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Shippingport LWBR (Th/U Oxide) Fuel Characteristics for Disposal Criticality Analysis

**Idaho National Engineering and Environmental Laboratory
Lockheed Martin Idaho Technologies Company
Idaho Falls, Idaho 83415**

September 1999

This report was produced under a quality assurance program that satisfies the requirements of the National Spent Nuclear Fuel Program and DOE/RW-0333P, Office of Civilian Radioactive Waste Management Quality Assurance Requirements Description. However, the historical data presented in this report are unqualified.

**Prepared for the
U.S. Department of Energy
Assistant Secretary for Environmental Management
Under DOE Idaho Operations Office
Contract No. DE-AC07-94ID13223**

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**SHIPPINGPORT LWBR (Th/U Oxide) FUEL
CHARACTERISTICS FOR
DISPOSAL CRITICALITY ANALYSIS**

Idaho National Engineering and Environmental Laboratory
Lockheed Martin Idaho Technologies Company
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Revision 0

September 1999

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Abstract

DOE-owned spent nuclear fuels encompass many fuel types. In an effort to facilitate criticality analysis for these various fuel types, they were categorized into eight characteristic fuel groups with emphasis on fuel matrix composition. Out of each fuel group, a representative fuel type was chosen for analysis as a bounding case within that fuel group. Generally, burnup data, fissile enrichments, and total fuel and fissile mass govern the selection of the representative or candidate fuel within that group.

The Shippingport LWBR fuels incorporate more of the conventional materials (zirconium cladding/heavy metal oxides) and fabrication details (rods and spacers) that make them comparable to a typical commercial fuel assembly. The LWBR seed/blanket configuration tested a light-water breeder concept with Th-232/U-233 binary fuel matrix. Reactor design used several assembly configurations at different locations within the same core. The seed assemblies contain the greatest fissile mass per (displaced) unit volume, but the blanket assemblies actually contain more fissile mass in a larger volume; the atom-densities are comparable.

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ASSIGNMENT PAGE

**SHIPPINGPORT LWBR (Th/U Oxide) FUEL
CHARACTERISTICS FOR
DISPOSAL CRITICALITY ANALYSIS**

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Terms

blanket	- core assemblies that contain fertile material to capture excess or escaping neutrons and converting to fissile material
burnup	- is a measure of the amount of fissile material consumed before the fuel element is removed from the reactor
fertile	- material, that after neutron capture(s) and decay, becomes fissile
fissile	- materials which will undergo fission with neutrons of any energy
fissile loading	- the amount of fissionable material per unit volume within a fuel pin, assembly, or reactor core
liner	- a stainless steel canister used for interim storage of LWBR assemblies; not expected to be a part of the disposal package
seed fuel	- the active portion of the nuclear reactor core associated with the bulk of neutrons being generated to sustain criticality
Zircaloy-4	- an improved zirconium alloy (ASTM grade R60805) with a low nickel composition which avoids hydriding and loss of ductility [Ref. 1, p. 324]

Acronyms

BOL	beginning-of-life
ECF	Expended Core Facility (@ INEEL)
EOL	end-of-life
DOE	Department of Energy
ICPP	Idaho Chemical Processing Plant
INEEL	Idaho National Engineering and Environmental Laboratory
INTEC	Idaho Nuclear Technology and Engineering Center (formerly ICPP)
LWBR	light water breeder reactor

Acronyms (cont'd)

MTHM	metric ton heavy metal
MWd/MTHM	megawatt-days/metric ton heavy metal
PIE	post-irradiation examination
PWR	pressurized water reactor
SNF	spent nuclear fuel
TBV	to be verified
WP	waste package

1. INTRODUCTION

1.1 Shippingport Light Water Breeder Reactor, SP LWBR

The Shippingport Light Water Breeder Reactor (LWBR) was a small water-cooled, U-233/Th-232 cycle breeder reactor developed by the Pittsburgh Naval Reactors to improve utilization of the nation's nuclear fuel resources in light water reactors. The LWBR was operated at Shippingport Atomic Power Station (APS), which was a Department of Energy (DOE) (formerly Atomic Energy Commission)-owned reactor plant.

