10.55	49,390	11.56	54,090
1606710	Thoria	0.13	580	0.14	630
	Binary	0.86	3,640	0.86	3,780

5.3 Iodine and Cesium Analysis of the Fuel Cladding

Stress corrosion cracking of metallic components, such as the Zircaloy-4 cladding, has historically been a problem concerning reactor safety and fuel performance. Iodine and cesium have been identified as possible corrosive agents causing stress corrosion cracking. Under reactor conditions, fission product iodine can react with zircaloy. Measurement of fission product iodine and cesium inventories in the fuel rod samples was performed to determine the fraction of these nuclides that migrate to the gap region and into the cladding. (The gap region was defined as the fuel-cladding gap, fuel cracks, and the interconnected, open porosity in the fuel.) The quantity of fission products I-129 and Cs-137 in the fuel-cladding gap and, separately, dissolved in the fuel and cladding, were determined for two seed fuel rods and two standard blanket fuel rods (Richardson et al. 1987, WAPD-TM-1606).

Fission products I-129 and Cs-137 deposited in the gap were determined by immersing the fuel and cladding separately in 2N HCl for 30 minutes. Ultrasonic vibration was applied to aid in dissolving any iodine and cesium deposits from the cladding surface only. Fuel particles remaining in the cladding and fuel wash solution were analyzed for Cs-137 by gamma-ray spectroscopy. The I-129 was precipitated, and the precipitate was counted for I-129 with a calibrated lithium-drifted germanium detector (Richardson et al. 1987, WAPD-TM-1606, pp. 44–45).

The I-129 and Cs-137 inventory in fuel and cladding were determined using similar techniques described above. Results for the analyses are presented in Tables 5-11 and 5-12. All analyses demonstrate that almost all the I-129 and Cs-137 stayed in the fuel rather than migrating to the gap where they could have induced accelerated corrosion and cracking. These results agree with the nondestructive examination findings with the REX that no gross cladding defects resulted from reactor operations (see Table 5-2).

Table 5-11. Concentration of I-129 in Light Water Breeder Reactor fuel rod cladding and fuel pellets (μg/g) (Richardson et al. 1987, WAPD-TM-1606, Table 16).

Rod S/N	Type Fuel	Sample No.*	Cladding Wash	Fuel Wash	In Cladding	In Fuel
Seed Region Fuel						
0205071	Thoria	1A	N.D.	N.D.	N.D.	123.2
		1B	N.D.	N.D.	N.D.	135.7
	Binary	2A	N.D.	0.1	N.D.	309.3
		2B	N.D.	0.2	N.D.	317.9
0507672	Binary	1	N.D.	N.D.	N.D.	261.9
	Binary	2	N.D.	N.D.	N.D.	335.4
Blanket Region Fuel						
1606710	Binary	1A	0.4	0.2	N.D.	130.4
		1B	N.D.	N.D.	N.D.	153.3
	Binary	2	N.D.	N.D.	N.D.	136.0
1105717	Thoria	1	N.D.	N.D.	N.D.	112.8
	Binary	2	N.D.	N.D.	N.D.	149.3

* A and B samples were obtained from adjacent fuel rod sections.
N.D. = Not Detected

Table 5-12. Concentration of Cs-137 in Light Water Breeder Reactor fuel rod cladding and fuel pellets (μg/g) (Richardson et al. 1987, WAPD-TM-1606, Table 17).

Rod S/N	Type Fuel	Sample No.*	Cladding Wash	Fuel Wash	In Cladding	In Fuel
Seed Region Fuel						
0205071	Thoria	1A	0.1	1.8	2.8	1609.8
		1B	0.1	3.0	3.1	527.8
	Binary	2A	0.2	4.3	5.9	1261.5
		2B	0.2	4.4	6.5	294.0
0507672	Binary	1	0.2	2.4	5.8	1355.2
	Binary	2	**	**	6.2	1317.0
Blanket Region Fuel						
1606710	Binary	1A	0.6	0.4	2.8	622.1
		1B	0.1	0.6	N.M.	812.7
	Binary	2	0.1	0.4	2.9	571.6
1105717	Thoria	1	1.9	0.4	1.5	234.5
	Binary	2	0.1	0.7	1.8	622.0

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* A and B samples were obtained from adjacent fuel rod sections.
** 0.2 μg/g was recorded for a combined cladding and fuel wash solution.
N.M. = Not Measured

6. SHIPPING AND STORAGE

6.1 Shipment from Shippingport to Expended Core Facility

After the reactor was shut down, the reactor was defueled, and the fuel modules were partially disassembled then loaded into modified M-130 casks and shipped to ECF in 10 shipments (4 shipments of blanket modules, 2 of seed modules, and 4 of reflector modules) (Selsley 1987b, WAPD-TM-1553, p. 7). To ensure criticality control during defueling, potassium tetraborate was added to the reactor vessel and canal water to about 4,200 parts per million (ppm) by weight of natural boron (Selsley 1987a, WAPD-TM-1551, p. 111).

Disassembly of the modules at Shippingport APS was required to permit them to fit inside the M-130 shipping containers. The seed assemblies were modified by removing the support shaft, balance piston, and buffer cylinder. Lifting studs were installed, and a shipping plate was attached to them. The shipping plate was designed to accommodate a lift adapter used at ECF. The modified seed module received at ECF is shown in Figure 6-1 (Hodges 1987, WAPD-TM-1601).

To reduce the size of each blanket module, the support tube and seal block assembly at the top of the module and the guide tube extension and stub tube assembly at the bottom of the module were removed. For top end disassembly, the instrumentation tubes were cut, and the blanket support tube was unbolted. At the bottom end, the six guide tube extension bolts were severed, and the stub tube and guide tube extension were removed. A shipping plate was installed at the top of the module to provide structural support and to accommodate the lift adapter. The modified blanket module received at ECF is shown in Figure 6-2 (Hodges 1987, WAPD-TM-1601).

Reflector modules were modified by removing the top seal block assembly. As with the seed and blanket assemblies, a shipping plate was attached to the top of the reflector module to provide structural support and accommodate the lift adapter. The modified reflector module received at ECF is shown in Figure 6-3 (Hodges 1987, WAPD-TM-1601). Module holders for seed, blanket, and reflector modules are shown in Figures 6-4 through 6-6.

The modified M-130 container used to ship the assemblies is shown in Figure 6-7 (Williams 1987, WAPD-TM-1611). The M-130 is an upright, right circular cylinder, with outside dimensions of 84 in. in diameter by 158 in. high. Inside dimensions are 55 in. in diameter by 132 in. high (Selsley 1987b, WAPD-TM-1553, Appendix A). Each of the M-130 containers was fitted with module holders, which were designed to accommodate the largest of each module type within the respective containers. The M-130s modified for blankets used special inserts for the Type I and Type II blanket modules; the M-130s modified for reflectors used special inserts for the Type V reflectors (Selsley 1987b, WAPD-TM-1553, p. A1-4). A recessed head was used for LWBR shipping because of module length and the need for specified holddown devices required in the event of a container accident. M-130 container modifications were reviewed by the Nuclear Regulatory Commission, and a certificate of compliance was issued (Selsley 1987b, WAPD-TM-1553, p. 7).

An A-frame on the railcar served to suspend the M-130 slightly from the deck of the railcar and functioned as a shock absorber (Figure 6-8). Energy absorbers were also fastened to the top of each M-130 container (Selsley 1987b, WAPD-TM-1553).

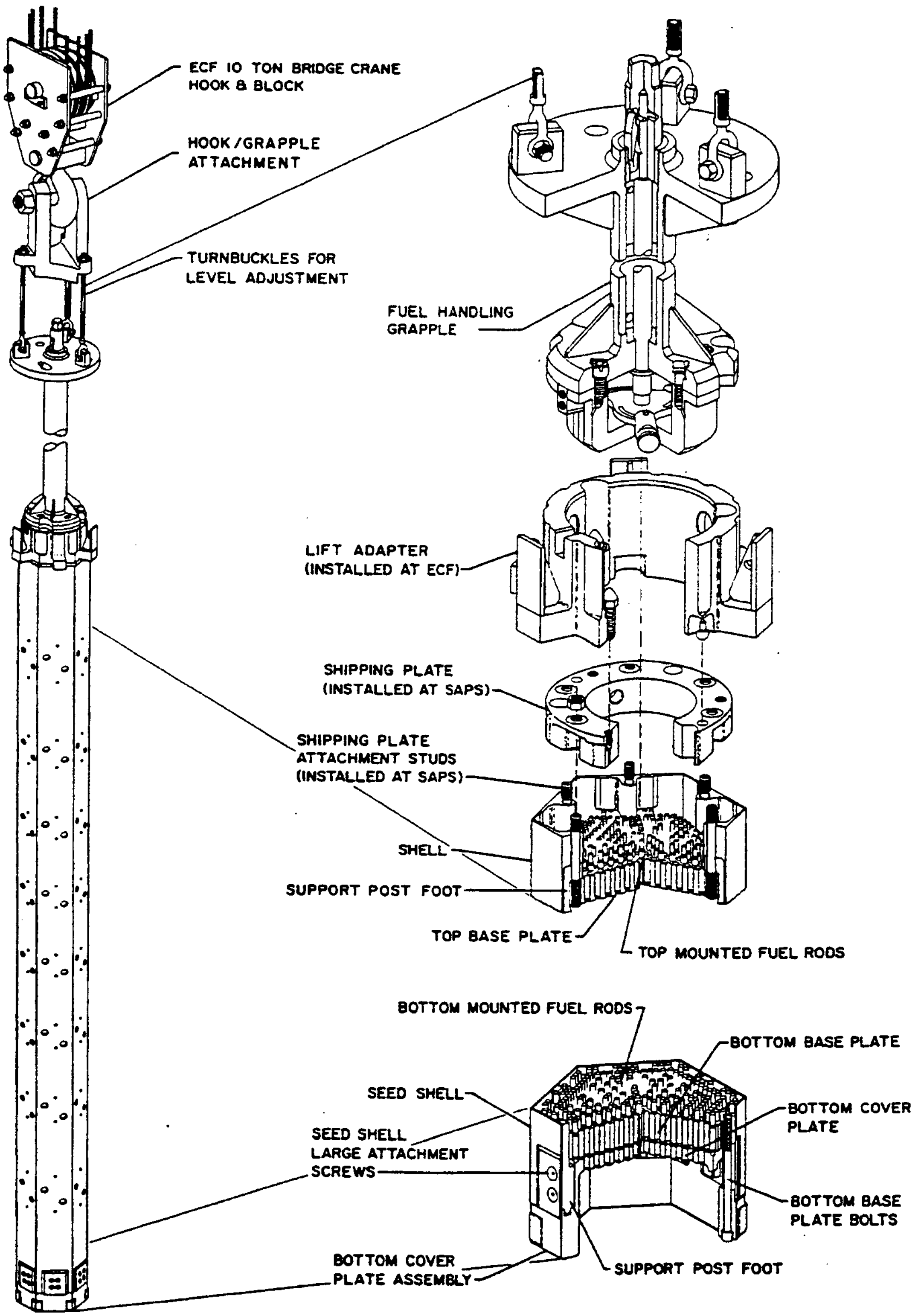

Figure 6-1. Light Water Breeder Reactor seed module as received at the Expended Core Facility (Hodges 1987, WAPD-TM-1601, Figure 1-1).

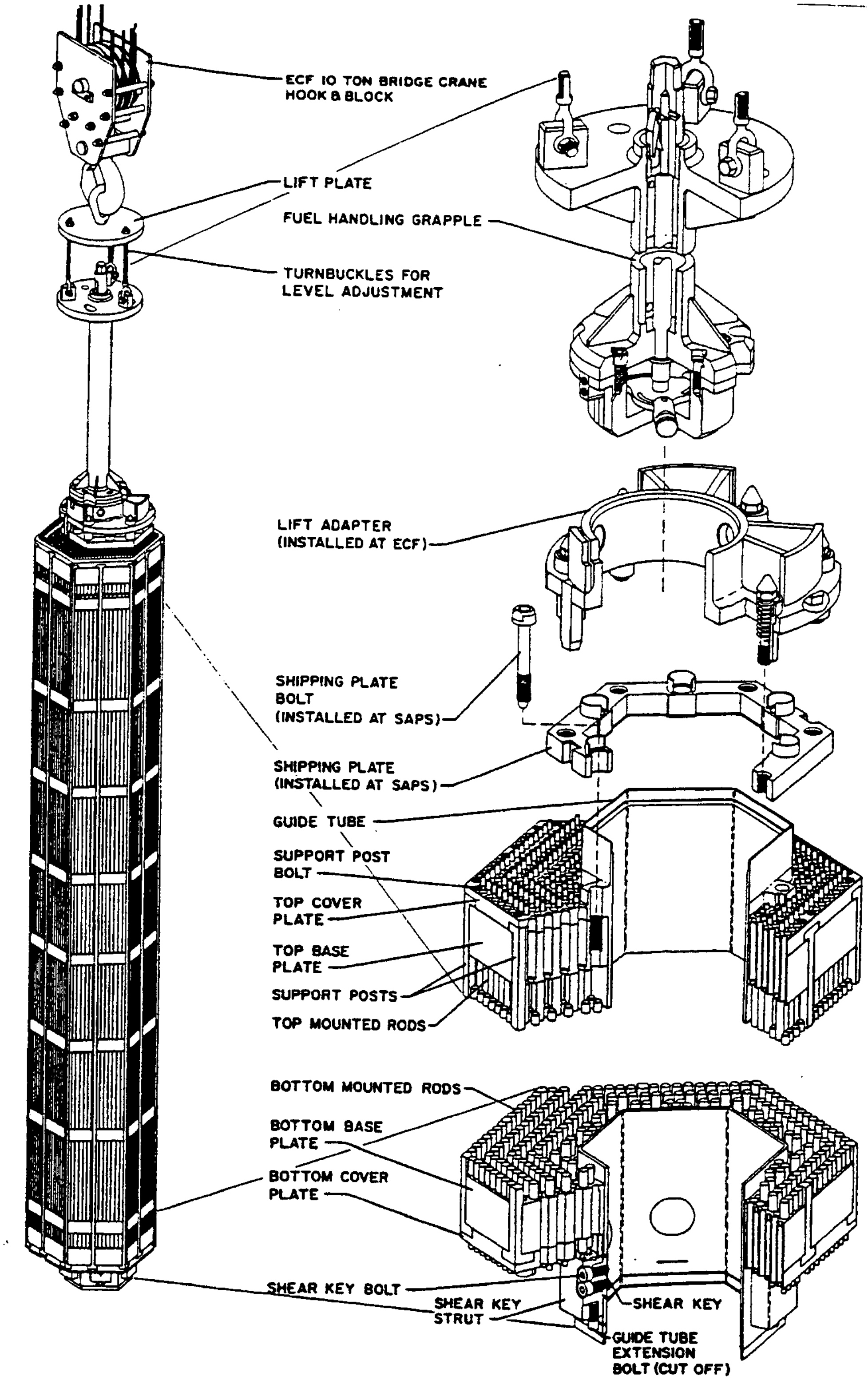

Figure 6-2. Light Water Breeder Reactor blanket module as received at Expended Core Facility (Hodges 1987, WAPD-TM-1601, Figure 1-2).

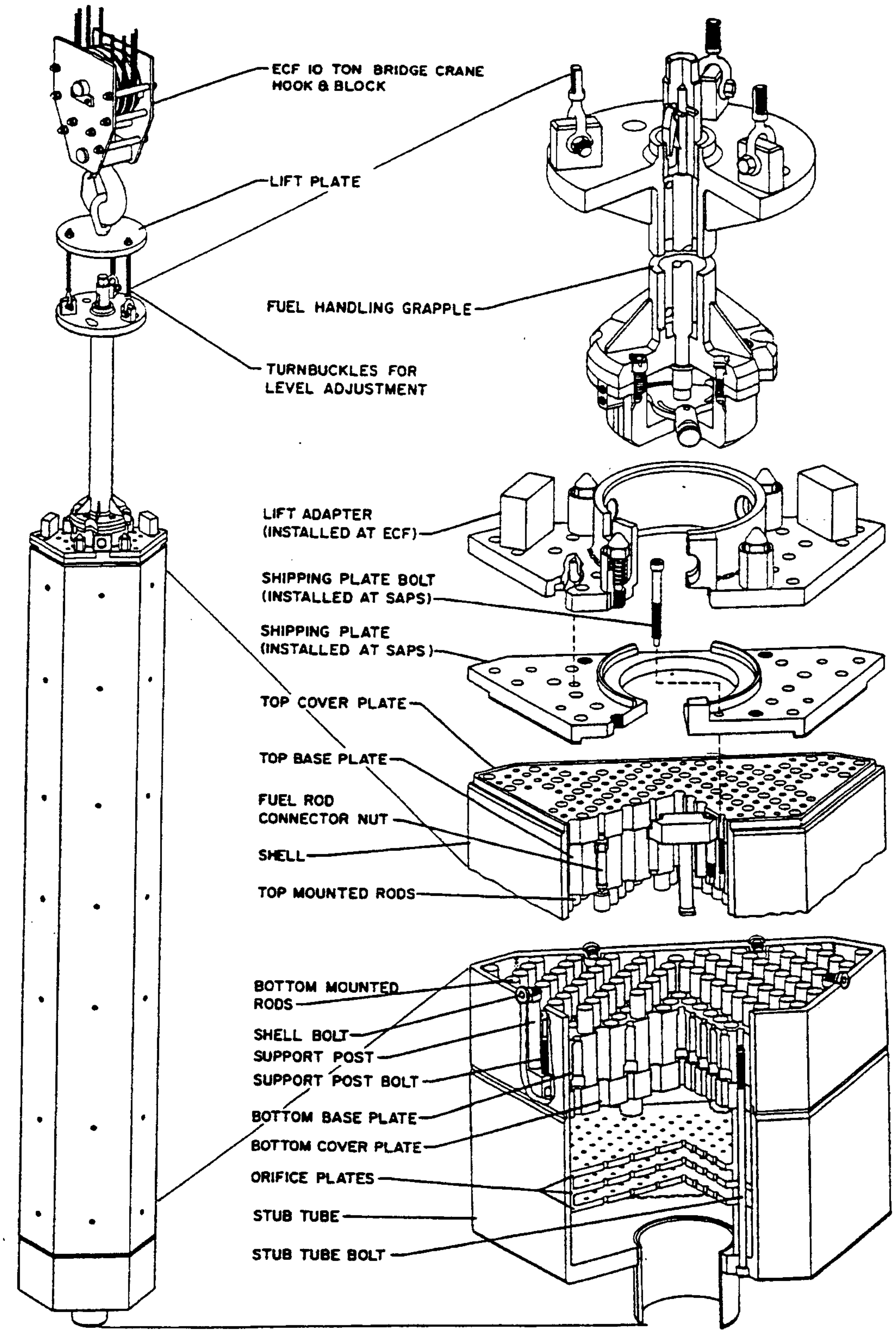

Figure 6-3. Light Water Breeder Reactor reflector module as received at Expended Core Facility (Hodges 1987, WAPD-TM-1601, Figure 1-3).

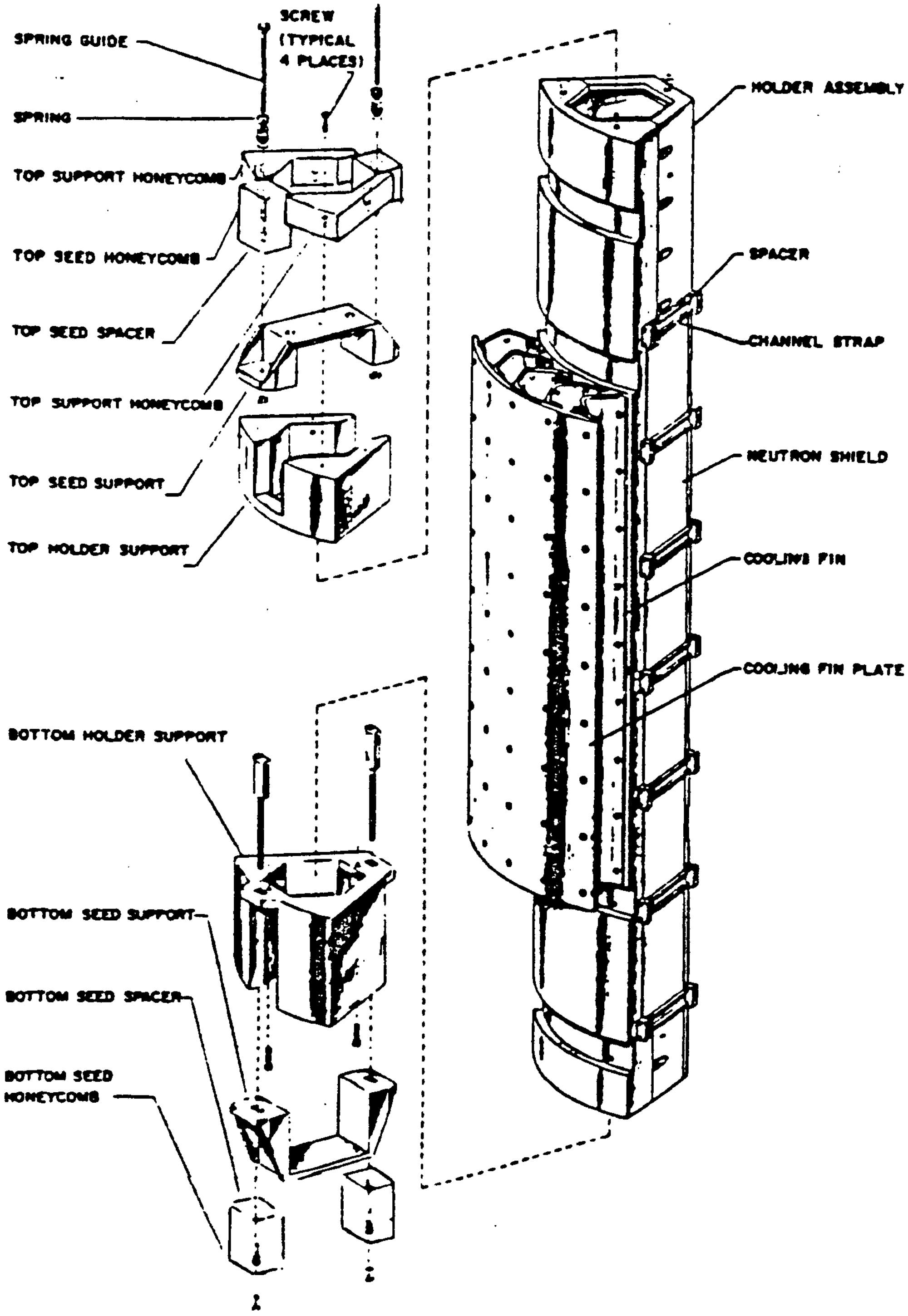

Figure 6-4. Module holder for seed modules (Selsley 1987b, WAPD-TM-1553, Figure A1-3).

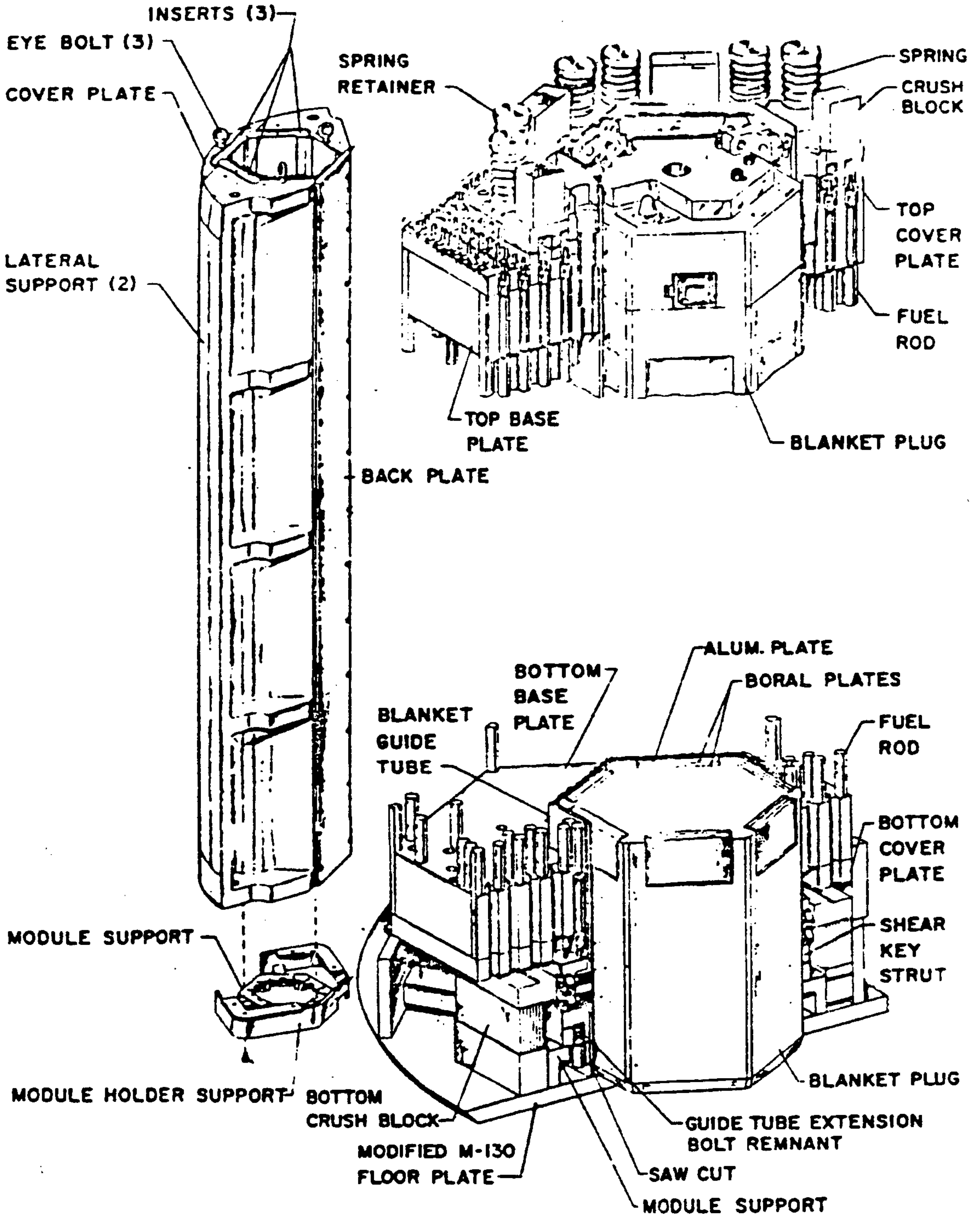

Figure 6-5. Module holder for blanket modules (Selsley 1987b, WAPD-TM-1553, Figure A1-4).