After final shutdown, the 39 core assemblies of the LWBR were shipped to the Expanded Core Facility (ECF) at Naval Reactors Facility at the Idaho National Engineering and Environmental Laboratory (INEEL). At ECF, 12 of the 39 assemblies were dismantled and about 1000 of more than 17,000 rods were removed from the modules for proof-of-breeding and fuel performance testing. Some of the removed rods were kept at ECF, some were sent to Argonne National Laboratory-West (ANL-W) in Idaho and some to ANL-East in Chicago for a variety of physical, chemical and radiological examinations. All rods and rod sections remaining after the examinations were shipped back to ECF, where modules and loose rods were repackaged in liners for dry storage. In a series of shipments, the liners were transported from ECF to Idaho Nuclear Technology Engineering Center (INTEC), formerly the Idaho Chemical Processing Plant (ICPP). The 47 liners containing the fully-rodded and partially-derodded core modules, the loose rods, and the rod scraps, are now stored in underground dry wells at INTEC.

2. REACTOR INFORMATION

The Shippingport LWBR core was operated successfully from September 1977 to October 1, 1982 at the Shippingport APS. At full power, the thermal power output of the reactor was 236.6 MW [Ref. 2, p. 5]. The core operated for 29,047 Effective Full Power Hours (EFPH) over the five-year period of operation [Ref. 2, p. 27].

The reactor vessel at Shippingport was approximately 10 m (33 ft) high with an inner diameter of 2.7 m (9 ft) and a nominal wall thickness of 22.5 cm (8-7/8 in) [Ref. 3, p. 2]. Within the vessel was a core barrel, a long cylinder that locates fuel assemblies within the vessel. The core barrel was supported in the vessel by a large doughnut-shaped weldment, called the support flange, that rests on top of the vessel. The support flange also served as the entrance point of various types of core instrumentation and safety injection piping. The support flange was clamped in position by a 127 cm (50-inch) thick steel closure head using 15 cm (6-inch) diameter studs, which were installed in mating bolting flanges of the closure head and reactor vessel [Ref. 3, p. 2].

3. DOE SHIPPINGPORT FUEL INFORMATION

3.1 Reactor Design Parameters

The LWBR was designed as a pressurized, light-water moderated and cooled thermal reactor that utilized the thorium/uranium-233 fuel cycle.

The LWBR core design provided a good simulation of a large LWBR core environment in the interior of the core, and permitted net breeding in the entire core [Ref. 4, p. 15]. Nuclear design of the LWBR core utilized a seed-blanket concept similar to that successfully applied to the first two pressurized water reactor (PWR) cores operated at Shippingport, but with reactivity control provided by core geometry changes (movable fuel) instead of poison rods [Ref. 5, p. 4]. Figure 3-1 shows a plan cross section of the LWBR core installed in the Shippingport pressurized water reactor vessel.

The LWBR core was designed to minimize parasitic neutron absorption in core and structural materials. Among the core design features, which contributed to improved neutron economy in the LWBR, were:

1. Use of movable fuel assemblies to control core reactivity, rather than conventional poison control rods, soluble poison, or burnable poison.
2. Use of peripheral radial and axial thorium reflector blanket regions to reduce neutron leakage from the core.
3. Use of Zircaloy with a low hafnium content for fuel rod cladding and for all structures in the active fuel region except the fuel rod support grids
4. Use of stainless steel (AM-350) rather than Inconel for fuel rod support grids [Ref. 6, p. 3].

The central portion of the core consisted of 12 movable-fuel seed assemblies each surrounded by a stationary blanket assembly [Figure 3-2, from Ref. 7, Figure II-1]. Reactivity in this seed-blanket reactor was controlled by raising and lowering the central movable seeds, a concept that eliminated the need for control poisons [Ref. 8, p. 3]. The UO_2 -rich seed assemblies generated neutrons, and the fertile fuel in the blanket/reflector assemblies absorbed excess neutrons while producing some fissile material and additional fissions. The fuel and blanket assembly design was optimized to maximize neutron production and minimize neutron loss [Ref. 8, p.8]. The power-flattening regions (see Figure 3-2) actually contained more U-233 mass than the standard blanket regions. Use of this highly loaded power-flattening blanket region produced a relatively uniform power distribution within the interior of the core. Radial and axial zoning of fuel loadings are shown in Figures 3-3 through 3-8.

FIGURE 3.1. LWBR CORE IN SHIPPINGPORT REACTOR VESSEL
(WAPD-TM-1208)

3.1.1 Shippingport LWBR SNF

The LWBR core was fueled with fertile Th-232 and fissile U-233, the relative concentrations of which varied axially and radially across the core to improve neutron economy. The uranium that was used in fabricating the fuel was very highly enriched in U-233, but some isotopic impurities were present (Table 3-1). These isotopics represent 'nominal design' values, and other reported/calculated U isotopic values may vary slightly due to blending differences in various batches of fissile material. The design included vertical fuel rods on a triangular pitch with the space between taken up by circulating cooling water. The fuel rods featured cladding tubes loaded with cylindrical ceramic fuel pellets of thoria (ThO_2) or a mixture of thoria and UO_2 . Rods were sealed and backfilled with helium at one atmosphere during welding [Ref. 5, p. 70].