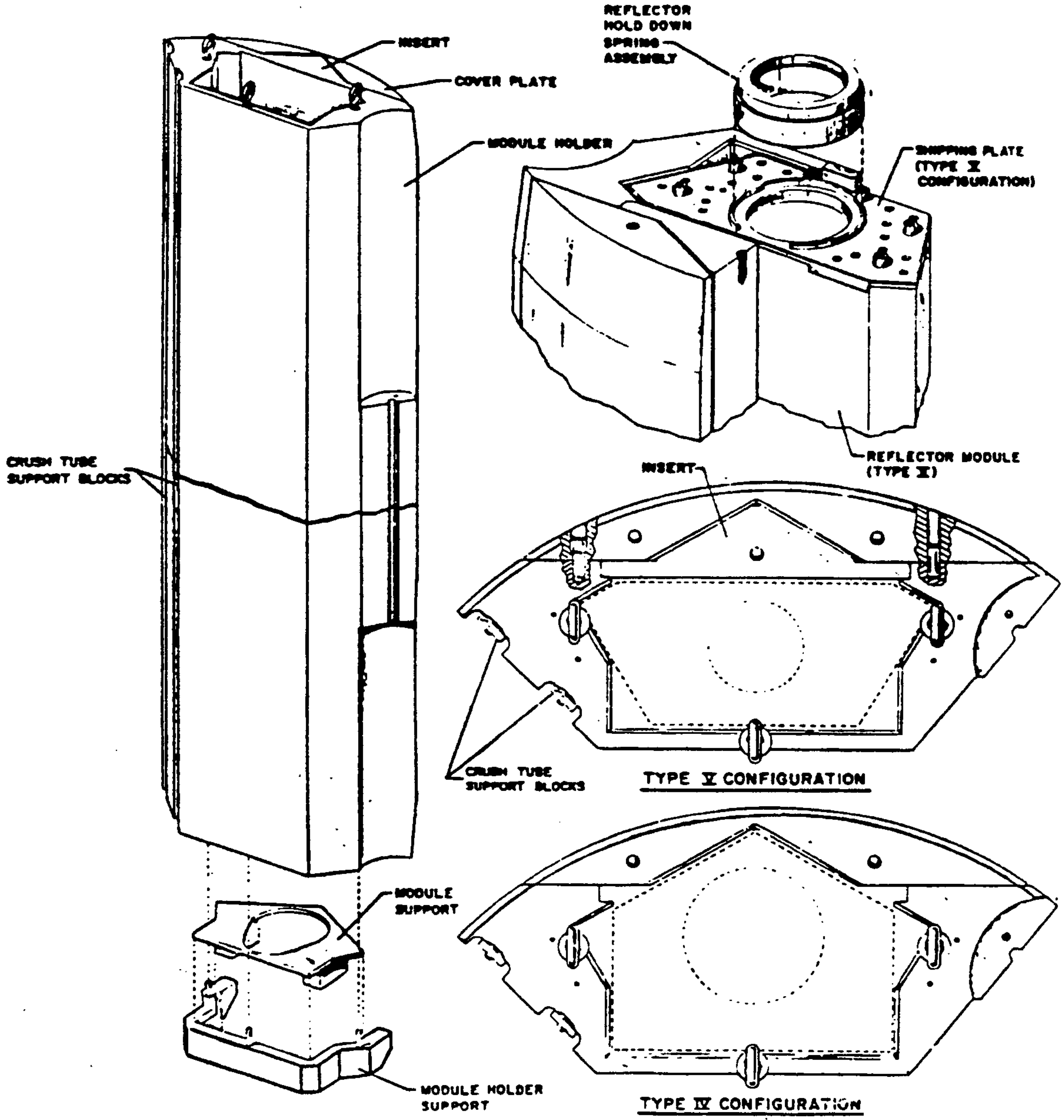

Figure 6-6. Module holder for reflector modules (Selsley 1987b, WAPD-TM-1553, Figure A1-5).

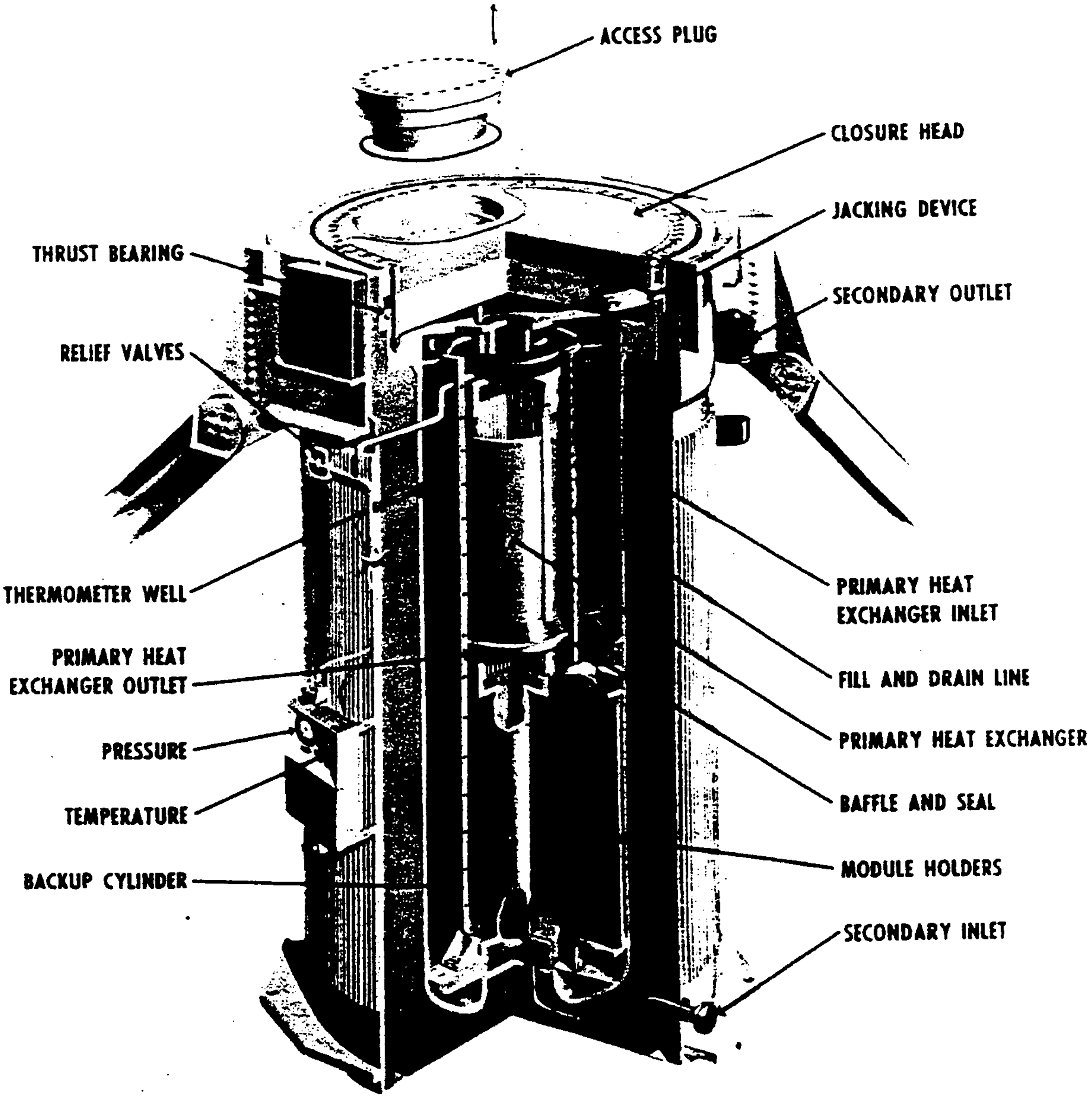

Figure 6-7. M-130 shipping container as modified for Light Water Breeder Reactor fuel shipments (Williams 1987, WAPD-TM-1611, Figure 8).

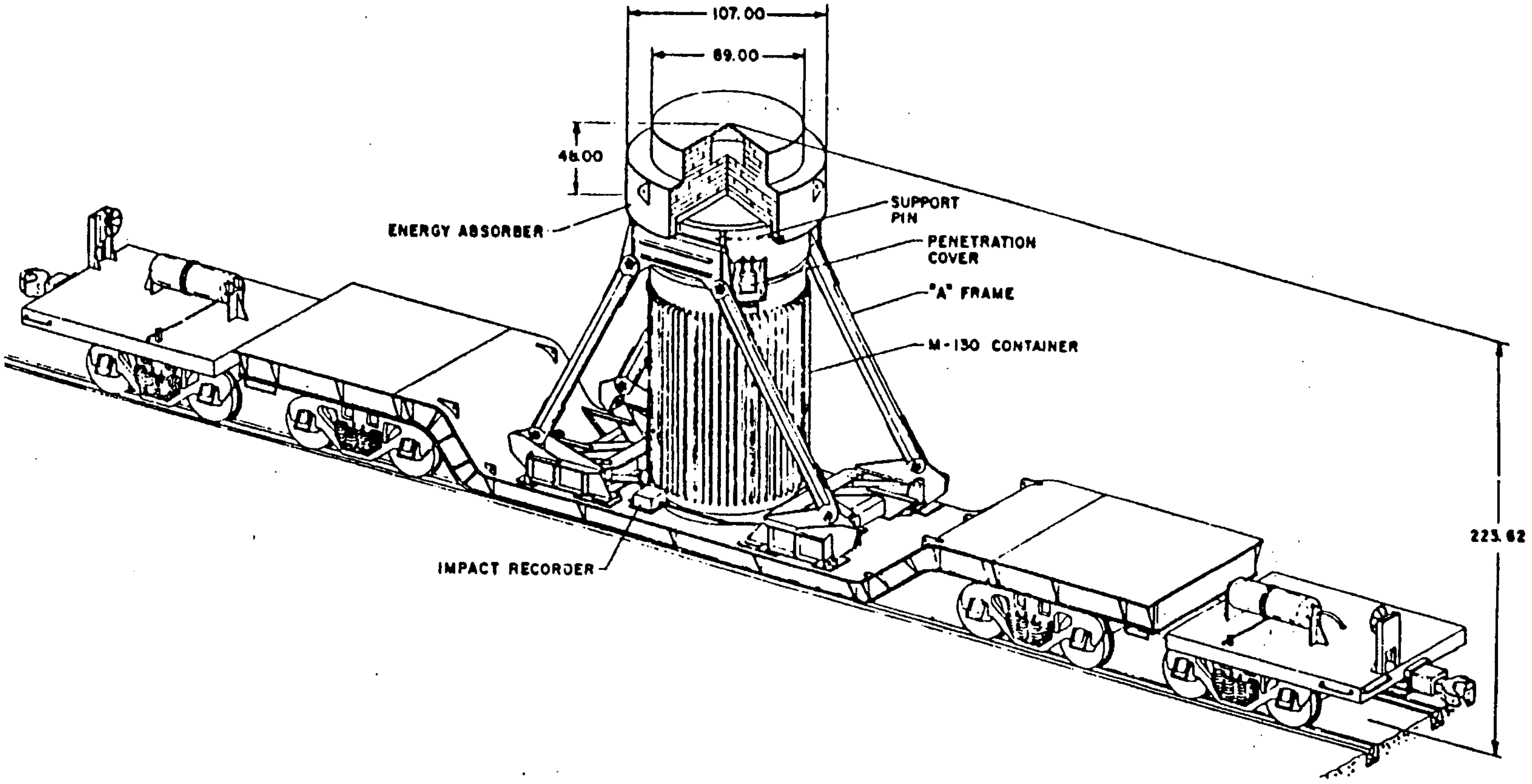

Figure 6-8. M-130 irradiated fuel shipping system (Selsley 1987b, WAPD-TM-1553, Figure A1-1).

M-130 preparations for shipment were as follows:

1. Loaded containers were flushed with nonborated water to reduce boron residue. Surfactant was added to the water used to flush the seed module container to enhance drainage from horizontal surfaces that were not present in other containers.
2. Containers were filled with neon gas.
3. Decay heat generation values for the seed shipments and for the first blanket shipment were obtained by performing a calorimetric test (Selsley 1987b, WAPD-TM-1553).

All shipments were completed successfully with no damage to fuel modules. Details for the shipping operations from Shippingport to ECF are provided in Selsley 1987b (WAPD-TM-1553).

6.2 Handling, Disassembly of Selected Modules, and Storage at Expended Core Facility

The modules were sent to ECF (with shipping plates attached) in 10 shipments. Upon receipt, the internal atmosphere of each M-130 shipping cask was sampled for fission gases to determine the integrity of the fuel rod cladding, and the modules were placed in individual storage liners. The tests indicated that all shipments were completed without damage to the fuel cladding in any of the fuel modules (Hodges 1987, WAPD-TM-1601, p. 2-1).

The shipping container was transferred from the railcar to the water pit at ECF, and the fuel modules were transferred individually to one of two water pits for storage in the module storage racks. The fuel was stored in the ECF water pits for 3 to 5 years (depending on the liner). The fuel module grapple used to lift the modules is shown in Figure 6-9. The ECF water pits are shown in Figure 6-10. All LWBR modules were individually installed into a liner for storage purposes at ECF. Liners were constructed of stainless steel and were 25.50 in. in diameter and had a length, with the closure head installed, of 157.80 in. (Hodges 1987, WAPD-TM-1601, p. 3-1).

Twelve modules (four seed, four reflectors, and four blankets) were remotely disassembled underwater to free the core components and fuel rods (Greenberger and Miller 1987, WAPD-TM-1608, p. 15). Ten of the modules had their baseplates cut off, and two of the modules (a reflector IV-4 and a seed II-3) were deshelled, then had their baseplates cut off. The two modules were deshelled so that the exposed fuel rods could be visually examined and could free the module structural components for examination (including shells, grid sections, and grid fasteners). Deshelling took place in the module disassembly apparatus. Baseplate cutoff for all 12 modules was performed with the cutoff system, which cut off both ends of the module and severed the structural components to free all fuel rods (Greenberger and Miller 1987, WAPD-TM-1608). About 1000 rods were then removed from the 12 modules using the rod removal system and were later examined for EOL properties as described in Section 5.

Before cutting the 12 modules designated for EOL rod examination, remnant clamps were installed and the bandsaw was aligned for cutting at the top and bottom module baseplates. The cut location was approximately in the center of each baseplate, and the resulting module lengths after cutting ranged from about 116 to 124 inches (Greenberger and Miller 1987, WAPD-TM-1608, p. 51). Fuel assemblies excluded from the EOL program were transported from ECF to INTEC while examinations of the selected LWBR fuel assemblies were in progress (Hodges 1987, WAPD-TM-1601, p. 1-2).

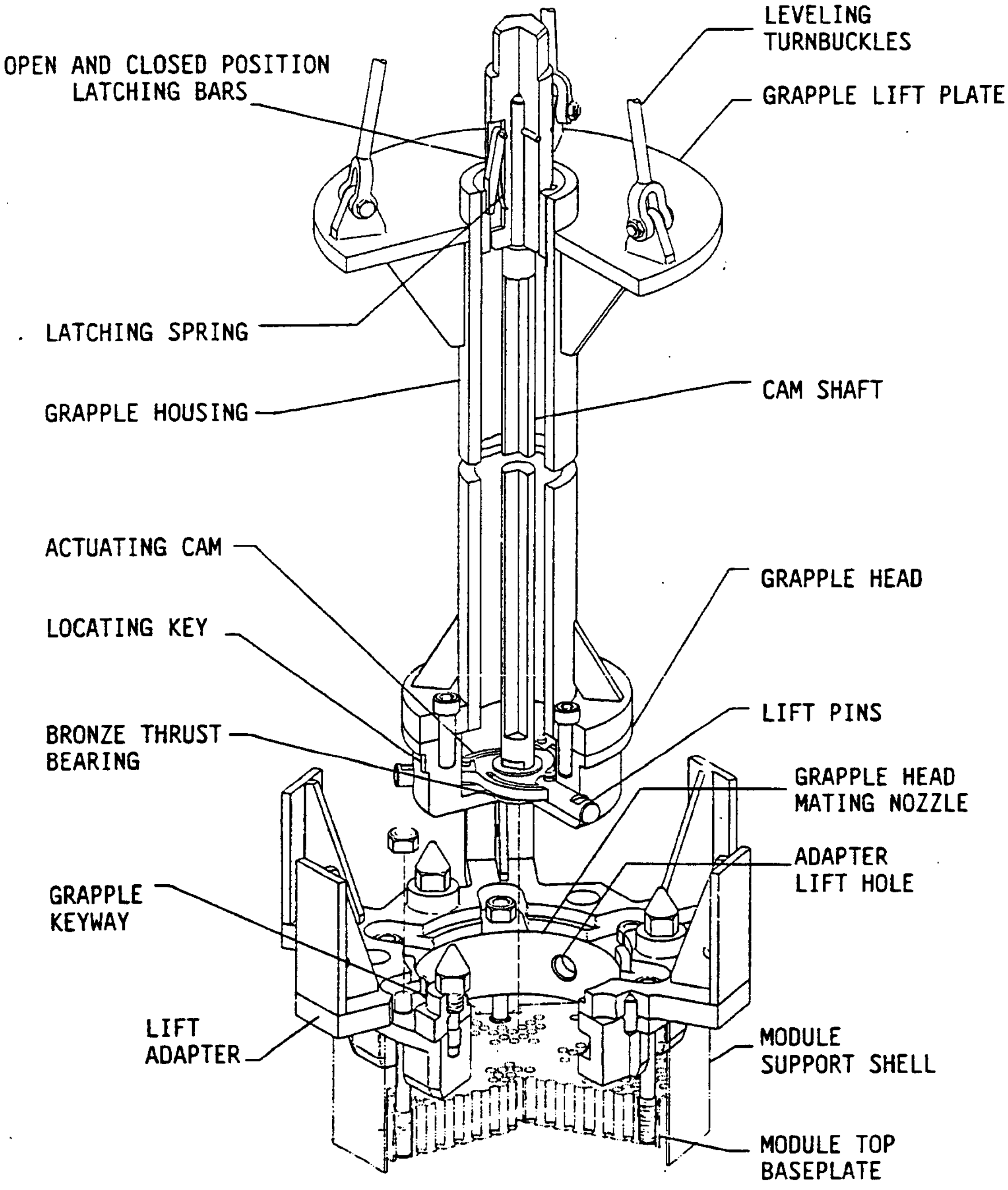

Figure 6-9. Light Water Breeder Reactor fuel module grapple shown with seed module (Greenberger and Miller 1987, WAPD-TM-1608, Figure 8).

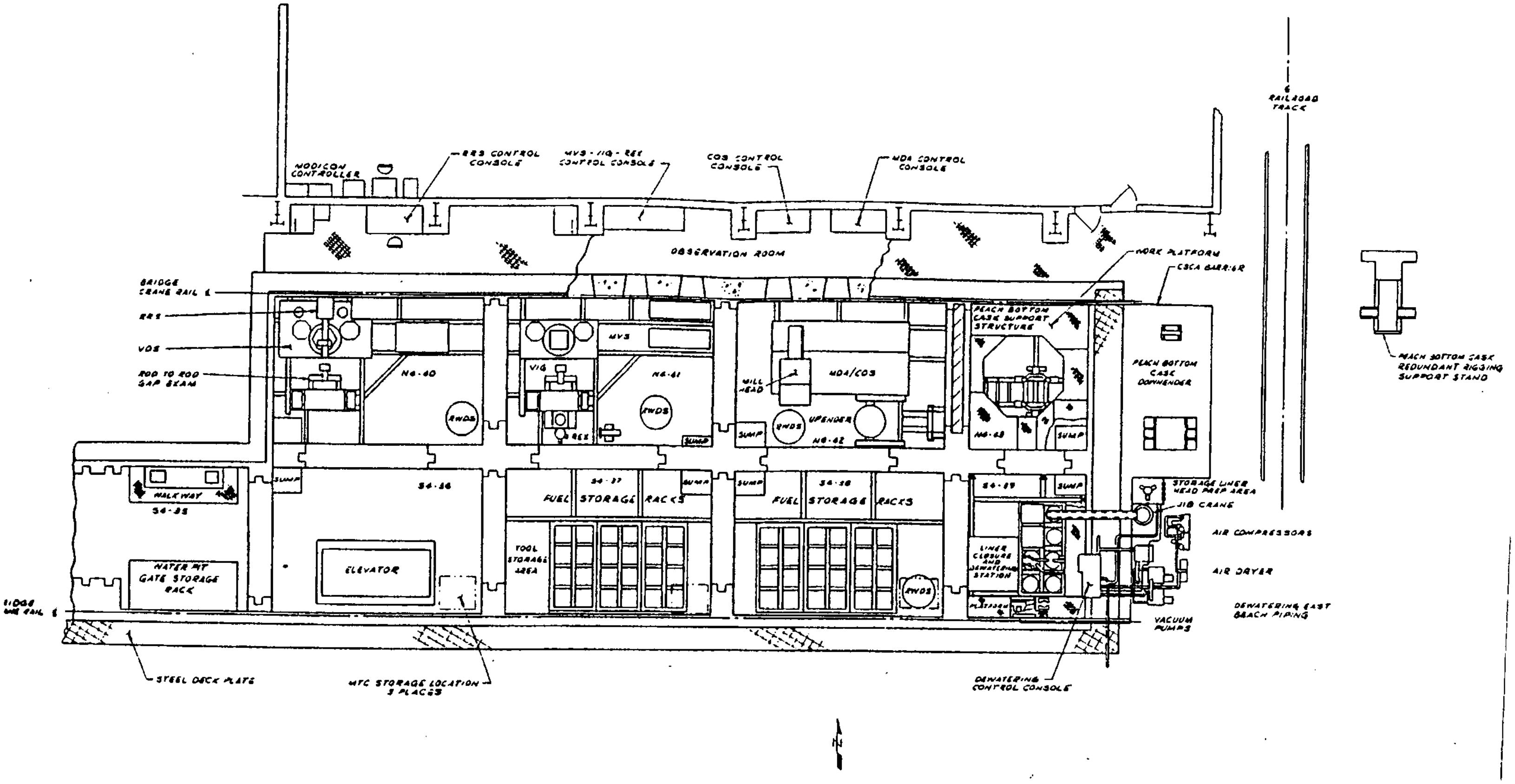

Figure 6-10. Area of the Expended Core Facility water pits used for Light Water Breeder Reactor program (Hodges 1987, WAPD-TM-1601, Figure 1-4).

The cut modules were secured with stabilization clamps, which were designed to provide a means for vertical lifting and handling of the cutoff modules. The stabilization clamp assembly used for the seed modules is shown in Figure 6-11. Similar stabilization clamp assemblies were used for the blanket and reflector modules. The drawing numbers for the stabilization clamps, lift adaptors, modules, and rod storage liner are identified in Cole (2001).

After each module processing operation, the clamped modules were returned to their designated storage liners. When all scheduled module examinations were completed, the storage liners were transferred to the Liner Closure Station for final closure head installation and water removal.

6.2.1 Water Removal at Expended Core Facility

Fuel liner blowdown removed the bulk water from the liner. A schematic of the liner blowdown system is presented in Figure 6-12. The water blowdown process occurred under water. The liner head was bolted onto the storage liner. Compressed air was forced through the blowdown system until the flowmeter downstream of the blowdown tank registered 450 gallons, ensuring the fuel storage liner was empty of bulk water.

Air circulation through the fuel storage liner was the second fluid process. A schematic of the liner air circulation system is presented in Figure 6-13. Dry compressed air was pumped for 20 minutes at about 17 cfm through the air dryer system, down through the fuel liner and filter system, and into the blowdown tank (Hodges 1987, WAPD-TM-1601). The forced air displaced the water out of the storage liner through the liner's standpipe, the drain fitting, and the drain umbilical tool, forcing the water out. Once the bulk amount of water was removed from the liner, only droplets of water remained on all the fuel and liner surfaces.

Residual water was removed using a vacuum pump, then the liner was backfilled with neon gas. Leak testing with neon gas to 150% of the maximum postulated liner pressure was performed underwater for 20 minutes to ensure that the storage liners were adequately sealed for shipment and storage. The dried and sealed liner was then transferred to the Peach Bottom Cask shipping container for subsequent shipment to INTEC for underground (dry) storage (Hodges 1987, WAPD-TM-1601).