The LWBR core contained about 17,290 rods in 39 core assemblies [Ref. 9, p. I-1]. There were 15 types of rods used in the LWBR core to achieve the designed axial and radial zoning. The different rod types required different pellet geometries, so several types of fuel pellets were manufactured. Pellets varied in size, shape, and enrichment. Zircaloy-4 with a low hafnium content was used for the cladding tubes and all other structures (ducting, blanket support posts) in the fuel region, except the grids, which were made of AM-350 stainless steel [Ref. 10, p. 8]. The fuel and fuel components suffered minimal damage during operation. Extensive destructive and non-destructive examinations after shutdown confirmed that the fuel was in good condition with minimal deformation of the cladding and minimal cracking of fuel pellets. Fuel assembly packaging in existing liners, shipping controls, and existing dry-storage have all contributed to fuel 'stability' and virtual elimination of any further interim damage or degradation.

Table 3-1. Isotopic Composition of the Uranium Used in Fabricating the Fuel
[from Ref. 6, Table II-2, p. 11]

Isotope	Weight Percent
U-232	<0.001
U-233	98.23
U-234	1.29
U-235	0.09
U-236	0.02
U-238	0.37

Core reactivity control was achieved by moving the 12 seed assemblies up and down within the stationary blanket assemblies using individual control drive mechanisms. To shut the reactor down, the bottoms of the seed assemblies were lowered 152-cm (60-in) below the bottoms of the blanket assemblies. To start up the reactor, the seed assemblies were raised, thus bringing the fissile uranium-bearing parts of the fuel closer together (Figure 3-9), [Ref. 7, Figure II-3].

FIGURE 3-2. REACTOR CROSS SECTION FOR ASSEMBLY IDENTIFICATION
[Ref. 7, p. 8]

	Rod Type ¹	Binary Stack Length	Enrichment (U-fissile wt %) ²	Theoretical Density (g/cm ³) ²	Mass Initial Fissile (g/Rod) ³	Number of Rods/Core	Mass Initial Fissile (g/Core)
05, 06	84"	5.195	10.042	34.57	3,972	137,312
04	70"	4.327	10.035	23.92	792	18,945
03	56"	4.327	10.035	19.14	864	16,537
01, 02, 07, 08	42"	4.327	10.035	14.33	1,800	25,794
						7,428	198,586

619 Rods (306 top mounted)
.306" Diameter
.369" Pitch

¹ Rod type: First two digits of a rod serial number correspond to the rod type number

² WAPDÖTMD1605, Tables 1 and 5

³ WAPDÖTMD1612, Table V-2. WAPDÖTMD1326, Table A-5

FIGURE 3-3. LAYOUT OF FUEL RODS IN A SEED ASSEMBLY
[Ref. 14, P. 12]

Rod Type ¹	Binary Stack Length	Enrichment (U-fissile wt %) ²	Theoretical Density (g/cm ³) ²	Mass Initial Fissile (g)/Rod ³	Number of Rods/Core				Mass Initial Fissile (g)/Core
11,12	42"	1.211	10.009	16.45	B1	B2	B3	
						378 +	240 +	354 =	972
14	56"	1.662	10.013	30.34	216 +	129 +	186 =	531
13	70"	2.000	10.016	45.47	231 +	135 +	192 =	558
16	84"	2.000	10.016	54.66	252 +	141 +	198 =	591
15	84"	1.662	10.013	45.66	252 +	138 +	192 =	582
						1,329 +	783 +	1,122 =	3,234
						116,350.4			

443 Rods (222 top mounted)
.5715" Diameter
.630" Pitch

¹ Rod type: First two digits of a rod serial number correspond to the rod type number

² WAPD-TMD 1605, Tables 1 and 5

³ WAPD-TMD 1612, Table V-2. WAPD-TMD 1326, Table A-5

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FIGURE 3-4. LAYOUT OF FUEL RODS IN A TYPE I BLANKET ASSEMBLY
[Ref. 14, p13]

	Rod Type ¹	Binary Stack Length	Enrichment (U-fissile wt %) ²	Theoretical Density (g/cm ³) ²	Mass Initial Fissile (g)/Rod ³	Number of Rods/Core	Mass Initial Fissile(g)/Core
21, 22	42"	1.649	10.013	18.96	180	3,412.8
24	56"	2.005	10.016	30.74	93	2,858.8
23	70"	2.733	10.022	52.56	93	4,888.1
25, 26	84"	2.733	10.022	63.06	517	32,602.0
27	84"	2.005	10.016	46.4	24	1,113.6
						907	44,875.3

Region 1
261 Standard Rods (131 top mounted)
.5712" Diameter
.630" Pitch

Region 2
303 Power Flattening Rods (151 top mounted)
302 for Types II-1 and Types II-3
.5265" Diameter
.630" Pitch

Rod Location 25H 1 Occupied by
Flux Wall in Modules II-1 and II-3

¹ Rod type: First two digits of a
rod serial number correspond to the rod type number

² WAPD-TM-1605, Tables 1 and 5

³ WAPD-TM-1612, Table V-2, WAPD-TM-1326, Table A-5

Y59 0003

FIGURE 3-5. LAYOUT OF RODS IN A TYPE II BLANKET ASSEMBLY
[Ref. 14, p15]

	Rod Type ¹	Binary Stack Length	Enrichment (U-fissile wt %) ²	Theoretical Density (g/cm ³) ²	Mass Initial Fissile (g)/Rod ³	Number of Rods/Core	Mass Initial Fissile (g)/Core
21,22	42"	1.643	10.013	18.96	488	9,214.6
24	56"	2.005	10.016	30.74	258	7,930.9
23	70"	2.733	10.022	52.56	264	13,875.8
25, 26	84"	2.733	10.022	63.06	1,618	102,031.1
27	84"	2.005	10.018	48.4	48	2,227.2
						2,674	135,279.6

Region 1
187 Standard Rods (94 top mounted)
.5715" Diameter
.630" Pitch

Region 2
446 Power Flattening Rods (94 top mounted)
445 for Types III-1 and Types III-2
.5265" Diameter
.630" Pitch

- ¹ Rod type: First two digits of a rod serial number correspond to the rod type number
² WAPD-TM-1605, Tables 1 and 5
³ WAPD-TM-1612, Table V-2. WAPD-TM-1328, Table A-5

Y99 0052

FIGURE 3-6. LAYOUT OF RODS IN A TYPE III BLANKET ASSEMBLY
[Ref. 14, p16]

FIGURE 3-7. R-Z SCHEMATIC OF A TYPE I MODULE
[Ref. 14, p. 11]

* Except for eight Medium zone rods per module in row six
(4 on each side, along interface between modules).

FIGURE 3-8. R-Z SCHEMATIC OF POWER FLATTENING SIDES OF TYPE II AND TYPE III BLANKET MODULES
[Ref. 14, p.14]

After final shutdown, the 39 assemblies were shipped to the Expended Core Facility (ECF) at Naval Reactors Facility at the Idaho National Engineering and Environmental Laboratory (INEEL). At ECF, 12 of the 39 assemblies were partially dismantled and about 1,000 spent fuel rods were removed underwater from the assemblies for proof-of-breeding and fuel-performance testing [Ref. 11, pp. 27 and 37]. Some of the removed rods were kept at ECF; the rest were sent to Argonne National Laboratory-West (ANL-W) in Idaho or ANL-East in Chicago for a variety of physical, chemical, and radiological examinations. All rods and rod sections remaining after the examinations were shipped back to ECF, where assemblies and loose rods were repackaged in liners for dry storage. In a series of shipments, the liners were transported from ECF to Idaho Nuclear Technology Engineering Center (INTEC), formerly the Idaho Chemical Processing Plant (ICPP). The 47 liners (39 modules, 7 containers of intact fuel rods, and 1 container of cut fuel rods) are stored in underground dry wells at the CPP-749 dry fuel storage facility in upright right circular liners with an outside diameter of 647.70-mm (25.5-in.) and length of 4008.12-mm (157.8-in.) [Ref. 11, p. 3-1].

The Fuel Receipt Criteria describe the 47 liners stored in CPP-749. The liners consisted of:

1. 27 "Type A" liners, which contain intact LWBR assemblies (i.e., assemblies from which no rods have been removed). Type A liner interiors are configured to fit seed, standard and power flattening blanket, and reflector assemblies.
2. 12 "Type B" liners, which contain partially derodded assemblies. Derodding required sawing off the tops and bottoms of the assemblies.
3. 7 "Type C" liners, which contain intact spent fuel rods that have been removed from the assemblies that now occupy the Type B liners plus some unirradiated rods that were used for calibration of instruments during post-irradiation testing.
4. 1 "scrap can" liner, which contains sections and pieces of unirradiated rods and irradiated rods that had been cut up or punctured for testing purposes, as well as unirradiated rods that were used for calibration. There are at least 22 containers within the scrap can. Many of the rods in the scrap can have been run through a variety of tests, which may have altered their physical, chemical, or radiological properties. Some 260 to 275 test rods similar to the LWBR fuel rods are included in the scrap can liner.