The Part C Fuel Receipt Criteria for all the storage liners includes the certification checklists for the liners. The ECF Shift Supervisor and LWBR Engineering manager were required to check a box on a form indicating that they checked the following items for each liner: liner identification, module identification, liner vendor certification, fission product leakage certification (including water pit sample analysis), no liquid water in liner, and neon gas backfill of the liner.

6.2.2 Shipment from Expended Core Facility to INTEC

Two types of fuel storage liners (rod and module) were fabricated for the LWBR fuel disposal program. The exterior of all storage liners was a stainless steel cylindrical shell with an outer diameter of 25.50 in. and a length, with the closure head installed, of 157.80 in. (Hodges 1987, WAPD-TM-1601, p. 3-1). The exteriors of all the liners are identical, except for the unique labels painted on the top of the liner closure heads. Video tapes showing the loading of the liners into the Peach Bottom transport casks confirmed that all the labels were legible when the casks were loaded at ECF for shipment to INTEC for dry storage.[c]

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[c] Olson and McCardell viewed the tapes; tapes are in records storage with other LWBR records with Vicky Boyer at INTEC.

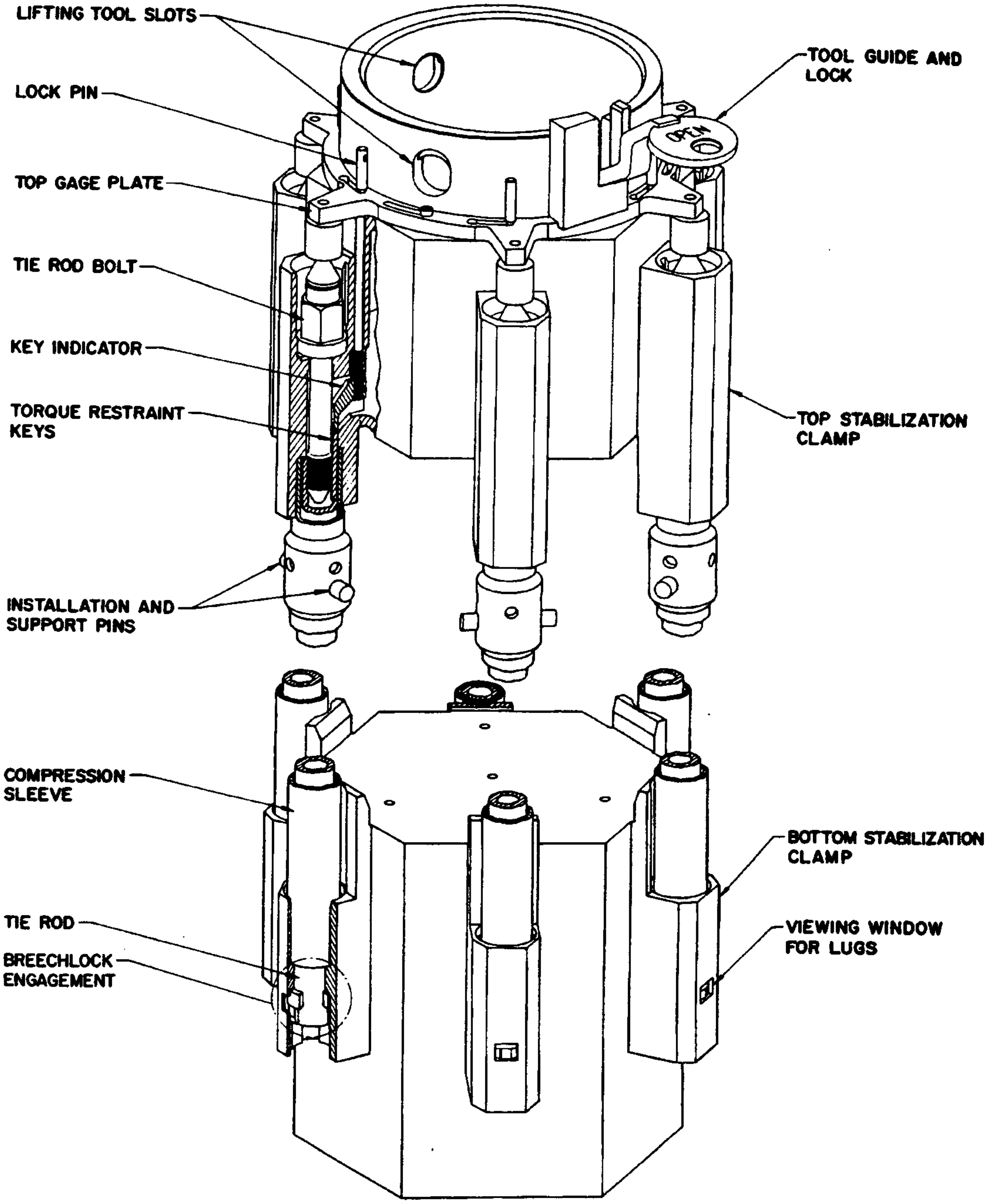

Figure 6-11. LWBR Seed Stabilization Clamp (Greenberger and Miller 1987, WAPD-TM-1608, Figure 27).

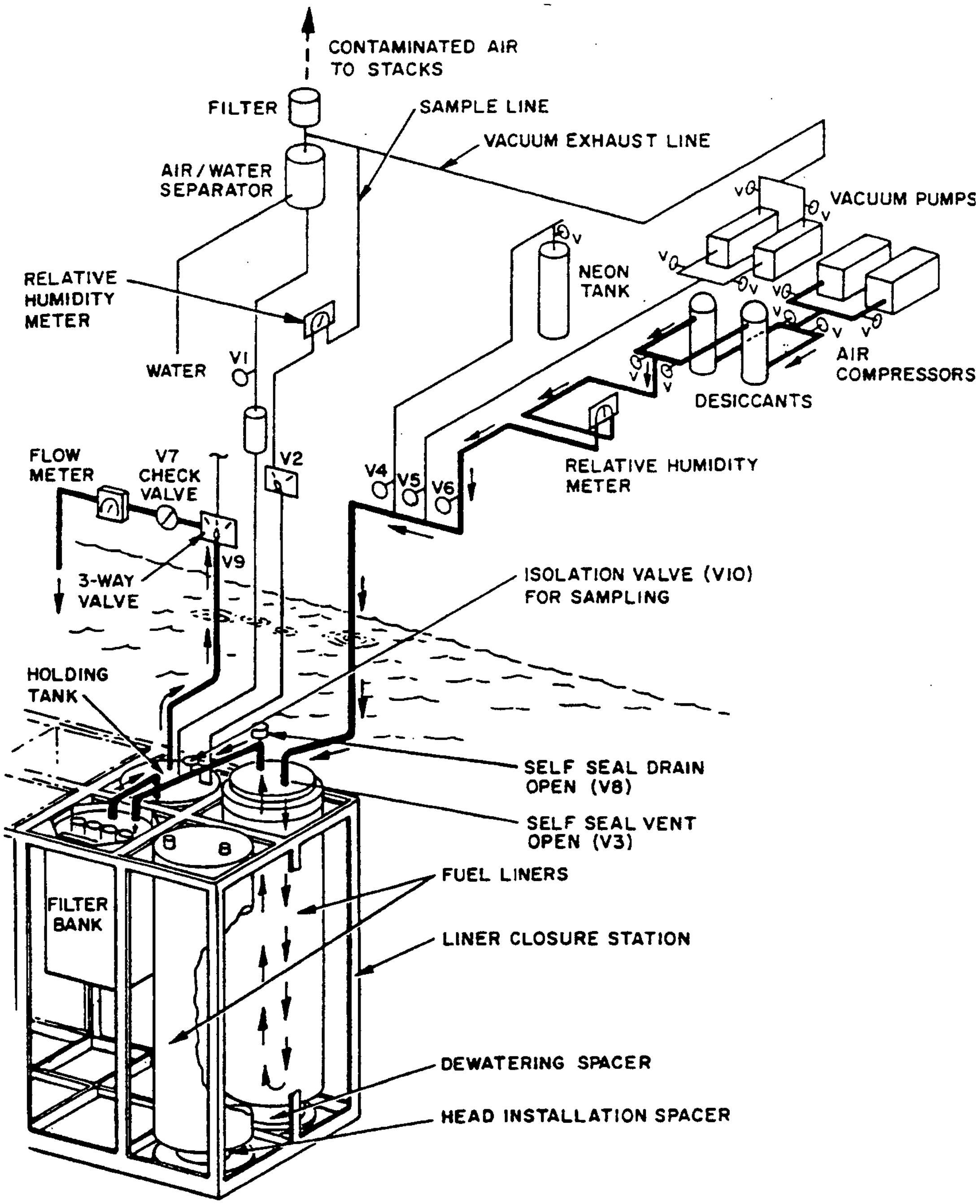

Figure 6-12. Light Water Breeder Reactor storage liner blowdown schematic (Hodges 1987, WAPD-TM-1601, Figure 3-11).

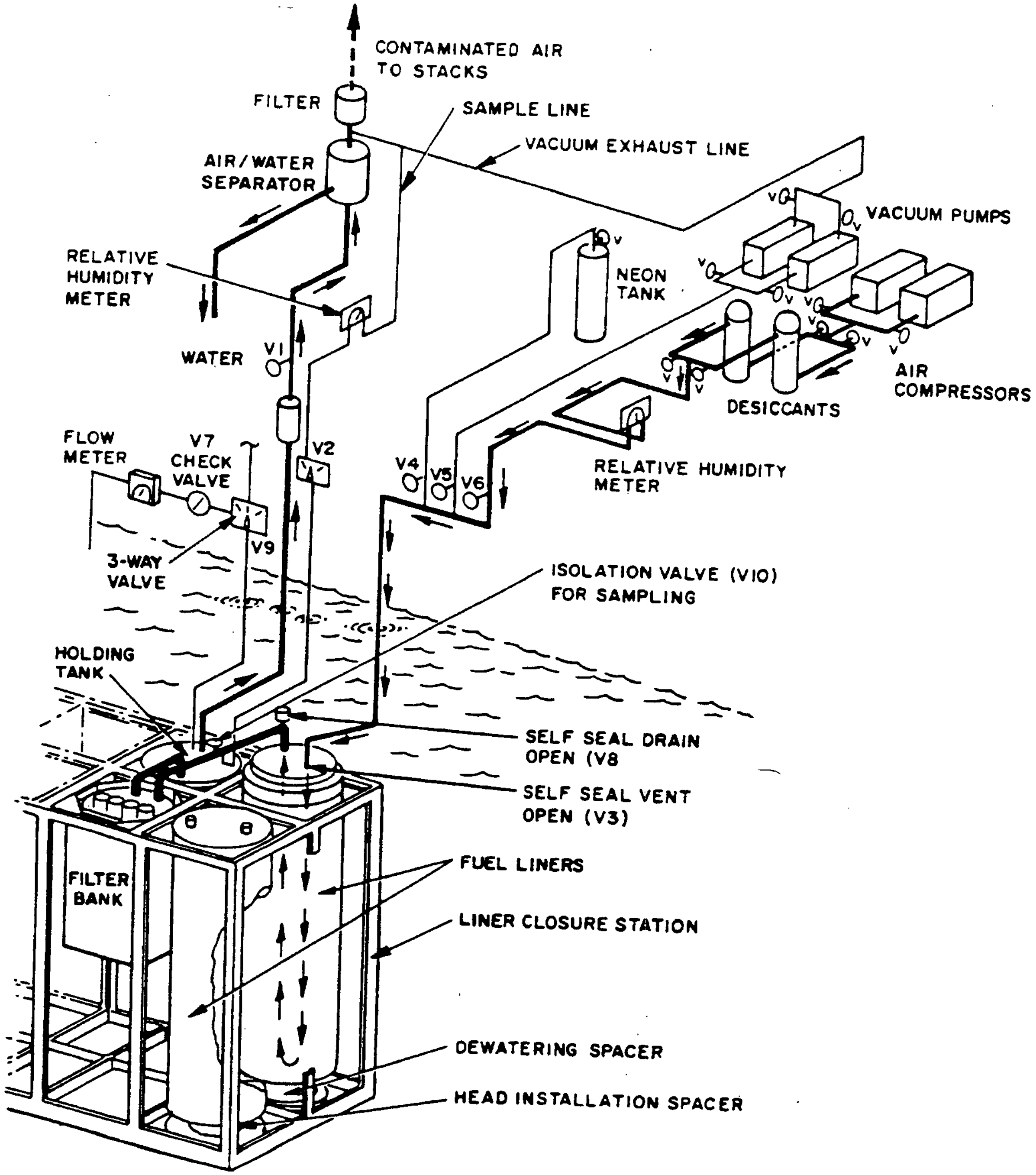

Figure 6-13. Light Water Breeder Reactor storage liner air circulation schematic (Hodges 1987, WAPD-TM-1601, Figure 3-15).

The interior of the rod storage liners had tube bundle inserts to house the individual fuel rods. The interior of the module storage liners had features configured to the various module cross sections. A typical LWBR fuel module storage liner is shown in Figure 6-14. Each module type had a corresponding storage liner type because of the vastly different sizes and cross-sectional shapes of the LWBR fuel modules. Liner internals were fabricated to accept both as-received and cut modules. Liners containing LWBR assemblies and loose rods were shipped from ECF to INTEC in a Peach Bottom Cask from December of 1985 until the last of the test rods were packaged and shipped in 1987 (Fuel Receipt Criteria Package B and C).

The storage liner preparation process included monitoring for fission products (Cs-137 and Cs-134) and fission gas (Kr-85) to indicate the possible existence of through-clad defects in fuel rods. No through-clad defects were indicated by fill water analysis for cesium when the modules arrived at ECF from Shippingport. However, positive indications were discovered during ECF liner preparations of two of the 12 LWBR seed modules (3-5 and 3-6) at initiation of the neon gas bleed cycle (Hodges 1987, WAPD-TM-1601, p. 3-37). After further testing, it was determined that the results suggested that there were fuel rod cladding defects in seed Modules 3-5 and 3-6, although available data were insufficient to conclude that fuel rod defects actually existed in the modules (Hodges 1987, WAPD-TM-1601, p. 3-38). The mechanism that may have led to a cladding defect while the modules were in storage at ECF was not identified (Hodges 1987, WAPD-TM-1601, p. 3-39). The presence of through-clad defects in seed Modules 3-5 and 3-6 remains questionable (Hodges 1987, WAPD-TM-1601, p. 3-39). Part C of the Fuel Receipt and Storage papers confirms the potential for cladding defects:

For Seed 3-5: "An indication of radioactive gas was noted during initial bleedoff. A gas sample taken during neon bleedoff indicated 8×10^{-6} µCi/mL K-85...Further sampling indicated no presence of Krypton 85" (Shipment No. 27, S-3-5, November 1986).

For Seed 3-6: "A gas sample taken during neon bleedoff indicated 1.2×10^{-4} µCi/mL Kr-85...Further sampling indicated 3.2×10^{-5} µCi/mL Kr-85 at the initiation of vacuuming. However, sampling one hour into vacuuming and at the initiation of neon bleedoff indicated no presence of Krypton 85" (Shipment No. 28, S-3-6, December 1986).

6.3 Storage at INTEC

The 39 LWBR core modules, 7 containers of intact fuel rods, 1 container of cut fuel rods, and 1 container of an unirradiated seed (not discussed in this report) are presently in underground dry storage at CPP-749 in the upright position. The Dry Well Design for irradiated LWBR Fuel Storage Dry Wells is shown in Figure 6-15. The plot plan of LWBR fuel storage facility at CPP-749 is shown in Figure 6-16.

There are 27 Type A liners, which contain intact LWBR modules (i.e., modules from which no rods have been removed). Type A liners are configured to fit seed, standard, and power-flattening blanket, and reflector modules. There are 12 Type B liners, which contain partially derodded modules. Rods had been pulled from the various modules for testing and to access the rods chosen for testing. There are 7 Type C liners, which contain intact spent fuel rods (irradiated and unirradiated; unirradiated rods were used for calibration of instruments during postirradiation testing). Type C liners contain cells that are appropriately sized for the various diameters of the seed, blanket, and reflector rods. The exteriors of the liners are identical, except for their labels.

In addition to the Type A, B and C liners, there is one scrap can liner (Liner 15718), which contains sections and pieces of unirradiated rods and irradiated rods that have been cut up or punctured for testing purposes as well as unirradiated rods used for calibration. There are at least 22 containers

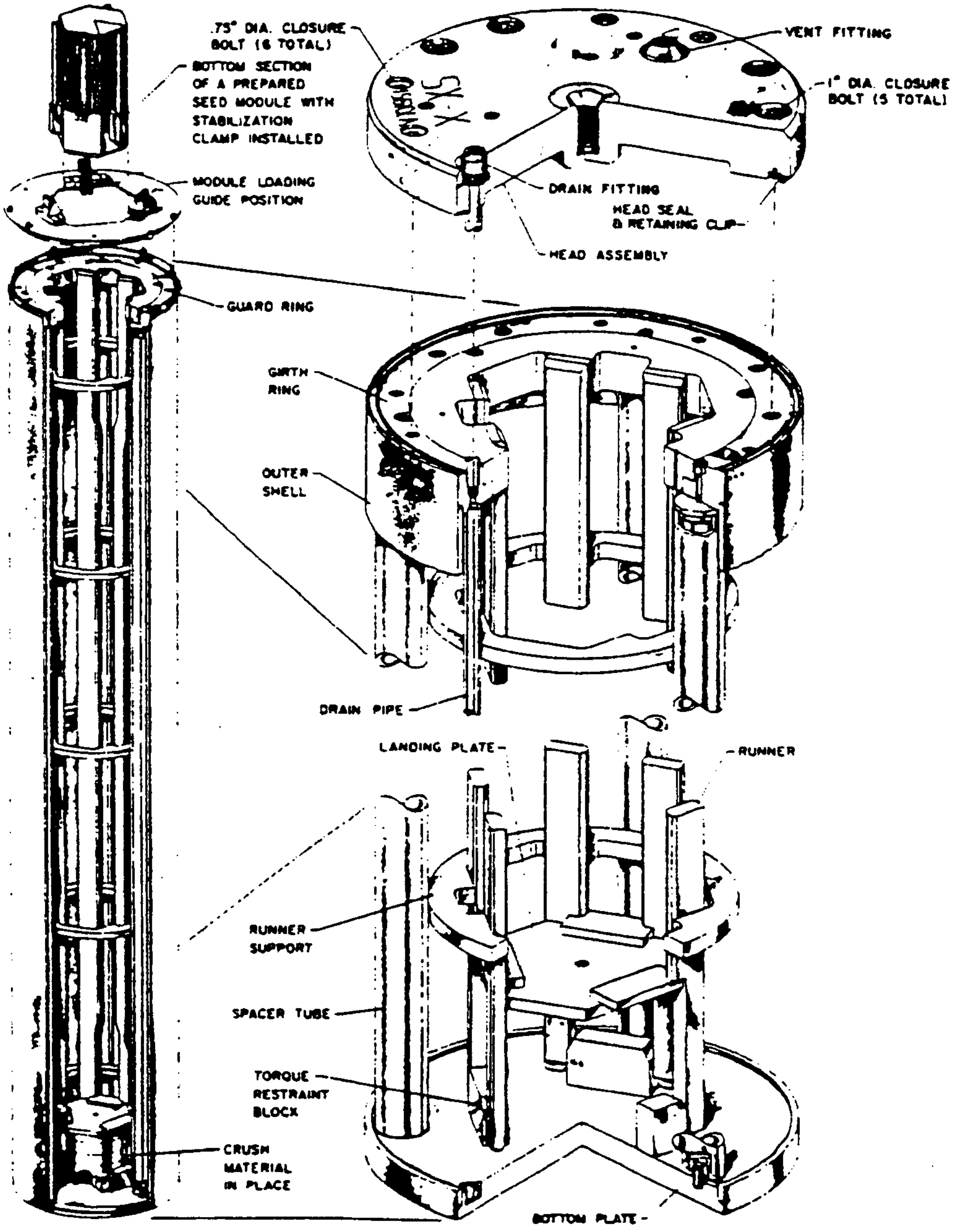

Figure 6-14. Typical Light Water Breeder Reactor fuel module storage liner (Hodges 1987, WAPD-TM-1601, Figure 3-1).

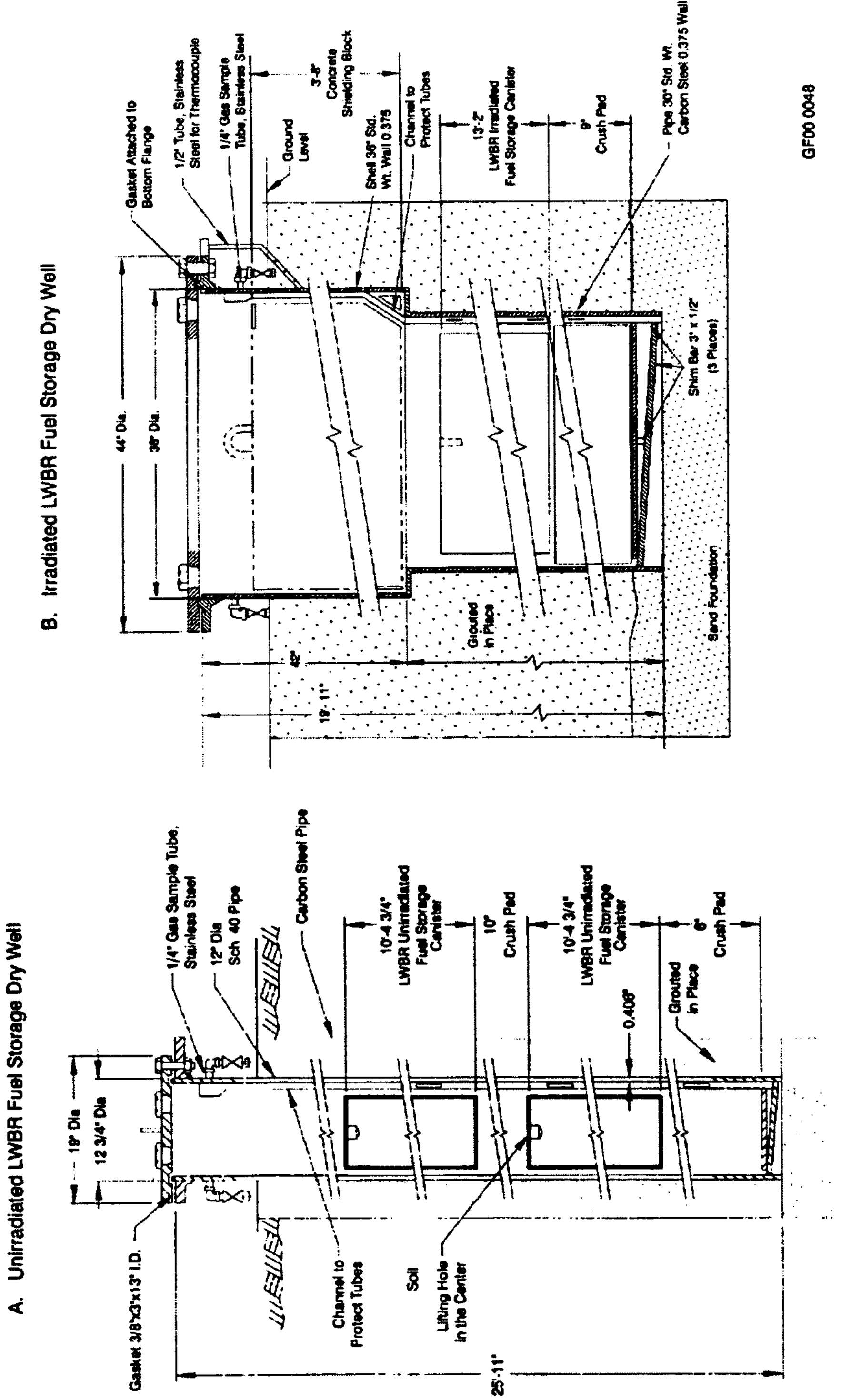

Figure 6-15. Section views of the dry well design for both unirradiated and irradiated Light Water Breeder Reactor fuel storage dry wells (INTEC Plant Safety Document 4.7A, 2002, Figure 4-7).

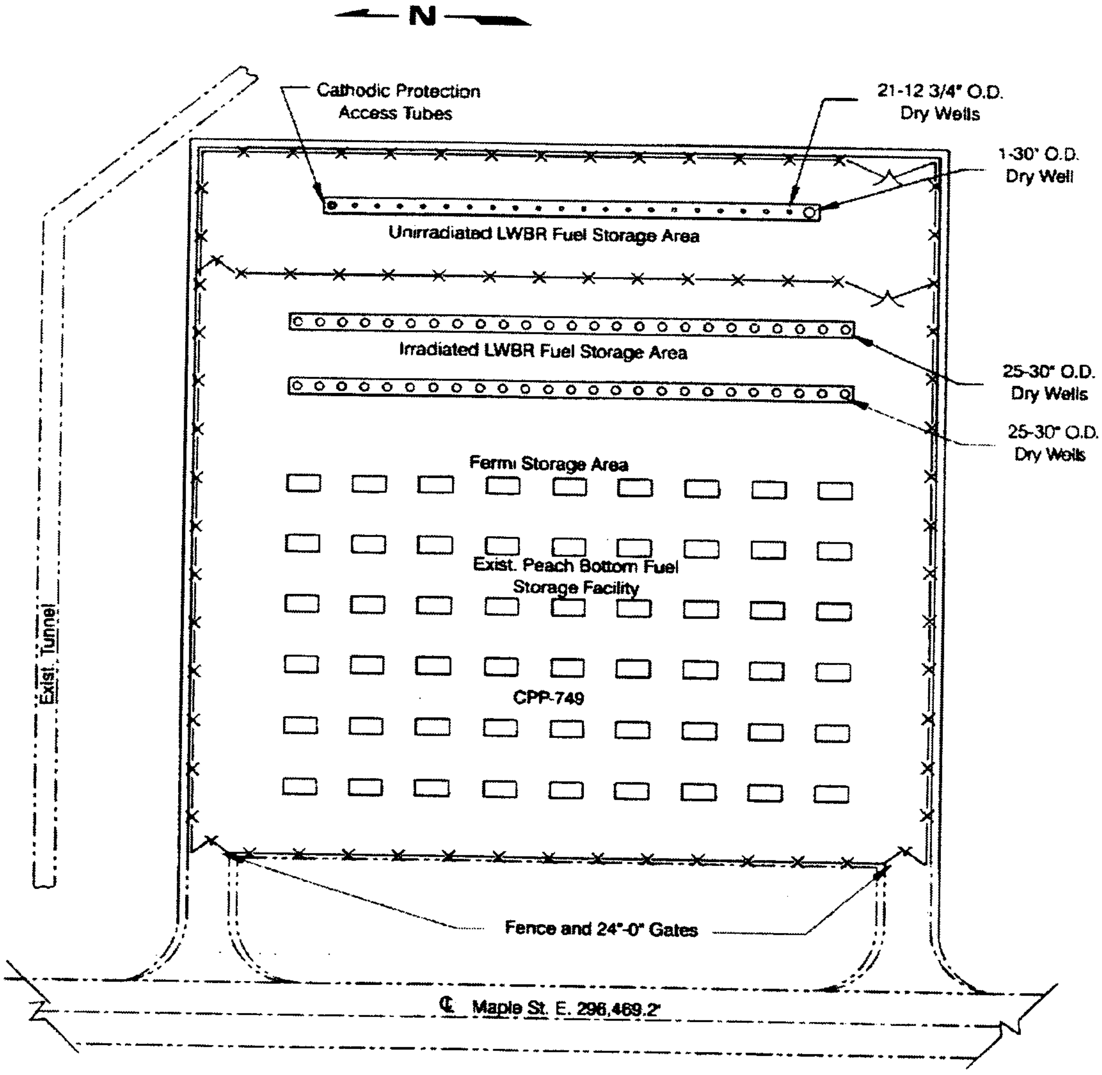

Figure 6-16. Plat plan of the Light Water Breeder Reactor fuel storage facility (INTEC Plant Safety Document, Section 4.7A, 2002, Figure 4-2).

within the scrap can, and these containers contain irradiated, unirradiated, intact, and cut fuel rods. Many of the rods have been run through a variety of tests, which may have altered their physical, chemical, and radiological status. The contents of the scrap can and information about the various tests that were conducted on the fuels inside the scrap can are provided in Appendix C.

Table 6-1 identifies the types of storage liners, how many rods are in each type of storage liner, the liner number, and the INTEC dry well number. Table 6-2 details the number and type of fuel rods for each Type C liner. Appendix D lists the rod serial numbers and isotopic contents (modeled) of each of the rods stored in the Type C liners.

Figures 6-17 through 6-23 identify the location of the rods within the Type C liners. Liner numbers, module serial numbers, and module types were confirmed March 18, 1998, by viewing a video of the loading of the Peach Bottom casks taken at ECF. Postirradiation isotopic data for the rods in the Type C liners are presented by rod in Part C of the Fuel Receipt Criteria.

Table 6-1. Types and contents of Light Water Breeder Reactor storage liners.

Dry Well Number	Module ID	Fuel Piece Serial Number	Liner Number	Liner Type[a]	Number of Rods Initially [b]	Number of Rods in "A" Liner[c]	Number of Rods Removed[d]	Number of Rods in "B" Liner [d]	Number of Rods in "C" Liner
I-7	S I-1	L-BB01-04	15601	B	619		50	569	
I-34	S I-2	L-BB01-05	15602	A	619	619			
I-37	S I-3	L-BB01-06	15603	A	619	619			
I-44	S II-1	L-BB01-09	15604	A	619	619			
I-12	S II-2	L-BB01-10	15605	A	619	619			
I-46	S II-3	L-BB01-13	15606	B	619		127	492	
I- 6	S III-1	L-BB01-07	15607	B	619		42	577	
I- 5	S III-2	L-BB01-08	15608	B	619		39	580	
I-11	S III-3	L-BB01-12	15609	A	619	619			
I-35	S III-4	L-BB01-11	15610	A	619	619			
I-39	S III-5	L-BB01-14	15611	A	619	619			
I-38	S III-6	L-BB01-16	15612	A	619	619			
I-15	B I-1	L-GR01-01	15613	A	442[e]	442[e]			
I-30	B I-2	L-GR01-02	15614	A	442[e]	442[e]			
I-13	B I-3	L-GU51-01	15615	B	443		52	391[e]	
I- 8	B II-1	L-GS01-01	15616	A	563[e]	563[e]			
I-50	B II-2	L-GS22-01	15617	B	564		84	480	
I-36	B II-3	L-GS01-02	15618	A	563[e]	563[e]			
I- 3	B III-1	L-GT01-01[f]	15619	A	632	632			
I-18	B III-2	L-GW52-01	15620	B	632		391	241[e]	
I-16	B III-3	L-GT01-03	15621	A	633	633			
I- 9	B III-4	L-GT01-04	15622	A	633	633			
I-28	B III-5	L-GT01-05[f]	15623	A	633	633			
I-14	B III-6	L-GT22-03	15624	B	633		84	549	
I- 2	R IV-1	L-RA01-06	15625	A	228	228			
I-27	R IV-2	L-RA01-02	15626	A	228	228			
I-41	R IV-3	L-RA01-10	15627	B	228		33	195	

Table 6-1. (continued).

Dry Well Number	Module ID	Fuel Piece Serial Number	Liner Number	Liner Type[a]	Number of Rods Initially[b]	Number of Rods in "A" Liner[c]	Number of Rods Removed[d]	Number of Rods in "B" Liner[d]	Number of Rods in "C" Liner
I-43	R IV-4	L-RA01-09	15628	B	228		76	152	
I-40	R IV-5	L-RA01-07	15629	A	228	228			
I-31	R IV-6	L-RA01-04	15630	A	228	228			
I-10	R IV-7	L-RA01-05	15631	A	227[e]	227[e]			
I-32	R IV-8	L-RA01-08	15632	A	228	228			
I-42	R IV-9	L-RA01-03	15633	B	228		57	171	
I-1	R V-1	L-RB01-07	15634	A	166	166			
I-4	R V-2	L-RB01-04	15635	A	166	166			
I-26	R V-3	L-RB01-06	15636	A	166	166			
I-17	R V-4	L-RB01-08	15637	B	166		37	129	
I-33	R V-5	L-RB01-03	15638	A	166	166			
I-29	R V-6	L-RB01-05	15639	A	166	166			
				Subtotal	17,288	11,690	1,072		
I-19	FR-B-1	Blanket[g]	15682[g]	C[g]					175[g]
I-20	FR-B2	Blanket[h]	15684[h]	C[h]					144[h]
I-48	FR-B3	Blanket[i]	15685[i]	C[i]					243[i]
I-21	FR-B4	Blanket[j]	15687[j]	C[j]					62[j]
I-45	FR-R1	Reflector[g]	15681[g]	C[g]					127[g]
I-47	FR-R2	Reflector[h]	15683[h]	C[h]					80[h]
I-22	FR-S1	Seed[i]	15686[i]	C[i]					270[i]
I-23		624 sections	15718						
				Total	17,288	11,690	1,072		1,101[k]

a. WAPD-NRF(RE)FP-139 (Category A liners) and WAPD-NRF(RE)FP-192 (Category B liners)

b. Hecker 1979, WAPD-TM-1326, Table A-14 and A-15.

c. WAPD-NRF(RE)FP-192, p. 8; WAPD-NRF(L)C-58 (for module B III-2 only)

d. WAPD-NRF(RE)FP-192, p. 8; WAPD-NRF(L)C-58 (for module B III-2 only)

e. Plus one flux thimble

f. Base plate number

g. WAPD-NRF(L)C-93

h. WAPD-NRF(L)C-104

i. WAPD-NRF(L)C-117

j. WAPD-NRF(L)C-123

k. Some of the rods in the Type C liners are unirradiated.

Table 6-2. Number and type of fuel rods in each liner.

	Liner No.							
Module Type	15681[a]	15682[a]	15683[b]	15684[c]	15685[b]	15686[b]	15687[d]	Total
SI-1						42		42
SII-3						128		128
SIII-1						43		43
SIII-2						39		39
BI-3		31			6		8	45
BII-2		7		39	23		11	80
BIII-2		91		91	180		29	391
BIII-6		46		14	4		14	78
RIV-3	27		3					30
RIV-4	37		39					76
RIV-9	56		1					57
RV-4	7		30					37
Unirradiated rods	0	0	7	0	30	18	0	55
Total number rods	127	175	80	144	243	270	62	1,101

a. Reference: Letter WAPD-NRF(L)-C-93.

b. Reference: Letter WAPD-NRF(L)-149.

c. Reference: Letter WAPD-NRF(L)C-104.

d. Reference: Letter WAPD-NRF(L)-123.

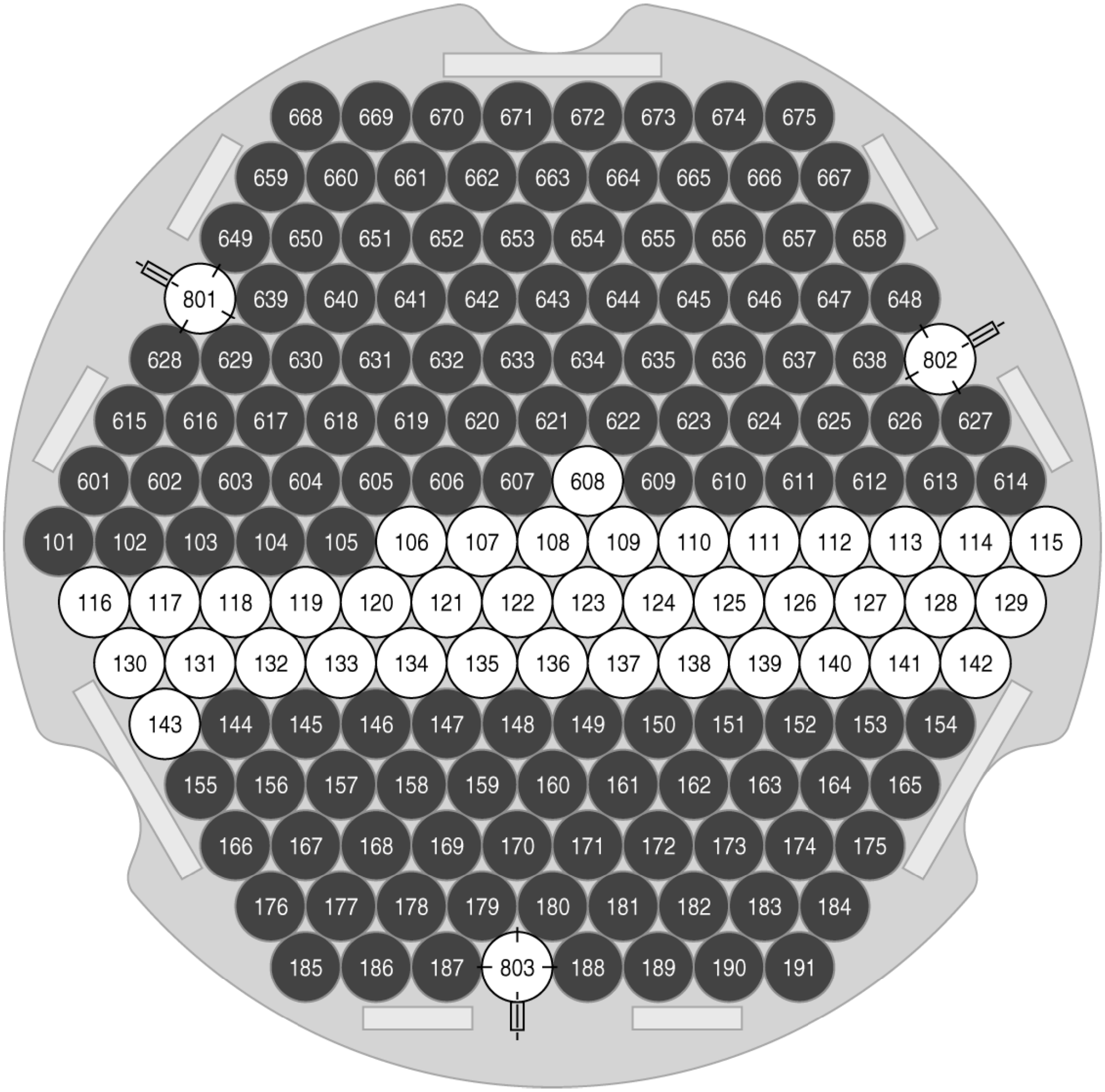

Figure 6-17. Occupied liner cells (in black) for reflector rod storage Liner 15681 (see attachment to letter WAPD-NRC(L) C-93).

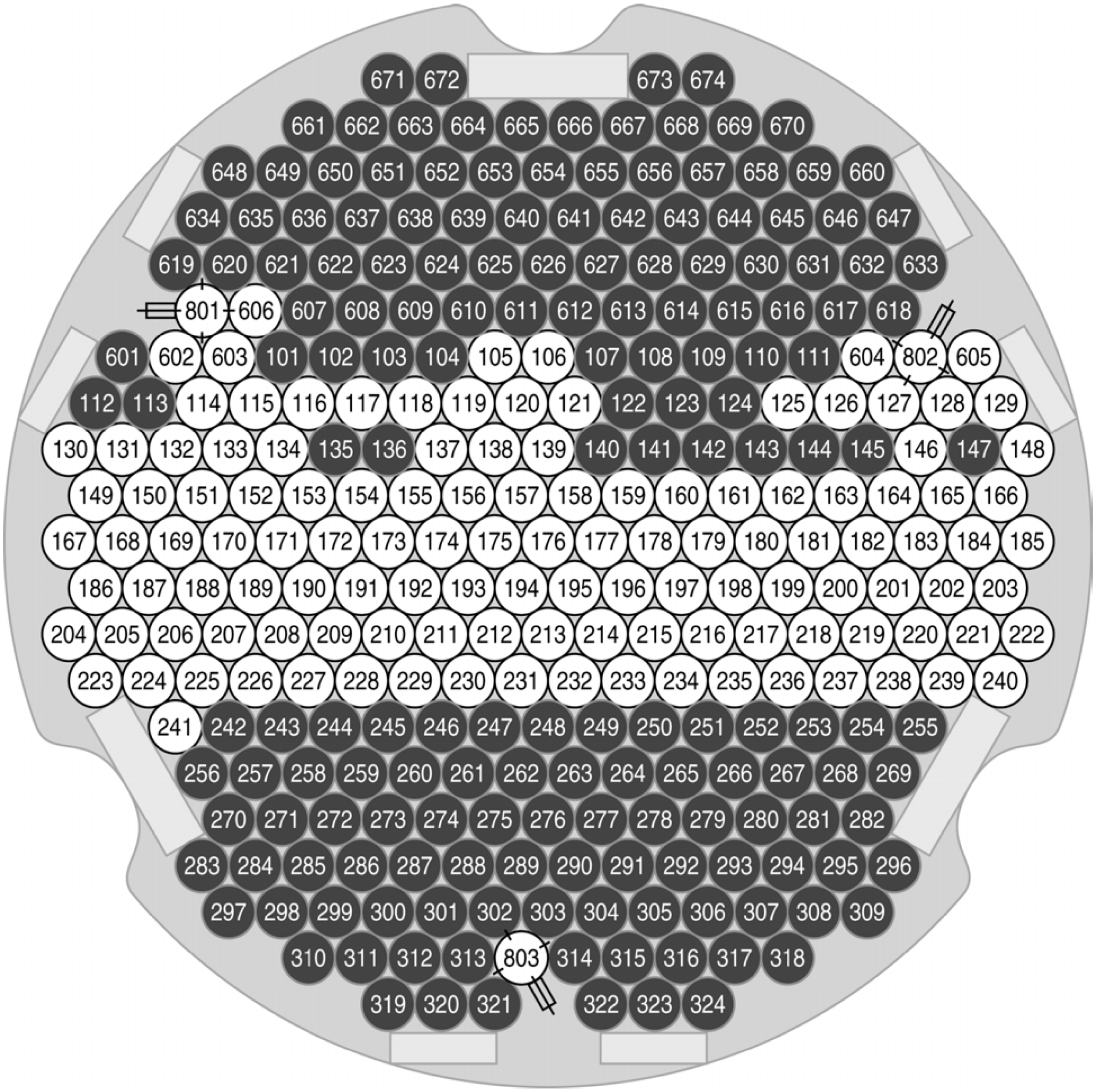

Figure 6-18. Occupied liner cells (in black) for blanket rod storage Liner 15682 (see attachment to letter WAPD-NRC(L) C-93).

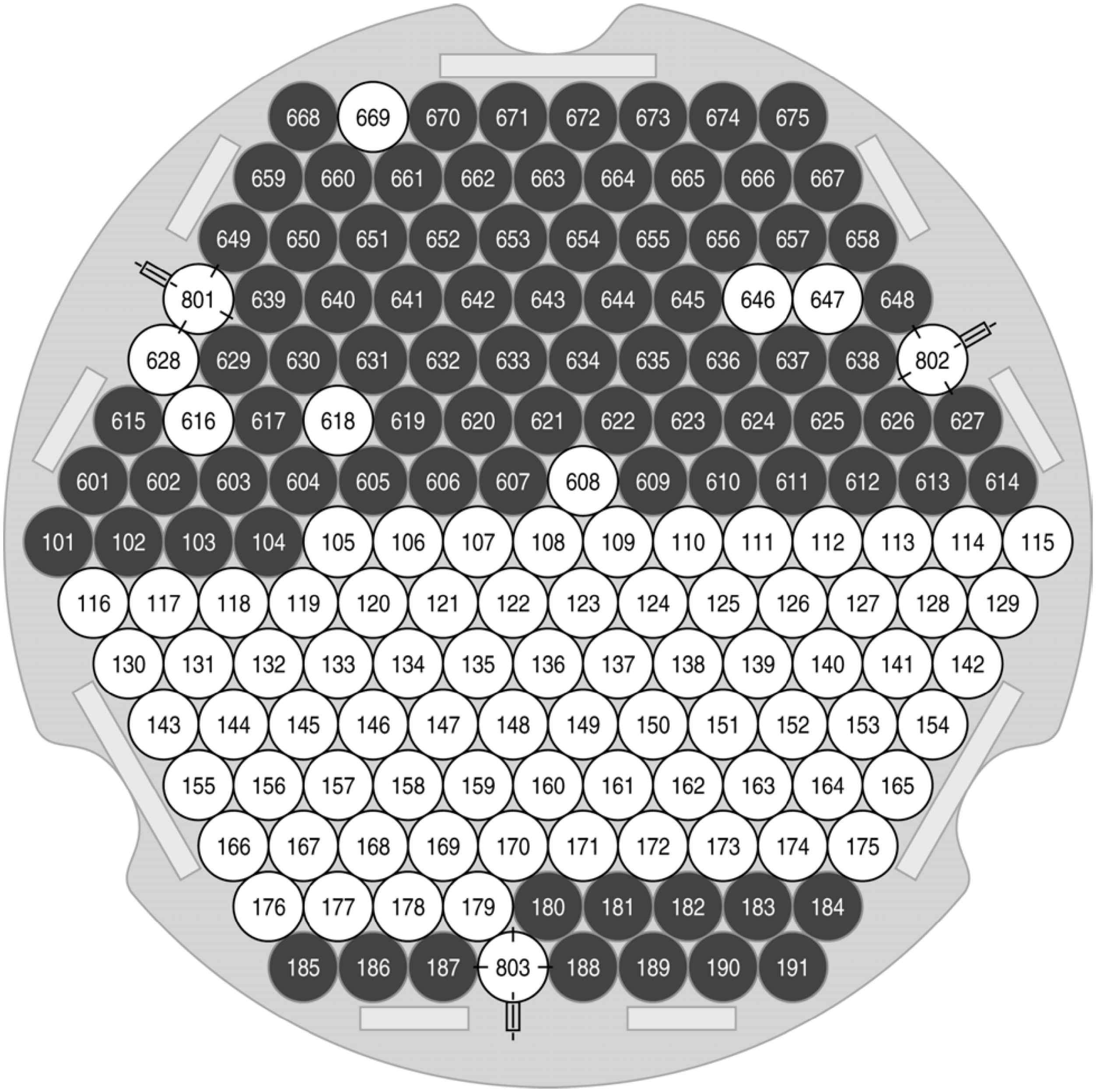

Figure 6-19. Occupied liner cells (in black) for reflector rod storage Liner 15683 (see attachment to letter WAPD-NRC(L)104 and WAPD-NRF(L)C-149).

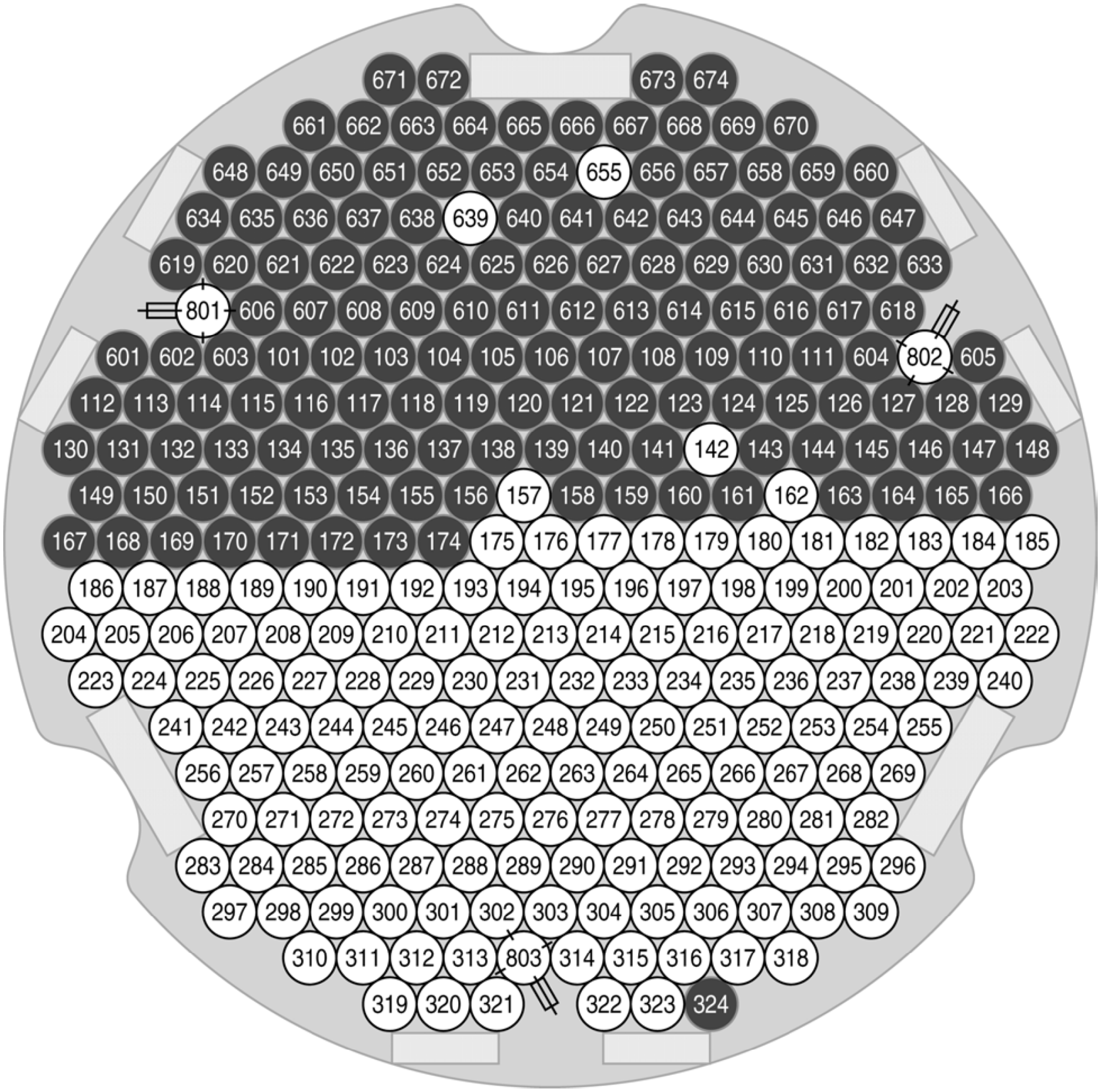

Figure 6-20. Occupied liner cells (in black) for blanket rod storage Liner 15684 (see attachment to letter WAPD-NRC(L) C-104).

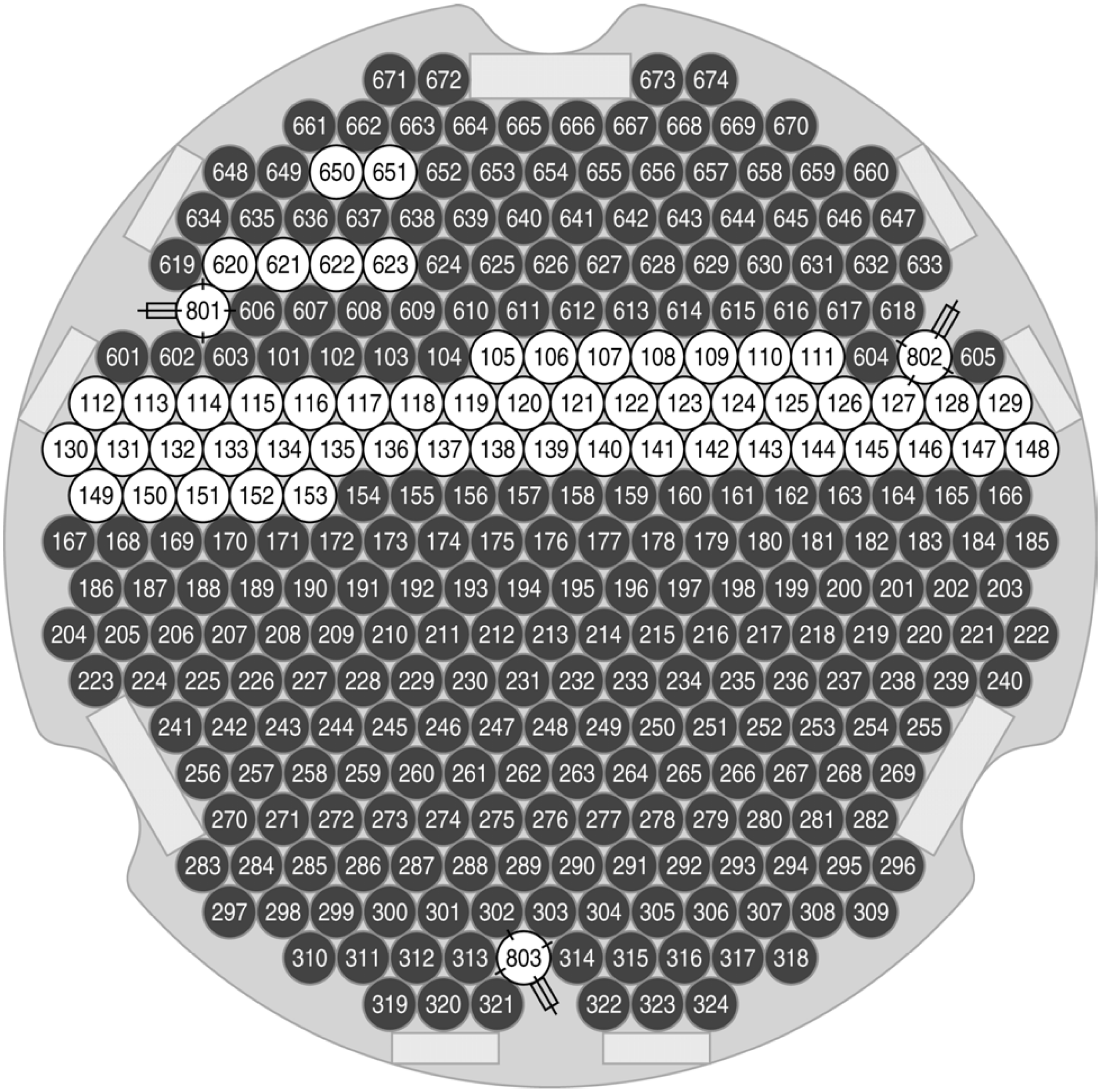

Figure 6-21. Occupied liner cells (in black) for blanket rod storage Liner 15685 (see attachment to letter WAPD-NRC(L)149).

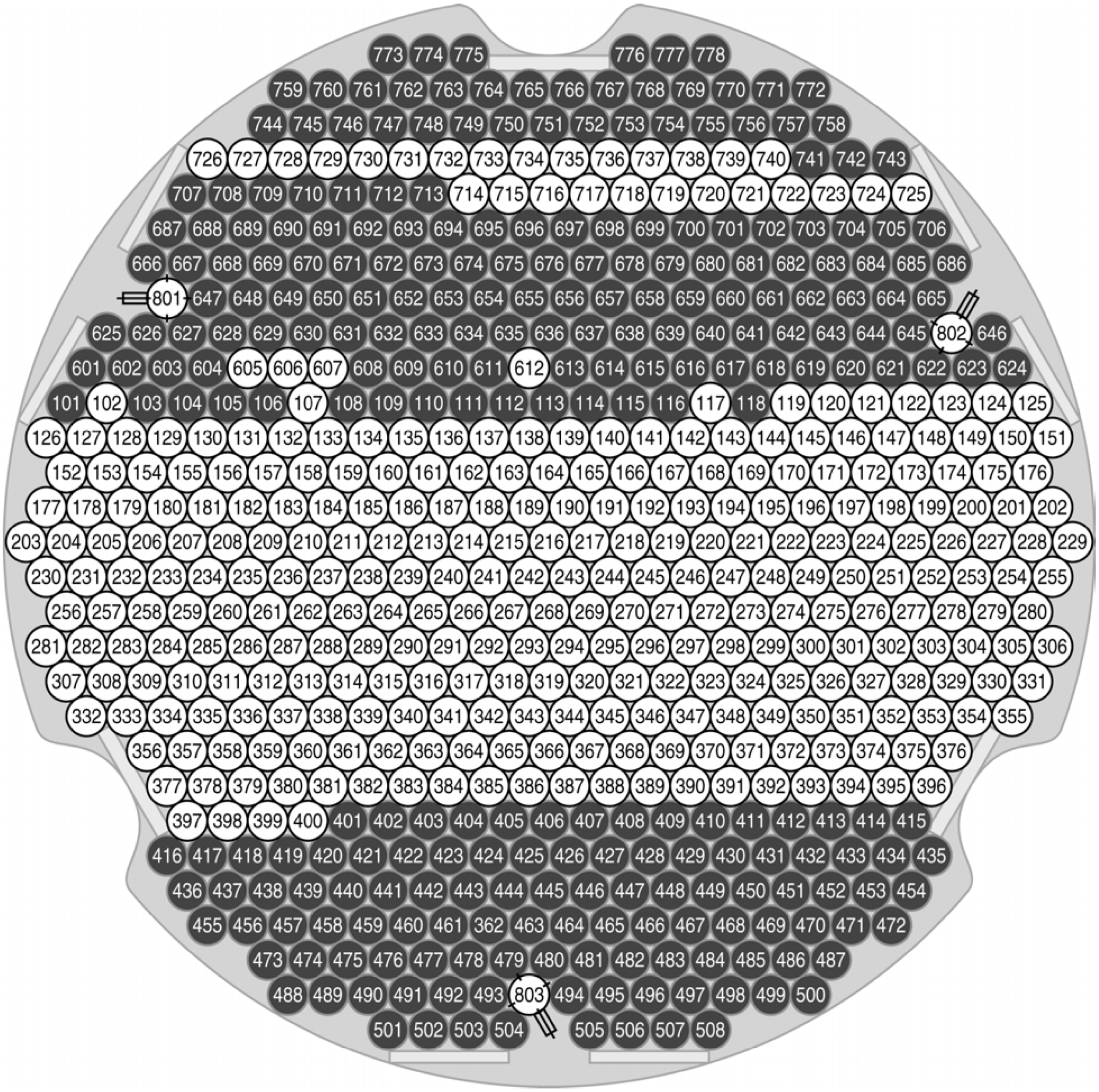

Figure 6-22. Occupied liner cells (in black) for seed rod storage Liner 15686 (see attachment to letter WAPD-NRC(L)149).

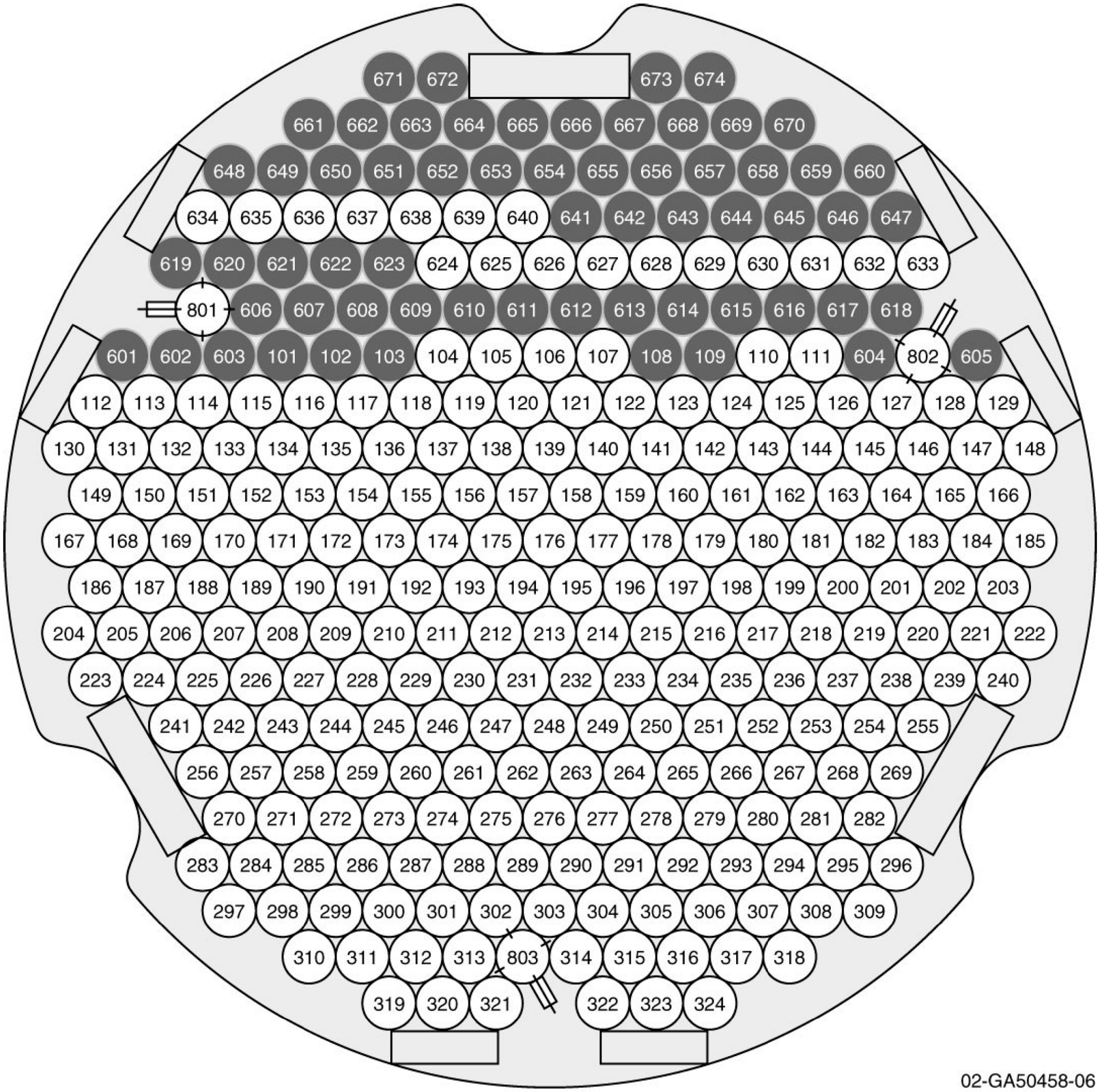

Figure 6-23. Occupied liner cells (in black) for blanket rod storage Liner 15687 (see attachment to letter WAPD-NRC(L)123).

6.4 Condition of SNF

Fuel in Type A liners is likely intact, although there may have been some cladding breach on two Type A seed modules (see Section 6.2.2 above). The information provided in the Part B data did not indicate which seed modules contained the possible breached cladding. Part C FRC data indicated that Seeds 3-5 (Shipment 27) and 3-6 (Shipment 28) were suspect for breached cladding because radioactive gas was present when the can atmosphere was sampled. Further sampling of both of these Type A liners indicated no presence of Krypton-85, and in both cases, the conclusion was that the fuel was sealed in liner storage containers (see WAPD-NRF(L)C-117, Attachment page 3).

Type B liners contain partially derodded modules. Derodding involved sawing off the top of the core with the cutoff system described in Greenberger and Miller 1987 (WAPD-TM-1608). Type C liners contain rods that have been removed from the modules that now occupy the Type B canisters.

The cut fuel can (Liner 15718) contains fuel pieces that were part of testing during design of the LWBR fuel. The fuel pieces and rods are in various stages of disassembly and condition due to destructive and nondestructive tests on the rods. The descriptions of the tests and the rods used in the tests are provided in Appendix C. Liner 15718 contains remnants from 260 to 275 test rods, which were similar in size and composition to the LWBR fuel rods. Most of the test rods were tested under normal LWBR pressure and temperature conditions, but some operated at low system pressure and low coolant temperatures. With the exception of 2 of 271 rods described in WAPD-TM-1208, no breach of cladding integrity was observed in any test rod during normal operations; however, several rods were cut up. Intentionally severe overtest conditions resulted in two rods damaged (Conners et al. 1979, WAPD-TM-1208, p. 30).

6.5 Thermal Output

Heat output data for each of the storage liners at the time of shipping were provided in the Part C Fuel Receipt Criteria and are presented in Table 6-3, along with other data from Part C. The decay heat curves as a function of cooling time for the hottest fully rodded seed, blanket, and reflector modules (i.e., upper limit rates) were included in the Part B Fuel Receipt Criteria (e.g., WAPD-NRF(L)C-104), see Figure 6-24. The decay heat curve spans over a 10-year cooling time. Assuming a start date of December 2, 1982, the curve spans through December 2, 1992.

Sterbentz and Wahnschaffe (2001) predicted heat rate generation for a single seed (Type I), standard blanket (Type I), standard/power-flattening blanket (Type II), standard/power-flattening blanket (Type III), Reflector IV, and Reflector V module. Module heat rates are given as a function of decay date (2000–2030). These calculated module heat rates were compared to heat rates reported in WAPD-NRF(L)C-104, which were calculated values verified against actual LWBR module decay heat measurements. The calculated values from Sterbentz and Wahnschaffe (2001) were 33% and 29% higher than the WAPD Fuel Receipt Criteria values for a single seed module and a single standard/power-flattening blanket module, respectively. The Type IV Reflector decay heat value from Sterbentz and Wahnschaffe (2001) was approximately 29% lower than the WAPD value. The estimated decay heat values from Sterbentz and Wahnschaffe for year 2005 are presented in Table 6-4.

6.6 Liquid Content of Canister

While at ECF, each fuel storage liner was stored in the ECF waterpit. Prior to shipment, each liner was dried to the extent that no liquid water remained (see p. 5 of the [Part B Fuel Receipt Criteria] attachment transmitted in WAPD-NRF(L)C-104, April 30, 1987). As stated in Part B FRC (p. 7 of Attachment to WAPD-NRF(L)C-104, April 30, 1987), “Prior to shipment, the LWBR fuel storage liner

Table 6-3. Data from Part C fuel receipt criteria (by liner number).

Liner No.	Type	Container	U-233 (Ci)	Th-232 (Ci)	Total Ci (Ci)	Surface Rad (mrem/hr)	Rad at 3 ft (mrem/hr)	Mass U Before Burnup[a] (g)	Est. Mass U after Burnup[a] (g)	Fissile Before Burnup[a] (g)	Est. Fissile After Burnup[a] (g)	Decay Heat (watts)	Mass of Contents (lb)	Liner Mass (lb)	Total Mass (lb)
15601	B	S-1-1	1.46E+02	4.38E-02	4.00E+05	11.5	0.3	16785	12841	16505	11308	462.9	2013	2696	4709
15602	A	S-1-2	1.59E+02		4.00E+05	6.5	3.5	16792	14014	16507	12343	586	1654	2696	4350
15603	A	S-1-3	1.82E-03		4.00E+05	9.5	5.5	16803	14014	16523	12343	465.9	1654	2696	4350
15604	A	S-2-1	1.60E+02	4.77E-01	4.00E+05	7.2	3	16808	14243	16529	12752	414	1654	2696	4350
15605	A	S-2-2			4.00E+05	8.3	3	16808	14243	16528	12752	419.3	1654	2696	4350
15606	B	S-2-3	1.30E+02	3.77E-04	4.00E+05	5.4	1.2	16844	11530	16569	10330	448.3	2013	2696	4709
15607	B	S-3-1	1.46E+02	4.38E-02	4.00E+05	3.9	1.6	16783	13414	16505	12169	377	2013	2696	4709
15608	B	S-3-2	1.46E+02	4.38E-02	4.00E+05	3.4	1.2	16821	13460	16545	12211	377	2013	2696	4709
15609	A	S-3-3	1.50E+02		4.00E+05	4	0.2	16833	14457	16558	13118	379.6	1654	2696	4350
15610	A	S-3-4	1.59E-02		4.00E+05	5.4	2.2	16827	14457	16552	13118	480.5	1654	2696	4350
15611	A	S-3-5	1.60E+02	1.26E-01	4.00E+05	5.9	2	16836	14457	16562	13118	379.6	1654	2696	4350
15612	A	S-3-6	1.38E+02	1.26E-01	4.00E+05	4.3	0.7	16834	14457	16557	13118	374.8	1654	2696	4350
15613	A	B-1-1	1.55E+02	1.43E-01	4.00E+05	9	2.5	16834	14457	16166	19363	696.8	4212	2238	6450
15614	A	B-1-2	1.54E+02	1.43E-02	4.00E+05	14.8	4.9	16444	21579	16164	19363	889.5	4212	2238	6450
15615	B	B-1-3	1.38E+02	1.26E-01	4.00E+05	14	2.4	16439	19041	16161	17086	698	4718	2238	6956
15616	A	B-2-1	2.80E+02		4.00E+05	20.5	3.5	25377	27954	24915	25427	879	4890	2210	7100
15617	B	B-2-2	Missing		Missing	Missing	Missing	25440	23795	24969	21641	755.9	5410	2210	7620
15618	A	B-2-3	1.59E-02		4.00E+05	19	8	25384	27954	24917	25427	937.6	4890	2210	7100
15619	A	B-3-1	2.78E+02		4.00E+05	35	9	30342	31784	29776	29285	994.7	6015	3300	9315
15620	B	B-3-2	1.55E+02	1.43E-01	4.00E+05	3.6	2	30328	11999	29754	11075	732.2	5809	2647	8456
15621	A	B-3-3	1.55E+02	1.43E-01	4.00E+05	13	3.1	30404	31844	29831	29343	740.8	5303	2647	7950
15622	A	B-3-4	2.88E+02		4.00E+05	8.5	2.6	30395	31844	29821	29343	890	5303	2647	7950
15623	A	B-3-5	2.78E+02		4.00E+05	25	8	30400	31840	29860	29620	Missing	Missing	Missing	Missing
15624	B	B-3-6	1.38E+02	1.26E-01	4.00E+05	7	1.8	30409	27525	29830	25360	744	5809	2647	8456
15625	A	R-4-1		1.10E-01	4.00E+05	2.7	1	0	2975	0	2908	Missing	Missing	Missing	Missing
15626	A	R-4-2		1.10E-01	4.00E+05	3.4	0.32	0	2975	0	2902	28.36	4933	2667	7600
15627	B	R-4-3		1.31E-01	4.00E+05	0.7	0.02	0	2413	0	2361	21.7	4933	2667	7600
15628	B	R-4-4		1.31E-01	4.00E+05	0.6	0.3	0	1596	0	1569	21.1	5200	2667	7867

Table 6-3. (continued).

Liner No.	Type	Container	U-233 (Ci)	Th-232 (Ci)	Total Ci (Ci)	Surface Rad (mrem/hr)	Rad at 3 ft (mrem/hr)	Mass U Before Burnup[a] (g)	Est. Mass U after Burnup[a] (g)	Fissile Before Burnup[a] (g)	Est. Fissile After Burnup[a] (g)	Decay Heat (watts)	Mass of Contents (lb)	Liner Mass (lb)	Total Mass (lb)
15629	A	R-4-5		1.26E-01	4.00E+05	1.35	0.25	0	3255	0	3175	25.3	4933	2667	7600
15630	A	R-4-6		1.43E-02	4.20E+05	1.15	0.25	0	3255	0	3175	29.3	4933	2667	7600
15631	A	R-4-7		1.43E-02	4.00E+05	0.8	0.3	0	3246	0	3167	27	4933	2667	7600
15632	A	R-4-8		1.43E-02	4.00E+05	1.4	0.7	0	3255	0	3175	29	4933	2667	7600
15633	B	R-4-9		1.31E-01	4.00E+05	<0.1	<0.1	0	2516	0	2454	21.4	5200	2667	7867
15634	A	R-5-1		1.10E-01	4.00E+05	1.2	0.2	0	1689	0	1662	Missing	Missing	Missing	Missing
15635	A	R-5-2		1.10E-01	4.00E+05	0.3	0.2	0	1689	0	1662	10.3	4028	2322	6350
15636	A	R-5-3		1.10E-01	4.00E+05	0.45	0.2	0	1689	0	1662	41	4028	2322	6350
15637	B	R-5-4		1.31E-01	4.00E+05	0.3	0.15	0	1255	0	1236	9.5	4204	2322	6526
15638	A	R-5-5		Missing	Missing	Missing	Missing	0	1689	0	1662	11.4	4028	2322	6350
15639	A	R-5-6		1.10E-01	4.00E+05	0.5	<0.1	0	1689	0	1662	12	4028	2322	6350
15681	C	FR-R1		8.50E-02	1.20E+03	0.4	0.17	0	2207	0	2144	23.44	4783	2017	6800
15682	C	FR-B1	8.50E+01	1.90E-01	2.10E+04	2.6	0.15	9040	9132	8865	8418	744.2	3435	2365	5800
15683	C	FR-R2	1.89	2.12E-01	4.00E+04	0.2	<0.1	201	1313	197	1281	73.12	2495	3505	5800
15684	C	FR-B2	6.70E+01	4.20E+01	1.27E+03	5	1.3	7092	7391	6958	6765	753	4802	2635	7167
15685	C	FR-B3	98.33	7.13E-01	2.40E+04	4.9	1.8	10530	11422	10332	10545	751.5	3985	2365	6350
15686	C	FR-S1	67.8	2.08E-01	3.00E+05	2.3	0.8	7230	6121	7109	5516	446.8	3524	2696	6220
15687	C	FR-B4	30	1.94E-01	1.23E+03	5.4	0.1	2464	2978	2421	2705	751.5	4970	2365	7335
15718	Cut fuel		4.78E+00	1.58E-03	6.24E+04	6.62	0.04	10267[b]	Missing	10715	Missing	234	7207	1036	8243

a. Values rounded to five significant figures

b. Inconsistent data from Bettis

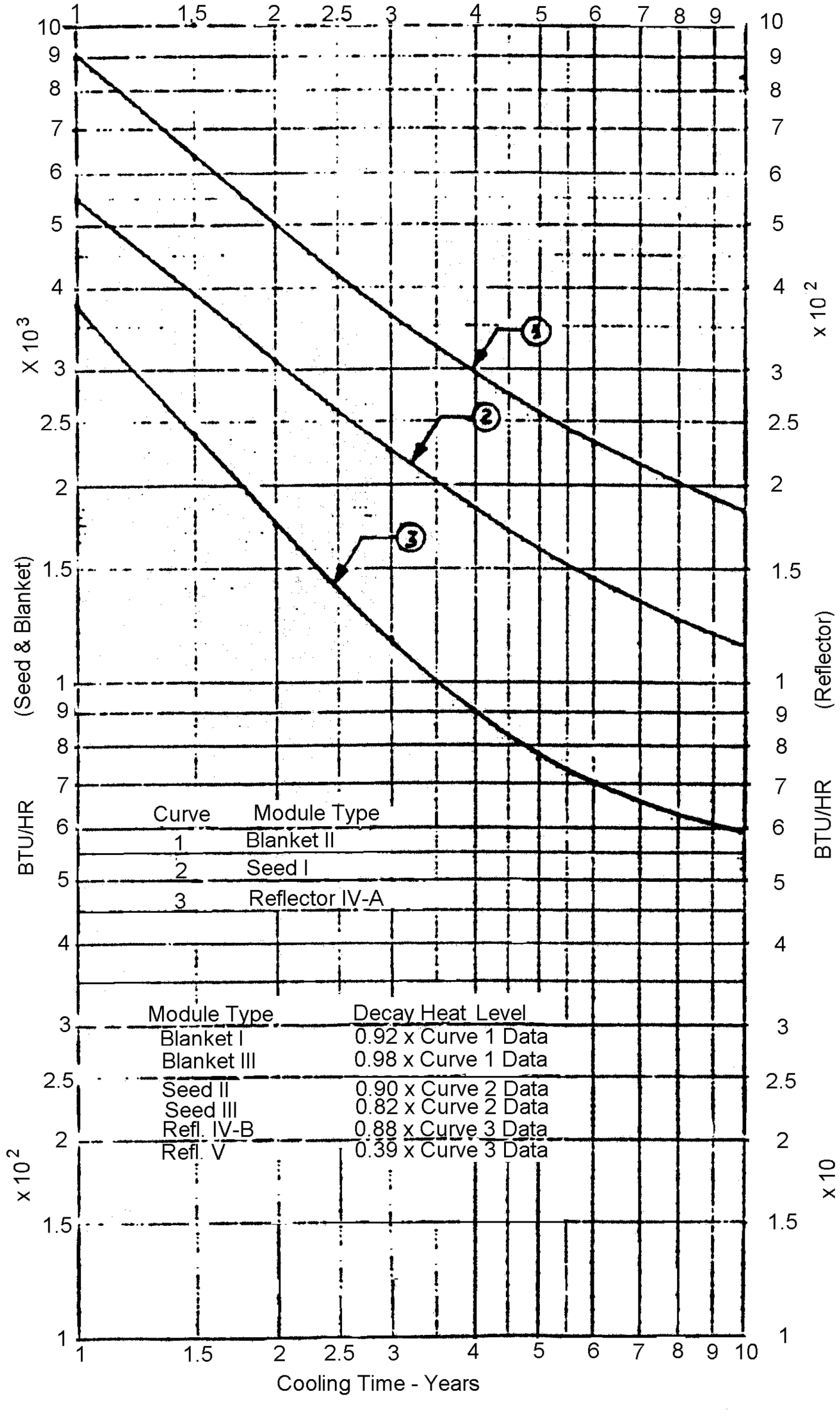

Figure 6-24. Decay heat as a function of cooling time for the hottest fully rodded seed, blanket, and reflector modules (attached to WAPD-NRF(L)C-104 [curve on p. 15, some discussion on p. 4-5], April 30, 1987, Fuel Receipt Criteria, Part B).

Table 6-4. Estimated decay heat values for Light Water Breeder Reactor core modules in the year 2005 (Sterbentz and Wahnschaffe, 2001).

Module Type	Decay Heat (Watts)
Single seed (Type I)	352.8
Standard blanket (Type I)	501.5
Standard/power flattening blanket (Type II)	517.1
Standard/power flattening blanket (Type III)	480.5
Reflector IV	9.62
Reflector V	4.7

must be internally dry and contain an inert atmosphere. A liner is defined as dry when all liquid water has been removed. The drying process was confirmed by checkout and testing of the LWBR Liner Closure Station dewatering equipment used on an actual fuel storage liner both at a vendor shop and at ECF. ECF will certify that the liner for each fuel handling unit is dry and contains the inert atmosphere as required." Pressure testing (hydrostatic test, neon and helium gas tests, and a hydraulic jack test) was conducted prior to shipment, and the completed certification checklists for each shipment, including shift supervisor and engineering checkoffs for "no liquid water in liner" are included in the Part C Fuel Receipt Criteria.

7. REFERENCES

Atherton, R. (coordinator), 1987, Water Cooled Breeder Program Summary Report (LWBR Development Program), WAPD-TM-1600, October 1987.

Beaudoin, B. R., 1987, *Loading Assurance Methods Used in the Manufacture of the Light Water Breeder Reactor (LWBR)*, WAPD-TM-1315, September 1987.

Budd, W. A. (ed.), 1986, *Shippingport Operations With the LWBR Core (LWBR Development Program)*, WAPD-TM-1542, March 1986.

Campbell, W. R., and J. F. Giovengo, 1987, *Light Water Breeder Reactor Fuel Rod Design and Performance Characteristics (LWBR Development Program)*, WAPD-TM-1387, October 1987.

Cole, L. N., 2001, *Shippingport LWBR Spent Nuclear Fuel Data for Transfer from CPP-749 to Spent Nuclear Fuel Dry Storage Project*, EDF-2875.

Conners, D. R., S. Milani, J. A. Fest, and R. Atherton, 1979, *Design of the Shippingport Light Water Breeder Reactor*, WAPD-TM-1208, January 1979.

DeGeorge, V. V., and I. Goldberg, eds., 1986, *The Fabrication and Loading of Fuel Rods for the Light Water Breeder Reactor (LWBR Development Program)*, WAPD-TM-1278, March 1986.

Eyler, J. H., 1981, *Development and Control of the Process for the Manufacture of Zircaloy-4 Tubing for LWBR Fuel Rods (LWBR Development Program)*, WAPD-TM-1289, January 1981.

Freeman, L. B. (ed.), 1978, *The Calculational Model Used in the Analysis of Nuclear performance of the Light Water Breeder Reactor (LWBR)*, WAPD-TM-1314, August 1978.

Fuel Receipt Criteria, Part A, sent from Westinghouse Electric Corporation LWBR Fuel Disassembly and Disposal Engineering, NRF Project to ECF LWBR Engineering at Naval Reactors Facility:

WAPD-NRF(L)D-96, August 10, 1987

WAPD-NRF(L)D-58, March 13, 1987

WAPD-NRF(L)D-5, September 22, 1986

WAPD-NRF(E)FD-09, Received March, 1985

WAPD-LP(CE)FD-38, October 12, 1984

Fuel Receipt Criteria, Part B sent from Westinghouse Electric Corporation to CPP-666 (listed alphabetically by letter number):

NRFE-LWBRE-1034, October 28, 1986

RDD-94-86 (transmittal letter from R.D. Denney, INEL, to R. E. Wilson, Manager, INEL Criticality Safety), transmitting WAPD-NRF(RE)FP-192, May 27, 1986

WAPD-NRF(E)-9, February 13, 1985

WAPD-NRF(L)-149, September 15, 1987

WAPD-NRF(L)C-104, April 30, 1987

WAPD-NRF(L)C-117, June 26, 1987

WAPD-NRF(L)C-123, July 8, 1987

WAPD-NRF(L)C-58, January 9, 1987

WAPD-NRF(L)C-93, March 26, 1987

WAPD-NRF(L)D-110, September 23, 1987

WAPD-NRF(RE)FP-132, December 6, 1985

WAPD-NRF(RE)FP-139, December 27, 1985

WAPD-NRF(RE)FP-192, May 27, 1986

Fuel Receipt Criteria, Part C (arranged by canister):

NRFE-LWBRE-863-21, August 29, 1986 and Shipment #21 (S-1-1) September 2, 1986

NRFE-LWBRE-863-12, Spril 17, 1986 and Shipment #14 (S-1-2), April 25, 1986

Shipment #15 (S-1-3), June 5, 1986

Shipment #38 (S-2-1), April 20, 1987

Shipment #16 [S-II-1 (sic)], June 12, 1986

Shipment #44 (S-2-3), July 31, 1987

Shipment #22 [S-III-I (sic)], September 12, 1986

Shipment #23 [S-III-2 (sic)], September 29, 1986

Shipment #17 (S-3-3), June 27, 1986

Shipment # not identified (S-3-4), May 2, 1986

Shipment #27 (S-3-5), November 24, 1986

Shipment #28 (S-3-6), December 23, 1986

Shipment #30 [B1-1 (sic)], January 29, 1987

Shipment #8 (B-1-2), March 19, 1986

Shipment #25 (B-1-3), November 3, 1986

Shipment #20 (B-2-1), August 25, 1986

Shipment #32 (B-2-2), March 9, 1987

Shipment #14 (B-2-3), May 28, 1986

Shipment #1 [B31 (sic)], December 12, 1985

Shipment #36 (B-3-2), April 2, 1987

Shipment #31 [B3-3 (sic)], February 5, 1987

Shipment #19 (B-3-4), August 8, 1986

Shipment #2 (B-3-5), December 12, 1985

Shipment #26 (B-3-6), November 14, 1986

Gorscak, D. A., W. R. Campbell, and J. C. Clayton, 1987, *End-Of-Life Nondestructive Examination of Light Water Breeder Reactor Fuel Rods (LWBR Development Program)*, WAPD-TM-1605, October 1987.

Graczyk, D. G., J. C. Hoh, F. J. Martino, R. E. Nelson, J. Osudar, and N. M. Levitz, 1987, *Final Report for the Light Water Breeder Reactor Proof-of-Breeding Analytical Support Project*, ANL-87-2.

Greenberger, R. J., and E. L. Miller, 1987, *Primary Disassembly of LWBR Modules for Core Evaluation (LWBR Development Program)*, WAPD-TM-1608, October 1987.

Hecker, H. C., 1979, *Summary of the Nuclear Design and Performance of the Light Water Breeder Reactor (LWBR)*, WAPD-TM-1326, June 1979.

Hecker, H. C., and L. B. Freeman, 1981, *Design Features of the Light Water Breeder Reactor Which Improve Fuel Utilization in LWRs (LWBR Development Program)*, WAPD-TM-1409, August 1981.

Hodges, B. W. (ed.), 1987, *Preparation of LWBR Spent Fuel for Shipment to ICPP for Long Term Storage (LWBR Development Program)*, WAPD-TM-1601, October 1987.

Idaho Nuclear Technology and Engineering Center (INTEC) Plant Safety Document, Section 4.7A, 2002, *Storage of Unirradiated and Irradiated Light Water Breeder Reactor Fuel in Underground Dry Wells at INTEC*, Rev. 3, July 17, 2002.

Massimino, R. J., and D. A. Williams, 1983, *The Installation of the Light Water Breeder Reactor at the Shippingport Atomic Power Station (LWBR Development Program)*, WAPD-TM-1342, May 1983.

Richardson, K. D., W. R. Campbell, J. C. Clayton, and B. C. Smith, 1987, *End of Life Destructive Examination of Light Water Breeder Reactor Fuel Rods*, WAPD-TM-1606, October 1987.

Sarber, W. K., 1983, *Reactor Physics Test Program for the Light Water Breeder Reactor (LWBR) Core at Shippingport (LWBR Development Program)*, WAPD-TM-1455, Addendum, December 1983.

Sarber, W. K., ed., 1976, *Results of the Initial Nuclear Tests on the LWBR (LWBR Development Program)*, WAPD-TM-1336, June 1976.

Schick, W. C., Jr., B. R. Beaudoin, W. J. Beggs, L. B. Freeman, and G. Tessler, 1987, *Proof of Breeding in the Light Water Breeder Reactor (LWBR Development Program)*, WAPD-TM-1612, September 1987.

Selsley, I. A., ed., 1987a, *Defueling of the Light Water Breeder Reactor at the Shippingport Atomic Power Station*, WAPD-TM-1551, September 1987.

Selsley, I. A., 1987b, *Shipment of the Light Water Breeder Reactor Fuel Assemblies from the Shippingport Atomic Power Station to the Expended Core Facility (Idaho)(LWBR Development Program)*, WAPD-TM-1553, October 1987.

Selsley, I. A. (ed.), 1987c, *Light Water Breeder Reactor Fuel Module Disassembly at the Shippingport Atomic Power Station (LWBR Development Program)*, WAPD-TM-1552, October 1987.

Sterbentz, J. W., 1999, *Validation Work to Support the Idaho National Engineering and Environmental Laboratory Calculational Burnup Methodology Using Shippingport Light Water Vreeder Reactor (LWBR) Spent Fuel Assay Data*, INEEL/EXT-99-00581, August 1999.

Sterbentz and Wahnschaffe (2001). Light Water Breeder Reactor (LWBR) Decay Heat Estimate Analysis. EDF 1781, rev. 1.

Tessler, G., B. R. Beaudoin, W. J. Beggs, L. B. Freeman, and W. C. Schick, 1987, *Nondestructive Assay of Spent Fuel Rods From the LWBR (LWBR Development Program)*, WAPD-TM-1614, September 1987.

Walter, J. F., and W. A. Weinreich, eds., 1976, *ThO_2 and ThO_2-$^{233}UO_2$ High Density Fuel Pellet Manufacture for the Light Water Breeder Reactor*, WAPD-TM-1244(L), January 1976.

Wargo, J. E., 1987, *Light Water Breeder Reactor End-of-Life Component Examinations at Shippingport Atomic Power Station and Module Visual and Dimensional Examinations at Expended Core Facility*, WAPD-TM-1602, October 1987.

Williams, J. T., 1987, *Light Water Breeder Reactor Core Evaluation Operations at the Expended Core Facility*, WAPD-TM-1611, October 1987.

Other References

Bacvinskas, W. S. (ed.), 1987, *Light Water Breeder Reactor Module and Rod Examinations LWBR Development Program,* WAPD-TM-1610, October 1987.

Beaudoin, B. R., W. J. Beggs, C. R. Case, and R. Wilczynski, 1979, *A System of Datatran Modules Which Process Core Fuel Loading for Use in As-Built Calculations (LWBR Development Program),* WAPD-TM-1316, February 1979.

Benton, Hugh, et al., 1997, Technical Strategy for the Management of Spent Nuclear Fuel, March 1997.

Berman, R. M., H. B. Meieran, and P. W. Patterson, 1967, *Irradiation Behavior of Zircaloy-Clad Fuel Rods Containing Dished-End UO_2 Pellets (LWB-LSBR Development Program),* WAPD-TM-629, July 1967.

Bolton, S. R., et al., ICPP Final Safety Analysis (Section 4.7) "Storage of Unirradiated and Irradiated Light Water Breeder Reactor Fuel in Underground Dry Wells at ICPP," WIN-107-4.7A-Rev. 1, March 1989.

Busby, C. C., and K. B. Marsh, 1970, *High Temperature Deformation and Burst Characteristics of Recrystallized Zircaloy-4 Tubing (LWBR Development Program),* WAPD-TM-900, January 1970.

Caffarel, A. J., 1979, *The Inspection of Assembled LWBR Fuel Rods for Internal Dimensions and Pellet Integrity Utilizing In-Motion Radiography (LWBR Development Program),* WAPD-TM-1239, February 1979.

Clayton, J. C., 1982, *Corrosion and Hydriding of Irradiated Zircaloy Fuel Rod Cladding (LWBR Development Program),* WAPD-TM-1440, September 1982.

Clayton, J. C., 1985, *Cladding Corrosion and Hydriding in Irradiated Defected Zircaloy Fuel Rods (LWBR Development Program),* WAPD-TM-1393, August 1985.

Clayton, J. C., 1987, *In-Pile and Out-of-Pile Corrosion Behavior of Thoria-Urania Pellets (LWBR Development Program),* WAPD-TM-1548, January 1987.

Daniel, R. C., 1971, *In-Pile Dimensional Changes of Zircaloy-4 Tubing Having Low Hoop Stresses (LWBR Development Program),* WAPD-TM-973, July 1971.

Duncombe, E., 1968, *Analysis of Void Migration, Clad Collapse and Fuel Cracking in Bulk Oxide Fuel Rods (LWBR Development Program),* WAPD-TM-794, July 1968.

Duncombe, E., and I. Goldberg, 1970, *Comparison of Dimensional Changes in Fuel Rods With Predictions Under Cyclic Conditions of Power and System Pressure (LWBR Development Program),* WAPD-TM-940, March 1970.

Duncombe, E., et al., *Comparisons With Experiment of Calculated Dimensional Changes and Failure Analysis of Irradiated Bulk Oxide Fuel Test Rods Using the CYGRO-1 Computer Program,* September 1966.

Emert, C. J., 1979, *The Nondestructive Assay of UO_2-ThO_2 Fuel Pellets Using the Delayed Neutron Pellet Assay Gauge (LWBR Development Program),* WAPD-TM-1368, June 1979.

Engel, J. T., and H. B. Meieran, 1968, *Performance of Fuel Rods Having 97 Percent Theoretical Density UO_2 Pellets Sheathed in Zircaloy-4 and Irradiated at Low Thermal Ratings (LSBR/LWBR Development Program)*, WAPD-TM-631, July 1968.

Eyler, J. H., 1979, *The Characteristics of the Zircaloy-4 Tubing in LWBR Fuel Rods (LWBR Development Program)*, WAPD-TM-869, November 1979.

Eyler, J. H., 1981, *Development and Control of the Process for the Manufacture of Zircaloy-4 Tubing for LWBR Fuel Rods*, WAPD-TM-1289, January 1981.

Fodor, G., 1987, *Light Water Breeder Reactor Rod Removal System (LWBR Development Program)*, WAPD-TM-1609, October 1987.

Galtz, C. S., 1983, *The Friction Grip Enclosure—A Means for Increasing the Fatigue Life of Fuel Rod End Welds (LWBR Development Program)*, WAPD-TM-1348, March 1983.

Giovengo, J. F., 1970, *In-Pile Dimensional Changes of ThO_2-UO_2 With Non-Free-Standing Cladding (LWBR Development Program)*, WAPD-TM-986, November 1970.

Giovengo, J. F., I. Goldberg, and G. L. Spahr, 1982, *Fission Gas Release From High Burnup ThO_2 and ThO_2-UO_2 Fuels Irradiated at Low Temperature (LWBR/AWBA Development Program)*, WAPD-TM-1350, Addendum 2, May 1982.

Goldberg, I., L. A. Walman, J. F. Giovengo, and W. R. Campbell, 1979, *Fission Gas Release and Grain Growth in ThO_2-UO_2 Fuel Irradiated at High Temperature (LWBR Development Program)*, WAPD-TM-1350, Addendum, July 1979.

Gourley, B. R. (ed.), 1981, *Fabrication of Seed, Blanket and Reflector Fuel Assemblies for the Light Water Breeder Reactor (LWBR Development Program)*, WAPD-TM-1317, May 1981.

Green, S. J., et al., 1969, *Critical Heat Flux Tests on a Coolant Channel Simulating a Closely Spaced Lattrice of Rods (LWBR Development Program)*, WAPD-TM-466, March 1969.

Hecker, H. C., 1984, *Nuclear Analysis and Performance of the Light Water Breeder Reactor (LWBR) Core Power Operation at Shippingport (LWBR Development Program)*, WAPD-TM-1376, April 1984.

Hecker, H. C., and C. J. Simon, 1984, Idaho Chemical Processing Plant Part A Fuel Receipt Criteria for the LWBR Core, WAPD-LP(CE)FD-38 attachment, October 1984.

Hecker, H. C., and C. J. Simon, 1985, ICPP Fuel Receipt Criteria (Part A) for the LWBR Core (Rev. 3), WAPD-NRF(E)FD-09 attachment, January 1985.

Hersey, B. A., and H. B. Meieran, 1969, *Behavior of an Intentionally Defected Fuel Rod Which Ruptured During Irradiation (Rod BETT 79-64D) (LWBR Development Program)*, WAPD-TM-628, July 1969.

Hoffman, R. C., and J. Sherman, 1978, *Irradiation Testing of Internally Pressurized and/or Graphite Coated Zircaloy-4 Clad Fuel Rods in the NRX Reactor (LWBR Development Program)*, WAPD-TM-1421, November 1978.

Hoffman, R. C., J. F. Yerman, and T. H. Alff, 1982, *Experimental Results of the Irradiation of Long Rod Duplex Pellet Screening Tests in the NRX Reactor (NLDR-1 Test) (AWBA Development Program)*, WAPD-TM-1492, July 1982.

I. Goldberg, I., C. L. Spahr, L. S. White, L. A. Waldman, J. F. Giovengo, P. L. Pfenningwerth, and J. Sherman, 1978, *Fission Gas Release From ThO_2 and ThO_2-UO_2 Fuels (LWBR Development Program)*, WAPD-TM-1350, August 1978.

Ivak, D. M., and L. A. Waldman, 1979, *Iodine and Cesium in Oxide Fuel Pellets and Zircaloy-4 Cladding of Irradiated Fuel Rods (LWBR Development Program)*, WAPD-TM-1394, March 1979.

Jacobs, D. C., 1969, *The In-Pile Thermoconductivity of Selected ThO_2-UO_2 Fuels at Low Depletions (LWBR Development Program)*, WAPD-TM-758. May 1969.

Jacobs, D. C., 1970, *In-Pile and Unirradiated Thermal Conductivity of a Single-Fired ThO_2 + 10 w/o UO_2, (LWBR Development Program)*, WAPD-TM-901, February 1970.

Kass, S., 1968, *Effects of Pressure Upon the Corrosion of Zircaloy-4 (LWBR Development Program)*, WAPD-TM-782, October 1968.

Kass, S., 1970, *The Influence of Prior Corrosion History Upon the Hydrogen Pickup by Zircaloy During Subsequent Exposure in Hot Water (LWBR Development Program)*, WAPD-TM-906, December 1970.

Kotula, J., 1979, *LWBR Automated Fuel Rod Loading Verification Gage System (LWBR Development Program)*, WAPD-TM-1226, February 1979.

Markowitz, J. M., and J. C. Clayton, 1970, *Corrosion of Oxide Nuclear Fuels in High Temperature Water (LWBR Development Program)*, WAPD-TM-909, February 1970.

McCauley, J. E., 1969, *Observations on the Irradiation Behavior of a Zircaloy-4 Clad Rod Containing Low Density ThO_2-5.3 w/o UO_2 Pellets (LWBR Development Program)*, WAPD-TM-664, December 1969.

Meieran, H. B., W. F. Bourgeois, and J. T. Engel, 1968, *Short Term Irradiation of Zircaloy-4 Clad Fuel Rods Containing Low Density or Annular ZrO_2-UO_2 Ceramic Fuel Pellets: X-1-t Test (LWBR-LSBR Development Program)*, WAPD-TM-630, June 1968.

Milani, S. and S. H. Weiss, 1967, *Small Uranium-233 Fueled Seed-and-Blanket Critical Experiments (LWBR-LSBR Development Program)*, WAPD-TM-614, November 1967.

Mitchell, J. A. (ed.), 1975, *BMU Series of ^{233}U Fueled Critical Experiments (LWBR Development Program)*, WAPD-TM-1117, January 1975.

Smith, B. C. (ed.), 1987, *End-of-Life Examinations of Light Water Breeder Reactor Grids and Other Module Structural Components (LWBR Development Program)*, WAPD-TM-1607, October 1987.

Smith, B. C., and W. R. Campbell, 1987, *Light Water Breeder Reactor Fuel Element Performance Characteristics for Extending Core Lifetime (LWBR Development Program)*, WAPD-TM-1603, October 1987.

Smithnosky, A. J., 1982, *In-Reactor Tests of Externally Pressurized, Short, Unsupported Lengths of Zircaloy Tubing (AWBA Development Program)*, WAPD-TM-1529, October 1982.

Sphar, C. D., and J. Sherman, 1979, *Early-In-Life Performance of Short Rod Duplex Pellet Screening (D-1) Test (AWBA Development Program)*, WAPD-TM-1378, November 1979.

Sphar, C. D., D. A. Mertz, W. S. Roesener, 1982, *Irradiation Performance of Duplex Fuel Pellet Test Rods Depleted to* 9×10^{20} *Fissions/*cm^3 *of Compartment - D-1 Test (AWBA Development Program)*, WAPD-TM-1460, January 1982.

Springer, J. R., et al., 1967, *Fabrication, Characterization, and Thermal-Property Measurements of* ThO_2-UO_2 *Fuel Materials (LWBR Development Program)*, BMI-X-1020, October 1967.

Stackhouse, R. M. (ed.), 1979, *Fuel Rod Grid Interaction Wear: In-Reactor Tests (LWBR Development Program)*, WAPD-TM-1347, November 1979.

Stooksberry, R. W., 1979, *Conceptual Evaluation of Nondestructive Assay of* $^{233}UO_2$-ThO_2 *Fuel Rods (LWBR Development Program)*, WAPD-TM-1256, January 1979.

Technical Specifications/Standards: 4.7B4 "Integrity of Storage Canisters and Canister Lifting Tools for Dry Well Storage of LWBR Fuels"; 4.7B6 "Spare Dry Well Requirement for LWBR Fuel Storage"; 4.7B7 "Handling of LWBR Fuel Storage Canisters—Peach Bottom Transfer Cask"; 4.7C2 "Surveillance of the LWBR Fuel Storage Dry Wells."

Waldman, L. A., C. D. Sphar, and T. H. Alff, 1982, *Irradiation Performance of Long Rod Duplex Fuel Pellet Bundle Test -LDR Test (LWBR Development Program)*, WAPD-TM-1481, April 1982.

Wargo, J. E., and K. D. Richardson, 1987, *Light Water Breeder Reactor End-Of-Life Component Examinations at Shippingport Atomic Power Station and Module Visual and Dimensional Examinations at the Expended Core Facility (LWBR Development Program)*, WAPD-TM-1602, October 1987.

Appendix A

End-of-Life Fissile Data from the Production Irradiated Fuel Assay Gauge (PIFAG)

Appendix A

End-of-Life Fissile Data from the Production Irradiated Fuel Assay Gauge (PIFAG)

The following tables were copied from Tessler et al. 1987, WAPD-TM-1614, for convenience. The pages have not been altered, and retain the table numbers inherent from the original report. Rod numbers correspond to the rod types noted in Figures 3-2, 3-3, 3-6, 3-7, 3-9 and 3-10 in INEEL-EXT-98-00799, *Fuel Summary Report: Shippingport Light Water Breeder Reactor.*

Table 26

Seed Module I-1 Fissile Fuel Loadings in Grams

		PIFAG Thermal			PIFAG Epithermal			Epithermal - Thermal
			Standard Deviation			Standard Deviation		
Rod No.	As-Built Loading	Loading	Grams	%	Loading	Grams	%	Percent Difference
0502228	34.668	25.682	0.075	0.29	25.712	0.095	0.37	+0.11
0507057	34.682	25.398	0.071	0.28	25.665	0.045	0.18	+0.26
0603327	34.551	25.481	0.072	0.28	25.372	0.065	0.26	-0.43
0605269	34.494	25.224	0.073	0.29	25.245	0.070	0.28	+0.08
0603464	34.566	25.202	0.075	0.30	25.336	0.070	0.27	+0.53
0604519	34.164	25.133	0.074	0.29	25.182	0.069	0.27	+0.19
0603289	34.440	25.353	0.074	0.29	25.317	0.064	0.25	-0.14
0501128	34.646	25.153	0.080	0.32	25.296	0.070	0.28	+0.57
0600577	34.149	24.741	0.073	0.29	24.787	0.068	0.28	+0.18
0607184	34.446	24.830	0.074	0.30	24.827	0.072	0.29	-0.01
0601504	34.222	24.837	0.072	0.29	24.813	0.069	0.28	-0.10
0501779	34.740	24.240	0.075	0.31	24.291	0.071	0.29	+0.21
0501265	34.373	24.476	0.075	0.31	24.494	0.070	0.28	+0.07
0504648	34.702	24.802	0.072	0.29	24.871	0.065	0.26	+0.28
0606681	34.248	24.069	0.080	0.33	24.141	0.072	0.30	+0.30
0608165	34.648	24.115	0.075	0.31	24.245	0.079	0.32	+0.54
0608313	34.420	23.389	0.077	0.33	23.387	0.065	0.28	-0.01
0605572	34.468	23.720	0.077	0.32	23.825	0.065	0.27	+0.44
0606378	34.407	23.883	0.087	0.36	23.902	0.069	0.29	+0.08
0606461	34.542	24.098	0.076	0.32	24.120	0.082	0.34	+0.09
0500082	34.594	23.426	0.078	0.33	23.431	0.072	0.31	+0.02
0507333	34.679	23.042	0.083	0.36	23.106	0.070	0.30	+0.28
0504042	34.604	22.949	0.078	0.34	22.964	0.050	0.22	+0.07
0507782	34.710	23.510	0.078	0.33	23.668	0.080	0.34	+0.67
0404355	23.903	17.282	0.066	0.38	17.346	0.069	0.40	+0.37
0401744	23.697	17.449	0.065	0.37	17.523	0.043	0.24	+0.42
0302578	19.055	15.498	0.061	0.39	15.556	0.069	0.45	+0.38
0307602	19.179	15.635	0.057	0.36	15.684	0.039	0.25	+0.32
0700219	14.255	14.166	0.049	0.35	14.225	0.059	0.41	+0.42
0201562	14.219	13.910	0.050	0.36	13.993	0.037	0.26	+0.60
0200343	14.347	14.219	0.048	0.34	14.231	0.062	0.44	+0.09
0211224	14.253	14.012	0.055	0.39	13.995	0.054	0.39	-0.12
0100821	14.310	13.969	0.055	0.39	13.927	0.054	0.39	-0.30

Table 27

Seed Module II-3 Fissile Fuel Loadings in Grams

		PIFAG Thermal			PIFAG Epithermal			Epithermal - Thermal Percent Difference
			Standard Deviation			Standard Deviation		
Rod No.	As-Built Loading	Loading	Grams	%	Loading	Grams	%	
0518387	34.602	26.377	0.071	0.27	26.468	0.103	0.39	+0.34
0524623	34.688	26.544	0.061	0.23	26.584	0.079	0.30	+0.15
0626528	34.694	26.357	0.069	0.26	26.514	0.087	0.33	+0.59
0626573	34.865	26.488	0.068	0.26	26.687	0.099	0.37	+0.75
0610818	34.536	26.381	0.067	0.26	26.557	0.086	0.32	+0.67
0631800	34.836	26.779	0.075	0.28	26.880	0.086	0.32	+0.38
0623860	34.871	26.545	0.068	0.26	26.555	0.087	0.33	+0.04
0615739	34.623	25.999	0.075	0.29	26.182	0.084	0.32	+0.70
0624465	34.705	26.159	0.069	0.26	26.182	0.091	0.35	+0.09
0615409	34.582	26.406	0.077	0.29	26.393	0.088	0.33	-0.05
0623724	34.321	26.371	0.064	0.24	26.283	0.082	0.31	-0.33
0614648	34.634	26.420	0.076	0.29	26.464	0.090	0.34	+0.17
0531737	34.536	26.428	0.059	0.22	26.549	0.084	0.32	+0.46
0628315	34.763	25.744	0.077	0.30	25.728	0.121	0.47	-0.06
0532763	34.540	25.120	0.070	0.28	25.277	0.111	0.44	+0.62
0535466	34.602	25.919	0.060	0.23	26.092	0.084	0.32	+0.67
0622532	34.793	24.651	0.070	0.28	24.680	0.085	0.34	+0.12
0610607	34.336	24.535	0.069	0.28	24.502	0.096	0.39	-0.13
0610239	34.573	25.092	0.071	0.28	25.226	0.084	0.33	+0.54
0624382	34.819	25.597	0.064	0.25	25.804	0.084	0.33	+0.81
0618516	34.821	25.528	0.062	0.24	25.566	0.084	0.33	+0.15
0528325	34.187	23.616	0.076	0.32	23.599	0.085	0.36	-0.07
0536622	34.637	24.279	0.071	0.29	24.419	0.102	0.42	+0.58
0527703	34.446	24.693	0.065	0.26	24.744	0.083	0.34	+0.20
0535154	34.553	24.321	0.065	0.27	24.345	0.084	0.35	+0.10
0411534	23.967	17.829	0.070	0.39	17.860	0.071	0.40	+0.18
0411056	24.033	17.980	0.052	0.29	18.057	0.067	0.37	+0.43
0315310	19.120	15.670	0.070	0.45	15.773	0.080	0.51	+0.66
0312083	19.151	15.734	0.057	0.36	15.748	0.078	0.50	+0.09
0217061	14.350	14.065	0.046	0.33	14.181	0.067	0.47	+0.83
0202635	14.342	14.056	0.045	0.32	14.174	0.078	0.55	+0.84
0705084	14.225	14.208	0.044	0.31	14.267	0.105	0.74	+0.41
0216356	14.371	14.023	0.051	0.36	14.099	0.069	0.49	+0.54
0106614	14.268	13.762	0.042	0.30	13.805	0.062	0.45	+0.31

Table 28

Seed Module III-1 Fissile Fuel Loadings in Grams

Rod No.	As-Built Loading	PIFAG Thermal Loading	PIFAG Thermal Standard Deviation Grams	PIFAG Thermal Standard Deviation %	PIFAG Epithermal Loading	PIFAG Epithermal Standard Deviation Grams	PIFAG Epithermal Standard Deviation %	Epithermal - Thermal Percent Difference
0600633	34.439	27.188	0.076	0.28	27.182	0.083	0.31	-0.02
0505362	34.610	27.191	0.072	0.26	27.298	0.077	0.28	+0.40
0608349	34.699	27.617	0.063	0.23	27.667	0.071	0.26	+0.18
0506388	34.128	26.741	0.059	0.22	26.776	0.067	0.25	+0.13
0507039	34.636	26.978	0.061	0.23	27.026	0.067	0.25	+0.18
0510139	34.726	27.241	0.074	0.27	27.382	0.067	0.25	+0.52
0502200	34.596	27.444	0.058	0.21	27.603	0.068	0.25	+0.58
0602108	34.555	27.024	0.055	0.20	26.982	0.067	0.25	-0.16
0604876	34.524	26.729	0.057	0.21	26.714	0.067	0.25	-0.06
0603684	34.529	26.672	0.058	0.22	26.615	0.110	0.41	-0.21
0604472	34.544	27.316	0.057	0.21	27.487	0.067	0.24	+0.63
0506206	34.442	26.329	0.070	0.27	26.314	0.070	0.27	-0.06
0504363	34.596	27.309	0.063	0.23	27.542	0.066	0.24	+0.85
0508617	34.622	27.157	0.056	0.21	27.302	0.066	0.24	+0.54
0500385	34.463	26.270	0.060	0.23	26.288	0.067	0.25	+0.07
0501808	34.735	26.275	0.068	0.26	26.325	0.068	0.26	+0.19
0506453	34.341	25.703	0.061	0.24	25.825	0.078	0.30	+0.47
0502585	34.242	26.928	0.058	0.22	27.020	0.066	0.24	+0.34
0600430	34.518	25.321	0.064	0.25	25.360	0.063	0.25	+0.15
0602878	34.292	25.451	0.065	0.26	25.666	0.103	0.40	+0.85
0503622	34.390	24.827	0.064	0.26	24.860	0.067	0.27	+0.13
0504556	34.426	24.681	0.068	0.27	24.784	0.079	0.32	+0.41
0508451	34.726	25.104	0.062	0.25	25.078	0.067	0.27	-0.10
0508671	34.674	26.276	0.057	0.22	26.391	0.081	0.31	+0.44
0508516	34.736	25.975	0.059	0.23	26.012	0.061	0.23	+0.14
0407702	23.897	18.124	0.056	0.31	18.102	0.060	0.33	-0.12
0400083	23.813	18.763	0.047	0.25	18.774	0.057	0.30	+0.06
0302845	19.141	15.917	0.049	0.31	15.983	0.054	0.34	+0.42
0302203	19.132	15.778	0.050	0.32	15.785	0.055	0.35	+0.04
0203652	14.232	14.196	0.037	0.26	14.224	0.039	0.27	+0.20
0201342	14.300	14.276	0.031	0.22	14.316	0.052	0.36	+0.28
0701153	14.250	14.208	0.039	0.27	14.076	0.050	0.35	-0.93
0100683	14.332	13.835	0.041	0.29	13.982	0.051	0.36	+1.06
0102609	14.240	13.765	0.039	0.29	13.681	0.052	0.38	-0.62

Table 29

Seed Module III-2 Fissile Fuel Loadings in Grams

		PIFAG Thermal			PIFAG Epithermal			Epithermal - Thermal
			Standard Deviation			Standard Deviation		Percent
Rod No.	As-Built Loading	Loading	Grams	%	Loading	Grams	%	Difference
0537510	34.843	27.282	0.057	0.21	27.455	0.066	0.24	+0.63
0627076	34.534	27.507	0.063	0.23	27.579	0.066	0.24	+0.26
0537069	34.828	27.287	0.063	0.23	27.462	0.061	0.22	+0.64
0518333	34.501	27.086	0.060	0.22	27.065	0.057	0.21	-0.08
0606874	34.529	27.055	0.086	0.32	27.146	0.067	0.25	+0.34
0607561	34.466	26.585	0.075	0.28	26.785	0.067	0.25	+0.75
0601558	34.513	27.347	0.055	0.20	27.430	0.065	0.24	+0.30
0615216	34.483	27.465	0.054	0.20	27.576	0.083	0.30	+0.40
0516133	34.378	26.706	0.062	0.23	26.820	0.057	0.21	+0.43
0532120	34.815	26.747	0.062	0.23	26.881	0.061	0.23	+0.50
0536272	34.582	26.832	0.095	0.35	27.093	0.061	0.23	+0.97
0622889	34.474	26.632	0.057	0.21	26.666	0.061	0.23	+0.13
0618543	34.474	26.526	0.057	0.22	26.671	0.076	0.29	+0.54
0610275	34.438	27.157	0.055	0.20	27.244	0.065	0.24	+0.32
0608753	34.655	27.225	0.058	0.21	27.423	0.069	0.25	+0.73
0511625	34.596	26.484	0.061	0.23	26.552	0.053	0.20	+0.25
0517269	34.696	26.925	0.055	0.21	26.960	0.066	0.25	+0.13
0613676	34.686	25.860	0.061	0.23	25.774	0.072	0.28	-0.34
0630680	34.478	25.312	0.062	0.25	25.410	0.066	0.26	+0.39
0617865	34.321	26.257	0.056	0.21	26.464	0.089	0.34	+0.79
0624824	34.702	26.671	0.052	0.19	26.735	0.064	0.24	+0.24
0524302	34.636	25.012	0.067	0.27	25.121	0.060	0.24	+0.43
0526336	34.626	24.567	0.073	0.30	24.543	0.067	0.27	-0.10
0531728	34.516	24.768	0.065	0.26	24.758	0.078	0.31	-0.04
0523779	34.542	25.727	0.075	0.29	25.775	0.064	0.25	+0.19
0412652	23.966	18.064	0.056	0.31	18.072	0.049	0.27	+0.04
0408755	23.981	18.835	0.050	0.27	18.915	0.053	0.28	+0.42
0314384	19.179	15.842	0.051	0.32	15.879	0.054	0.34	+0.23
0315127	19.187	16.359	0.041	0.25	16.442	0.076	0.46	+0.50
0207428	14.292	14.220	0.042	0.29	14.379	0.051	0.35	+1.12
0202525	14.154	14.255	0.032	0.23	14.199	0.049	0.34	-0.39
0105624	14.445	14.087	0.046	0.32	14.081	0.051	0.36	-0.04
0106089	14.435	14.000	0.040	0.28	14.018	0.045	0.32	+0.13

Table 30

Blanket Module I-3 RB Rod Fissile Fuel Loadings in Grams

		PIFAG Thermal			PIFAG Epithermal			Epithermal - Thermal
			Standard Deviation			Standard Deviation		
Rod No.	As-Built Loading	Loading	Grams	%	Loading	Grams	%	Percent Difference
1208078	16.473	36.219	0.091	0.25	36.221	0.110	0.30	+0.00
1200665	16.442	36.058	0.090	0.25	35.997	0.103	0.29	-0.17
1200500	16.458	35.899	0.088	0.25	35.847	0.104	0.29	-0.14
1200830	16.454	36.884	0.097	0.26	36.796	0.081	0.22	-0.24
1107750	16.488	36.848	0.098	0.27	36.829	0.112	0.30	-0.05
1105477	16.502	35.122	0.081	0.23	35.387	0.101	0.29	+0.76
1208042	16.440	34.852	0.078	0.22	34.910	0.086	0.25	+0.16
1107623	16.469	34.967	0.082	0.23	34.787	0.092	0.27	-0.51
1103700	16.493	34.980	0.081	0.23	35.239	0.083	0.24	+0.74
1206347	16.461	35.341	0.083	0.23	35.469	0.094	0.27	+0.36
1106844	16.471	35.875	0.087	0.24	35.874	0.096	0.27	-0.00
1401166	30.494	40.877	0.091	0.22	40.902	0.128	0.31	+0.06
1400544	30.673	40.711	0.091	0.22	40.756	0.072	0.18	+0.11
1404356	30.051	40.043	0.099	0.25	40.404	0.133	0.33	+0.90
1411479	30.006	40.477	0.105	0.26	40.538	0.122	0.30	+0.15
1407187	30.515	41.183	0.106	0.26	41.345	0.109	0.26	+0.39
1306584	45.527	47.179	0.121	0.26	47.226	0.136	0.29	+0.10
1311738	45.432	47.107	0.118	0.25	47.177	0.140	0.30	+0.15
1302864	45.461	47.355	0.128	0.27	47.384	0.113	0.24	+0.06
1302873	45.443	47.397	0.128	0.27	47.430	0.132	0.28	+0.07
1311811	45.433	47.463	0.121	0.26	47.648	0.142	0.30	+0.39
1307152	45.427	47.749	0.149	0.31	47.709	0.166	0.35	-0.08
1510589	45.798	48.379	0.121	0.25	48.446	0.123	0.25	+0.14
1507058	45.808	47.928	0.117	0.24	47.957	0.118	0.25	+0.06
1506683	45.836	48.188	0.116	0.24	48.155	0.142	0.29	-0.07
1500386	45.752	48.422	0.142	0.29	48.437	0.126	0.26	+0.03
1500846	45.779	48.682	0.133	0.27	48.779	0.144	0.30	+0.20
1500157	45.808	48.491	0.129	0.27	48.279	0.127	0.26	-0.44
1503742	45.653	48.463	0.152	0.31	48.439	0.126	0.26	-0.05
1605876	54.491	52.386	0.123	0.23	52.576	0.148	0.28	+0.36
1612357	54.471	52.526	0.178	0.34	52.704	0.148	0.28	+0.34
1606278	54.452	52.512	0.152	0.29	52.636	0.159	0.30	+0.24
1605519	54.553	52.514	0.154	0.29	52.471	0.146	0.28	-0.08
1604318	54.748	52.542	0.138	0.26	52.705	0.158	0.30	+0.31
1604758	54.540	52.576	0.136	0.26	52.812	0.150	0.28	+0.45
1610157	54.503	52.579	0.133	0.25	52.602	0.180	0.34	+0.04

Table 31

Blanket Module II-2 RB Rod Fissile Fuel Loadings in Grams

		PIFAG Thermal			PIFAG Epithermal			Epithermal - Thermal Percent
			Standard Deviation			Standard Deviation		
Rod No.	As-Built Loading	Loading	Grams	%	Loading	Grams	%	Difference
1210125	16.463	36.098	0.089	0.25	35.880	0.094	0.26	-0.60
1210226	16.484	35.977	0.091	0.25	35.804	0.086	0.24	-0.48
1103672	16.379	35.854	0.095	0.27	35.784	0.108	0.30	-0.19
1208657	16.475	34.293	0.076	0.22	34.260	0.100	0.29	-0.10
1106137	16.480	33.513	0.070	0.21	33.608	0.116	0.35	+0.28
1106586	16.457	34.134	0.078	0.23	33.948	0.109	0.32	-0.54
1104525	16.403	34.882	0.081	0.23	34.959	0.121	0.35	+0.22
1102470	16.404	33.962	0.075	0.22	33.954	0.109	0.32	-0.02
1404668	30.083	39.917	0.099	0.25	39.980	0.120	0.30	+0.16
1412846	30.607	40.829	0.105	0.26	40.960	0.159	0.39	+0.32
1407748	30.248	40.012	0.098	0.25	40.032	0.145	0.36	+0.05
1402660	30.038	39.462	0.092	0.23	39.319	0.117	0.30	-0.36
1303248	45.523	46.165	0.110	0.24	46.457	0.179	0.39	+0.63
1302579	45.273	46.937	0.121	0.26	47.344	0.160	0.34	+0.87
1311334	45.511	47.133	0.140	0.30	47.683	0.192	0.40	+1.17
1305787	45.408	46.736	0.108	0.23	46.968	0.163	0.35	+0.50
1505363	45.489	47.766	0.112	0.23	47.806	0.112	0.23	+0.09
1504658	45.754	48.090	0.122	0.25	47.943	0.140	0.29	-0.31
1507619	45.679	48.454	0.133	0.27	48.376	0.176	0.36	-0.16
1504667	45.638	47.729	0.116	0.24	47.829	0.135	0.28	+0.21
1608083	54.657	51.750	0.112	0.22	52.121	0.136	0.26	+0.72
1603676	54.855	52.624	0.133	0.25	52.883	0.157	0.30	+0.49
1607479	54.600	52.492	0.132	0.25	52.784	0.182	0.35	+0.56
1602181	54.636	52.628	0.131	0.25	52.831	0.166	0.31	+0.39

Table 32

Blanket Module III-2 RB Rod Fissile Fuel Loadings in Grams

		PIFAG Thermal			PIFAG Epithermal			Epithermal - Thermal Percent Difference
			Standard Deviation			Standard Deviation		
Rod No.	As-Built Loading	Loading	Grams	%	Loading	Grams	%	
1105102	16.460	33.860	0.076	0.23	33.778	0.103	0.30	-0.24
1103012	16.425	34.105	0.076	0.22	34.072	0.104	0.30	-0.10
1207520	16.437	33.727	0.070	0.21	33.774	0.103	0.30	+0.14
1203709	16.389	33.824	0.113	0.33	33.868	0.103	0.30	+0.13
1100767	16.477	33.741	0.090	0.27	33.527	0.101	0.30	-0.63
1103460	16.394	32.532	0.075	0.23	32.497	0.100	0.31	-0.11
1402542	30.639	39.894	0.091	0.23	39.849	0.112	0.28	-0.11
1401828	30.192	39.566	0.091	0.23	39.716	0.103	0.26	+0.38
1410316	30.029	38.283	0.078	0.20	38.356	0.107	0.28	+0.19
1310187	45.413	46.101	0.109	0.24	46.110	0.125	0.27	+0.02
1310472	45.393	46.852	0.110	0.23	46.775	0.132	0.28	-0.16
1303872	45.563	47.082	0.115	0.24	47.246	0.163	0.34	+0.35
1514365	45.736	47.829	0.125	0.26	47.660	0.172	0.36	-0.35
1513339	45.714	48.186	0.117	0.24	48.227	0.148	0.31	+0.08
1511469	45.735	47.058	0.106	0.23	47.190	0.122	0.26	+0.28
1607416	54.562	51.499	0.110	0.21	51.608	0.133	0.26	+0.21
1607075	54.546	52.264	0.116	0.22	52.389	0.138	0.26	+0.24
1615502	54.667	52.743	0.125	0.24	52.512	0.142	0.27	-0.44

Table 33

Blanket Module III-6 RB Rod Fissile Fuel Loadings in Grams

		PIFAG Thermal			PIFAG Epithermal			Epithermal - Thermal Percent Difference
			Standard Deviation			Standard Deviation		
Rod No.	As-Built Loading	Loading	Grams	%	Loading	Grams	%	
1204542	16.457	34.555	0.084	0.24	34.721	0.108	0.31	+0.48
1200344	16.439	34.673	0.086	0.25	34.612	0.119	0.34	-0.18
1103443	16.450	34.117	0.079	0.23	34.134	0.127	0.37	+0.05
1101059	16.487	32.896	0.070	0.21	32.999	0.092	0.28	+0.31
1103315	16.399	33.108	0.076	0.23	32.994	0.094	0.29	-0.34
1104800	16.508	33.843	0.077	0.23	33.829	0.104	0.31	-0.04
1401882	30.705	38.748	0.085	0.22	38.943	0.110	0.28	+0.50
1404448	30.475	39.888	0.092	0.23	39.845	0.130	0.33	-0.11
1410646	30.523	38.704	0.082	0.21	38.891	0.129	0.33	+0.48
1306117	45.353	46.296	0.108	0.23	46.276	0.129	0.28	-0.04
1308564	45.529	46.917	0.118	0.25	47.065	0.169	0.36	+0.32
1305724	45.584	46.880	0.118	0.25	46.912	0.172	0.37	+0.07
1507545	45.760	47.751	0.109	0.23	47.770	0.117	0.25	+0.04
1513265	45.581	48.214	0.120	0.25	48.080	0.159	0.33	-0.28
1512486	45.619	47.736	0.111	0.23	47.815	0.125	0.26	+0.17
1603483	54.704	52.461	0.127	0.24	52.625	0.147	0.28	+0.31
1613457	54.482	52.333	0.135	0.26	52.640	0.178	0.34	+0.59
1601164	54.671	51.791	0.113	0.22	52.031	0.138	0.27	+0.46

Table 34

Blanket Module II-2 PFB Rod Fissile Fuel Loadings in Grams

Rod No.	As-Built Loading	PIFAG Thermal			PIFAG Epithermal			Epithermal - Thermal Percent Difference
			Standard Deviation			Standard Deviation		
		Loading	Grams	%	Loading	Grams	%	
2104416	18.977	31.138	0.086	0.28	31.054	0.131	0.42	-0.27
2103352	18.997	31.004	0.085	0.28	30.808	0.150	0.49	-0.63
2102225	18.985	30.632	0.086	0.28	30.606	0.096	0.31	-0.08
2102077	18.894	30.799	0.085	0.28	30.723	0.106	0.35	-0.25
2100245	18.925	30.416	0.079	0.26	30.415	0.087	0.29	-0.01
2405522	30.723	34.446	0.076	0.22	34.588	0.104	0.30	+0.41
2400287	30.771	35.286	0.109	0.31	35.228	0.101	0.29	-0.16
2406153	30.751	34.955	0.094	0.27	34.785	0.094	0.27	-0.49
2304138	52.563	45.815	0.129	0.28	45.864	0.147	0.32	+0.11
2303552	52.787	46.012	0.116	0.25	45.904	0.117	0.25	-0.23
2303560	52.787	45.919	0.110	0.24	46.031	0.128	0.28	+0.24
2610223	62.732	54.709	0.111	0.20	54.921	0.118	0.21	+0.39
2613505	63.183	54.060	0.115	0.21	54.309	0.128	0.24	+0.46
2610205	63.037	52.424	0.127	0.24	52.433	0.132	0.25	+0.02
2607600	63.042	51.687	0.135	0.26	51.714	0.128	0.25	+0.05
2620655	63.103	53.790	0.112	0.21	53.901	0.162	0.30	+0.21
2606389	62.571	53.904	0.107	0.20	53.962	0.118	0.22	+0.11
2504834	63.032	56.303	0.111	0.20	56.602	0.122	0.22	+0.53
2516759	63.108	54.553	0.121	0.22	54.547	0.121	0.22	-0.01
2517289	62.944	54.104	0.120	0.22	54.521	0.129	0.24	+0.77
2505025	63.122	53.928	0.124	0.23	54.027	0.137	0.25	+0.18
2518371	63.061	54.772	0.111	0.20	54.851	0.126	0.23	+0.14
2614769	63.115	54.475	0.113	0.21	54.791	0.113	0.21	+0.58
2610883	63.105	53.451	0.123	0.23	53.416	0.103	0.19	-0.07
2618866	63.394	54.400	0.120	0.22	54.706	0.122	0.22	+0.56
2608003	63.226	55.501	0.118	0.21	55.697	0.122	0.22	+0.35
2511663	63.033	55.335	0.138	0.25	55.206	0.133	0.24	-0.23
2504585	62.926	54.896	0.110	0.20	55.166	0.141	0.26	+0.49
2504347	62.838	54.750	0.121	0.22	54.721	0.111	0.20	-0.05
2516061	63.183	52.554	0.144	0.27	52.529	0.121	0.23	-0.05
2518142	62.980	54.576	0.114	0.21	54.554	0.129	0.24	-0.04
2617106	63.369	55.858	0.113	0.20	56.096	0.116	0.21	+0.42
2605583	62.732	55.354	0.106	0.19	55.359	0.123	0.22	+0.01
2616776	63.361	54.594	0.107	0.20	54.851	0.175	0.32	+0.47
2520288	62.914	53.976	0.105	0.20	54.223	0.115	0.21	+0.46
2513717	63.054	52.891	0.120	0.23	52.853	0.145	0.27	-0.07
2517823	62.702	52.225	0.125	0.24	52.152	0.118	0.23	-0.14
2504706	62.510	52.704	0.105	0.20	52.600	0.143	0.27	-0.20
2506814	63.221	54.818	0.102	0.19	54.822	0.116	0.21	+0.01
2701357	46.528	42.750	0.121	0.28	42.695	0.144	0.34	-0.13
2700055	46.187	42.474	0.120	0.28	42.392	0.116	0.27	-0.19

Table 35

Blanket Module III-2 PFB Rod Fissile Fuel Loadings in Grams

		PIFAG Thermal			PIFAG Epithermal			Epithermal - Thermal Percent Difference
			Standard Deviation			Standard Deviation		
Rod No.	As-Built Loading	Loading	Grams	%	Loading	Grams	%	
2202278	18.912	30.067	0.080	0.27	29.982	0.094	0.31	-0.28
2200805	18.907	30.548	0.079	0.26	30.503	0.117	0.38	-0.15
2100759	18.990	28.529	0.059	0.21	28.627	0.095	0.33	+0.34
2201178	18.913	28.105	0.059	0.21	28.079	0.085	0.30	-0.09
2202518	18.894	29.381	0.069	0.23	29.419	0.090	0.30	+0.13
2101758	18.894	29.609	0.070	0.23	29.338	0.090	0.31	-0.92
2402314	30.763	33.718	0.072	0.21	33.824	0.145	0.43	+0.32
2401048	30.769	34.312	0.078	0.23	34.432	0.111	0.32	+0.35
2401636	30.876	34.402	0.075	0.22	34.488	0.123	0.36	+0.25
2300601	52.531	46.680	0.092	0.20	46.821	0.110	0.24	+0.30
2300279	52.669	46.507	0.088	0.19	46.857	0.142	0.30	+0.75
2304652	52.765	45.950	0.105	0.23	46.003	0.118	0.26	+0.12
2302378	52.514	45.692	0.104	0.23	45.736	0.105	0.23	+0.10
2620509	63.028	55.998	0.097	0.17	56.247	0.114	0.20	+0.44
2603383	63.177	55.581	0.127	0.23	55.758	0.118	0.21	+0.32
2606775	63.024	54.587	0.107	0.20	54.585	0.150	0.28	-0.00
2600653	63.039	53.799	0.111	0.21	53.862	0.118	0.22	+0.12
2611002	63.067	53.403	0.117	0.22	53.741	0.143	0.27	+0.63
2608755	62.826	51.301	0.162	0.32	51.570	0.125	0.24	+0.53
2515513	62.860	56.244	0.100	0.18	56.122	0.142	0.25	-0.22
2517363	62.964	55.952	0.106	0.19	56.040	0.172	0.31	+0.16
2516777	62.965	55.740	0.101	0.18	56.166	0.116	0.21	+0.76
2511810	63.128	53.149	0.121	0.23	53.258	0.113	0.21	+0.20
2520656	63.103	54.400	0.130	0.24	54.738	0.131	0.24	+0.62
2516850	63.083	54.651	0.111	0.20	54.895	0.187	0.34	+0.45
2615016	62.991	56.980	0.126	0.22	57.207	0.157	0.27	+0.40
2601147	62.998	57.018	0.100	0.18	57.018	0.113	0.20	-0.00
2607031	62.956	56.721	0.103	0.18	57.033	0.114	0.20	+0.55
2602375	63.137	56.947	0.100	0.17	57.369	0.120	0.21	+0.74
2621407	62.964	55.324	0.106	0.19	55.636	0.108	0.19	+0.56
2608434	62.901	54.431	0.110	0.20	54.882	0.118	0.21	+0.83
2607325	63.161	52.721	0.112	0.21	52.865	0.088	0.17	+0.27
2605455	62.956	54.487	0.113	0.21	54.784	0.118	0.22	+0.54
2622433	63.145	54.942	0.110	0.20	55.158	0.110	0.20	+0.39
2622478	62.916	57.100	0.134	0.23	57.408	0.129	0.22	+0.54
2517704	62.780	56.768	0.098	0.17	57.185	0.113	0.20	+0.73
2511350	62.971	57.030	0.096	0.17	57.153	0.114	0.20	+0.22
2516281	63.138	55.888	0.099	0.18	55.743	0.108	0.19	-0.26
2512754	62.975	55.733	0.101	0.18	56.028	0.126	0.22	+0.53

Table 35 (Continued)

Blanket Module III-2 PFB Rod Fissile Fuel Loadings in Grams

		PIFAG Thermal			PIFAG Epithermal			Epithermal - Thermal Percent Difference
			Standard Deviation			Standard Deviation		
Rod No.	As-Built Loading	Loading	Grams	%	Loading	Grams	%	
2517244	62.948	56.010	0.100	0.18	56.290	0.114	0.20	+0.50
2517179	63.154	57.001	0.093	0.16	56.995	0.113	0.20	-0.01
2607563	63.014	57.091	0.098	0.17	57.314	0.126	0.22	+0.39
2603044	63.137	56.345	0.109	0.19	56.311	0.111	0.20	-0.06
2607471	62.989	56.077	0.119	0.21	56.214	0.104	0.19	+0.25
2611157	62.879	54.302	0.106	0.20	54.530	0.132	0.24	+0.42
2614640	63.134	54.418	0.103	0.19	54.699	0.116	0.21	+0.52
2610240	62.777	55.818	0.101	0.18	56.172	0.104	0.19	+0.63
2605152	62.950	57.039	0.094	0.17	57.217	0.113	0.20	+0.31
2502082	63.030	56.423	0.092	0.16	56.449	0.192	0.34	+0.04
2521022	63.033	56.277	0.097	0.17	56.379	0.112	0.20	+0.18
2518041	63.129	55.722	0.095	0.17	55.710	0.096	0.17	-0.02
2515585	63.070	55.428	0.119	0.22	55.488	0.112	0.20	+0.11
2516503	62.960	53.904	0.115	0.21	53.670	0.106	0.20	-0.43
2514128	63.172	54.478	0.156	0.29	54.417	0.112	0.21	-0.11
2516319	63.066	55.902	0.098	0.17	55.869	0.111	0.20	-0.06
2700643	46.374	42.939	0.110	0.26	43.143	0.112	0.26	+0.47
2701274	46.300	43.035	0.138	0.32	42.845	0.117	0.27	-0.44

Table 36

Blanket Module III-6 PFB Rod Fissile Fuel Loadings in Grams

		PIFAG Thermal			PIFAG Epithermal			Epithermal - Thermal
			Standard Deviation			Standard Deviation		Percent
Rod No.	As-Built Loading	Loading	Grams	%	Loading	Grams	%	Difference
2204855	18.997	29.110	0.063	0.22	29.154	0.088	0.30	+0.15
2204846	18.998	30.389	0.087	0.28	30.264	0.088	0.29	-0.41
2200840	18.977	29.275	0.071	0.24	29.282	0.090	0.31	+0.02
2101363	18.993	28.354	0.062	0.22	28.304	0.087	0.31	-0.18
2101464	18.980	28.964	0.092	0.32	28.820	0.094	0.32	-0.50
2102187	18.997	29.367	0.056	0.19	29.318	0.049	0.17	-0.17
2400408	30.780	33.914	0.054	0.16	34.018	0.053	0.16	+0.31
2406355	30.720	34.791	0.082	0.23	34.891	0.096	0.28	+0.29
2404018	30.802	33.952	0.078	0.23	34.003	0.093	0.27	+0.15
2305853	52.402	46.515	0.086	0.18	46.712	0.102	0.22	+0.42
2305449	52.385	46.629	0.093	0.20	46.415	0.108	0.23	-0.46
2300711	52.511	45.364	0.104	0.23	45.350	0.077	0.17	-0.03
2305312	52.551	45.734	0.106	0.23	45.975	0.114	0.25	+0.53
2612735	63.218	56.216	0.128	0.23	56.189	0.120	0.21	-0.05
2600314	63.295	55.488	0.118	0.21	55.482	0.119	0.21	-0.01
2622083	62.976	55.995	0.108	0.19	55.896	0.187	0.33	-0.18
2617005	63.090	56.536	0.109	0.19	56.587	0.121	0.21	+0.09
2612827	62.967	54.296	0.111	0.21	54.418	0.123	0.23	+0.23
2600745	63.053	53.214	0.124	0.23	53.525	0.125	0.23	+0.58
2604887	63.264	53.165	0.115	0.22	53.424	0.112	0.21	+0.49
2606481	63.116	51.575	0.115	0.22	51.624	0.082	0.16	+0.09
2503808	63.193	56.424	0.108	0.19	56.650	0.112	0.20	+0.40
2514045	63.138	56.710	0.120	0.21	56.610	0.151	0.27	-0.18
2512579	63.142	56.679	0.108	0.19	56.744	0.146	0.26	+0.11
2517226	62.858	55.472	0.119	0.22	55.650	0.120	0.22	+0.32
2513854	63.272	53.670	0.101	0.19	53.752	0.076	0.14	+0.15
2502578	63.238	54.631	0.115	0.21	54.650	0.113	0.21	+0.04
2510738	62.935	54.755	0.129	0.24	54.876	0.121	0.22	+0.22
2517208	63.451	54.944	0.110	0.20	55.122	0.122	0.22	+0.32
2616684	62.794	56.311	0.137	0.24	56.632	0.163	0.29	+0.57
2600377	62.449	56.691	0.105	0.19	56.722	0.153	0.27	+0.06
2606876	62.938	55.919	0.136	0.24	56.187	0.187	0.33	+0.48
2601367	63.052	55.776	0.150	0.27	55.753	0.122	0.22	-0.04
2620747	62.967	55.066	0.112	0.20	55.312	0.128	0.23	+0.45
2612625	63.108	55.213	0.113	0.20	55.442	0.124	0.22	+0.41
2613413	63.193	56.010	0.109	0.20	56.179	0.113	0.20	+0.30
2502102	62.999	57.295	0.073	0.13	57.440	0.070	0.12	+0.25
2505236	63.207	57.413	0.104	0.18	57.527	0.149	0.26	+0.20
2516824	62.952	56.808	0.104	0.18	57.021	0.119	0.21	+0.38

Table 36 (Continued)

Blanket Module III-6 PFB Rod Fissile Fuel Loadings in Grams

		PIFAG Thermal			PIFAG Epithermal			
			Standard Deviation			Standard Deviation		Epithermal - Thermal Percent
Rod No.	As-Built Loading	Loading	Grams	%	Loading	Grams	%	Difference
2500618	63.204	57.485	0.125	0.22	57.519	0.113	0.20	+0.06
2500589	63.127	56.389	0.119	0.21	56.655	0.125	0.22	+0.47
2503018	62.711	55.376	0.108	0.20	55.429	0.120	0.22	+0.10
2622175	63.162	56.680	0.104	0.18	57.041	0.110	0.19	+0.64
2610167	62.934	56.988	0.142	0.25	57.173	0.121	0.21	+0.32
2615512	63.205	57.207	0.102	0.18	57.224	0.152	0.27	+0.03
2622617	63.366	57.336	0.117	0.20	57.287	0.134	0.23	-0.08
2607509	63.011	56.533	0.186	0.33	56.878	0.132	0.23	+0.61
2605502	63.280	53.224	0.116	0.22	53.606	0.124	0.23	+0.72
2622507	63.002	55.019	0.107	0.19	55.047	0.145	0.26	+0.05
2513880	63.239	56.656	0.140	0.25	56.308	0.129	0.23	-0.61
2518169	63.144	54.956	0.100	0.18	55.134	0.158	0.29	+0.32
2507720	63.226	52.943	0.116	0.22	52.874	0.120	0.23	-0.13
2501670	63.187	52.467	0.115	0.22	52.478	0.120	0.23	+0.02
2513634	63.122	54.042	0.110	0.20	53.700	0.133	0.25	-0.63
2501157	63.199	56.730	0.116	0.20	56.300	0.167	0.30	-0.76
2700414	46.562	42.732	0.125	0.29	42.852	0.117	0.27	+0.28
2701430	46.217	42.883	0.119	0.28	42.726	0.116	0.27	-0.37

Table 37

Reflector Module IV-3 Fissile Fuel Loadings in Grams

		PIFAG Thermal			PIFAG Epithermal			Epithermal - Thermal Percent Difference
			Standard Deviation			Standard Deviation		
Rod No.	As-Built Loading	Loading	Grams	%	Loading	Grams	%	
3222566	0.000	6.904	0.024	0.35	6.785	0.099	1.46	-1.72
3224023	0.000	6.566	0.020	0.31	6.380	0.105	1.64	-2.83
3214250	0.000	4.513	0.021	0.46	4.405	0.118	2.69	-2.39
3126159	0.000	4.088	0.021	0.50	3.999	0.133	3.33	-2.18
3117560	0.000	6.260	0.018	0.29	6.117	0.120	1.97	-2.28
3102583	0.000	5.013	0.020	0.40	4.765	0.124	2.61	-4.95
3225085	0.000	11.024	0.026	0.24	10.711	0.111	1.04	-2.85
3115580	0.000	8.131	0.035	0.43	8.034	0.103	1.28	-1.18
3223188	0.000	12.298	0.033	0.27	12.402	0.131	1.06	+0.85
3117709	0.000	11.386	0.024	0.21	11.173	0.131	1.17	-1.87
3213858	0.000	9.089	0.027	0.30	8.719	0.119	1.36	-4.07
3111504	0.000	18.418	0.031	0.17	18.428	0.126	0.68	+0.05
3112815	0.000	15.912	0.038	0.24	15.749	0.114	0.73	-1.03
3120156	0.000	14.928	0.028	0.19	14.651	0.113	0.77	-1.86
3201776	0.000	14.452	0.031	0.22	14.261	0.103	0.72	-1.32
3211429	0.000	17.014	0.040	0.23	16.886	0.127	0.75	-0.75
3211034	0.000	15.086	0.022	0.15	15.002	0.115	0.77	-0.56
3114804	0.000	24.718	0.037	0.15	24.696	0.139	0.56	-0.09
3208834	0.000	22.434	0.038	0.17	22.296	0.147	0.66	-0.61
3110624	0.000	21.798	0.046	0.21	21.509	0.156	0.73	-1.32
3110505	0.000	23.874	0.031	0.13	23.687	0.102	0.43	-0.78
3122879	0.000	20.452	0.077	0.37	20.283	0.119	0.59	-0.82
3102657	0.000	37.346	0.059	0.16	37.163	0.135	0.36	-0.49
3220357	0.000	31.984	0.048	0.15	31.939	0.143	0.45	-0.14
3211456	0.000	34.845	0.052	0.15	34.934	0.111	0.32	+0.26
3207716	0.000	31.203	0.075	0.24	31.172	0.129	0.41	-0.10
3114326	0.000	29.237	0.069	0.23	29.396	0.119	0.40	+0.54
3126022	0.000	28.490	0.034	0.12	28.380	0.124	0.44	-0.39

Table 38

Reflector Module IV-4 Fissile Fuel Loadings in Grams

		PIFAG Thermal			PIFAG Epithermal			Epithermal - Thermal Percent
			Standard Deviation			Standard Deviation		
Rod No.	As-Built Loading	Loading	Grams	%	Loading	Grams	%	Difference
3216258	0.000	8.124	0.026	0.32	8.093	0.120	1.48	-0.39
3203774	0.000	6.148	0.024	0.39	6.225	0.131	2.11	+1.25
3222474	0.000	4.920	0.018	0.36	4.925	0.127	2.57	+0.11
3216139	0.000	6.385	0.025	0.39	6.398	0.112	1.75	+0.19
3120744	0.000	5.239	0.024	0.45	5.242	0.115	2.20	+0.07
3113006	0.000	6.905	0.033	0.48	6.893	0.119	1.73	-0.17
3118019	0.000	6.206	0.026	0.43	6.051	0.117	1.93	-2.49
3218669	0.000	11.718	0.029	0.25	11.544	0.124	1.07	-1.49
3122163	0.000	8.855	0.027	0.30	8.798	0.139	1.58	-0.64
3218413	0.000	14.517	0.027	0.19	14.286	0.133	0.93	-1.59
3123245	0.000	13.375	0.054	0.40	12.999	0.123	0.95	-2.81
3122605	0.000	11.319	0.030	0.27	11.100	0.115	1.03	-1.94
3222833	0.000	9.260	0.024	0.26	9.204	0.121	1.32	-0.60
3104664	0.000	16.343	0.055	0.34	16.177	0.143	0.89	-1.01
3127075	0.000	15.663	0.028	0.18	15.612	0.122	0.78	-0.33
3217506	0.000	16.087	0.069	0.43	15.999	0.215	1.34	-0.55
3105488	0.000	16.326	0.024	0.15	16.181	0.178	1.10	-0.89
3126470	0.000	18.584	0.035	0.19	18.640	0.226	1.21	+0.30
3208127	0.000	22.792	0.039	0.17	22.544	0.135	0.60	-1.09
3118708	0.000	25.674	0.049	0.19	25.442	0.158	0.62	-0.90
3103555	0.000	21.224	0.033	0.16	21.144	0.133	0.63	-0.38
3203379	0.000	21.800	0.062	0.29	21.662	0.135	0.62	-0.63
3203545	0.000	24.727	0.046	0.19	24.703	0.175	0.71	-0.09
3107082	0.000	39.323	0.063	0.16	39.343	0.175	0.45	+0.05
3217266	0.000	36.574	0.057	0.16	36.275	0.173	0.48	-0.82
3211236	0.000	33.092	0.059	0.18	32.948	0.170	0.52	-0.44
3214875	0.000	29.115	0.050	0.17	28.943	0.142	0.49	-0.59
3116167	0.000	35.794	0.055	0.15	36.000	0.140	0.39	+0.58
3220751	0.000	28.963	0.057	0.20	29.081	0.164	0.56	+0.41

Table 39

Reflector Module IV-9 Fissile Fuel Loadings in Grams

		PIFAG Thermal			PIFAG Epithermal			Epithermal - Thermal Percent Difference
Rod No.	As-Built Loading	Loading	Standard Deviation Grams	Standard Deviation %	Loading	Standard Deviation Grams	Standard Deviation %	
3124805	0.000	7.593	0.026	0.34	7.334	0.148	2.02	-3.41
3124556	0.000	6.937	0.019	0.28	6.730	0.116	1.72	-2.98
3222815	0.000	7.104	0.026	0.36	7.174	0.135	1.89	+0.99
3218540	0.000	7.359	0.021	0.28	7.383	0.120	1.62	+0.33
3226176	0.000	6.344	0.020	0.32	6.440	0.135	2.10	+1.51
3223529	0.000	5.490	0.017	0.32	5.584	0.136	2.43	+1.69
3111448	0.000	5.590	0.028	0.50	5.423	0.114	2.10	-2.98
3224683	0.000	5.464	0.027	0.50	5.208	0.120	2.30	-4.67
3221530	0.000	5.890	0.018	0.30	5.547	0.126	2.27	-5.82
3222667	0.000	4.827	0.022	0.45	4.878	0.139	2.84	+1.05
3223050	0.000	8.088	0.027	0.33	7.948	0.117	1.48	-1.73
3215048	0.000	5.819	0.021	0.37	5.757	0.158	2.75	-1.07
3220229	0.000	4.648	0.022	0.48	4.616	0.114	2.48	-0.68
3125005	0.000	5.425	0.023	0.43	5.219	0.116	2.22	-3.80
3121265	0.000	4.955	0.023	0.46	4.782	0.135	2.83	-3.50
3124886	0.000	4.713	0.017	0.37	4.574	0.114	2.48	-2.94
3207256	0.000	7.305	0.026	0.35	7.198	0.117	1.63	-1.47
3121476	0.000	5.140	0.031	0.60	5.136	0.170	3.31	-0.08
3121173	0.000	4.736	0.030	0.63	4.613	0.114	2.47	-2.60
3104417	0.000	4.647	0.022	0.47	4.688	0.114	2.44	+0.88
3223152	0.000	13.737	0.031	0.23	13.600	0.129	0.95	-0.99
3224564	0.000	13.188	0.028	0.21	12.958	0.190	1.46	-1.74
3218743	0.000	10.658	0.042	0.39	10.599	0.123	1.16	-0.56
3202757	0.000	9.222	0.029	0.32	9.013	0.163	1.81	-2.27
3126140	0.000	8.692	0.025	0.29	8.662	0.119	1.37	-0.33
3211135	0.000	13.133	0.047	0.35	12.926	0.136	1.05	-1.58
3225783	0.000	9.390	0.028	0.30	9.234	0.136	1.48	-1.65
3222135	0.000	10.652	0.026	0.24	10.701	0.119	1.12	+0.46
3224748	0.000	9.696	0.024	0.25	9.651	0.151	1.56	-0.47
3218844	0.000	10.854	0.029	0.27	10.688	0.113	1.06	-1.53
3121586	0.000	11.361	0.030	0.27	11.151	0.119	1.07	-1.85
3125389	0.000	8.823	0.027	0.31	8.577	0.116	1.36	-2.78
3224739	0.000	13.716	0.033	0.24	13.562	0.129	0.95	-1.13
3221448	0.000	20.296	0.035	0.17	20.313	0.128	0.63	+0.08
3221659	0.000	16.077	0.054	0.34	15.821	0.117	0.74	-1.59
3123474	0.000	20.216	0.044	0.22	19.939	0.127	0.64	-1.37
3123135	0.000	17.233	0.038	0.22	17.126	0.190	1.11	-0.62
3122513	0.000	15.744	0.032	0.20	15.768	0.116	0.73	+0.15
3220404	0.000	26.358	0.046	0.17	26.405	0.134	0.51	+0.18
3123263	0.000	21.170	0.031	0.15	21.113	0.179	0.85	-0.27
3120165	0.000	21.654	0.040	0.19	21.668	0.120	0.56	+0.06
3218577	0.000	27.276	0.050	0.18	27.068	0.134	0.49	-0.76
3221062	0.000	20.679	0.046	0.22	20.643	0.136	0.66	-0.18
3100282	0.000	39.550	0.074	0.19	39.687	0.147	0.37	+0.35
3123236	0.000	35.777	0.060	0.17	35.766	0.158	0.44	-0.03
3118836	0.000	31.837	0.061	0.19	31.806	0.168	0.53	-0.10
3206542	0.000	29.191	0.053	0.18	29.033	0.135	0.47	-0.54
3120376	0.000	27.846	0.050	0.18	28.005	0.179	0.64	+0.57

Table 40

Reflector Module V-4 Fissile Fuel Loadings in Grams

		PIFAG Thermal			PIFAG Epithermal			Epithermal - Thermal Percent Difference
			Standard Deviation			Standard Deviation		
Rod No.	As-Built Loading	Loading	Grams	%	Loading	Grams	%	
3200815	0.000	6.947	0.021	0.30	6.994	0.168	2.40	+0.68
3106846	0.000	7.723	0.025	0.33	7.581	0.118	1.56	-1.84
3201464	0.000	7.309	0.025	0.35	7.279	0.113	1.55	-0.42
3204810	0.000	6.958	0.033	0.48	6.932	0.119	1.71	-0.37
3106635	0.000	5.663	0.018	0.32	5.681	0.116	2.05	+0.32
3102620	0.000	6.436	0.020	0.32	6.294	0.120	1.90	-2.22
3208852	0.000	4.763	0.019	0.40	4.742	0.126	2.65	-0.43
3223675	0.000	5.372	0.024	0.45	5.353	0.117	2.19	-0.35
3111513	0.000	4.888	0.022	0.46	4.796	0.173	3.61	-1.89
3201160	0.000	4.683	0.020	0.42	4.672	0.117	2.51	-0.23
3210136	0.000	4.241	0.019	0.45	4.133	0.145	3.52	-2.53
3113336	0.000	4.998	0.023	0.46	4.838	0.116	2.39	-3.20
3105167	0.000	12.657	0.031	0.25	12.656	0.152	1.20	-0.01
3204663	0.000	12.730	0.030	0.24	12.667	0.164	1.30	-0.49
3203030	0.000	12.152	0.022	0.18	12.133	0.123	1.02	-0.16
3206423	0.000	10.825	0.036	0.34	10.201	0.135	1.32	-5.76
3220182	0.000	11.359	0.041	0.36	11.581	0.190	1.64	+1.95
3204609	0.000	10.806	0.029	0.26	10.819	0.123	1.14	+0.13
3217275	0.000	10.487	0.029	0.27	10.517	0.123	1.17	+0.28
3200705	0.000	8.724	0.027	0.31	8.657	0.121	1.40	-0.77
3105315	0.000	9.330	0.029	0.32	9.030	0.120	1.33	-3.21
3204636	0.000	9.403	0.027	0.29	9.201	0.166	1.80	-2.15
3102015	0.000	21.094	0.038	0.18	21.027	0.134	0.64	-0.32
3225453	0.000	24.197	0.044	0.18	24.192	0.138	0.57	-0.02
3213629	0.000	21.984	0.040	0.18	22.044	0.166	0.75	+0.27
3102318	0.000	18.093	0.035	0.20	17.828	0.131	0.73	-1.46
3226636	0.000	20.238	0.027	0.13	20.090	0.126	0.63	-0.73
3201380	0.000	20.200	0.040	0.20	20.184	0.134	0.67	-0.08
3100228	0.000	17.077	0.048	0.28	16.754	0.164	0.98	-1.89
3206762	0.000	15.186	0.028	0.18	15.116	0.129	0.85	-0.46
3106819	0.000	15.451	0.044	0.29	14.926	0.164	1.10	-3.39
3111228	0.000	16.225	0.035	0.21	15.850	0.133	0.84	-2.31
3204654	0.000	14.973	0.035	0.23	14.998	0.128	0.85	+0.17
3207458	0.000	14.459	0.028	0.20	14.319	0.121	0.84	-0.97