The number of Type A and Type B liners for each module type are provided in Table 3-2. Number of rods are listed in Table 3-3.

Table 3-2. Number of Type "A" and "B" liners per module type
[Ref. 12, p.121)].

	Number of Type "A" Liners (fully rodged module)	Number of Type "B" Liners (partially derodded module)
Seed	8	4
Type I Blanket*	2	1
Type II Blanket*	2	1
Type III Blanket*	4	2
Type IV Reflector*	6	3
Type V Reflector*	5	1

* See Figure 3-2 for layout/arrangement of the various assemblies in the core.

Fully-rodged blanket assemblies have had mounting hardware removed from the tops and bottoms; intact seed and reflector assemblies have had hardware removed from the tops only. The tops and bottoms of some assemblies were sawn off to free up fuel rods for removal. Stabilization clamps were required to equip the partially derodded assemblies for subsequent handling and storage [Ref. 12, Appendix A; Ref. 13, Figure 28, p. 61]. The stabilization clamps consisted of end caps to hold the rods in place and full-length tie rods to hold the top and bottom end caps in place. Lugs to secure the tie rods to the end caps protruded from each face of the hexagonal seed assemblies. Records of weights of the stored assemblies reveal that the partially derodded assemblies with stabilization clamps weigh hundreds of pounds more than the intact ones. [Ref. 14, Table 6-3]

In addition to the 39 Type A and B liners listed above, there are seven Type C liners and a liner containing scrapped rods. The scrapped rods include some that were generated during development of the LWBR rod design and remnant pieces from LWBR PIE tests.

Table 3-3. Numbers of Fuel Rods and Assemblies in Storage
[Ref. 14, Table 6-1].

Module ID	Fuel Piece Serial #	Liner #	Liner Types ³	#Rods Initially ⁴	#Rods in "A" liner	#Rods in "C" liner ⁵	# P08 Rods ⁶	# DE Samples ⁷		#Should be in "B" liners A-(C+E+F)
								ANL-W	ANL-E	
S-1-1	L-BB01-04	15601	B	619		42	33	4	5	568
S-1-2	L-BB01-05	15602	A	619	619					
S-1-3	L-BB01-06	15603	A	619	619					
S-2-1	L-BB01-09	15604	A	619	619					
S-2-2	L-BB01-10	15605	A	619	619					
S-2-3	L-BB01-13	15606	B	619		128	34			491
S-3-1	L-BB01-07	15607	B	619		43	34			576
S-3-2	L-BB01-08	15608	B	619		39	33			580
S-3-3	L-BB01-12	15609	A	619	619					
S-3-4	L-BB01-11	15610	A	619	619					
S-3-5	L-BB01-14	15611	A	619	619					
S-3-6	L-BB01-16	15612	A	619	619					
B-1-1	L-GR01-01	15613	A	442	442					
B-1-2	L-GR01-02	15614	A	442	442					
B-1-3	L-GU51-01	15615	B	443		45	36	3	4	391
B-2-1	L-GS01-01	15616	A	563	563					
B-2-2	L-GS22-01 ¹	15617	B	564		80	65	4		480
B-2-3	L-GS01-02	15618	A	563	563					
B-3-1	L-GT01-01	15619	A	632	632					
B-3-2	L-GW52-01	15620	B	632		391	72			241
B-3-3	L-GT01-03	15621	A	633	633					
B-3-4	L-GT01-04	15622	A	633	633					
B-3-5	L-GT01-05	15623	A	633	633					
B-3-6	L-GT22-03	15624	B	633		78	75		6	549
R-4-1	L-RA01-06	15625	A	228	228					
R-4-2	L-RA01-02	15626	A	228	228					
R-4-3	L-RA01-10	15627	B	228		30	27	1	2	195
R-4-4	L-RA01-09	15628	B	228		76	29			152
R-4-5	L-RA01-07	15629	A	228	228					
R-4-6	L-RA01-04	15630	A	228	228					
R-4-7	L-RA01-05	15631	A	227	227					
R-4-8	L-RA01-08	15632	A	228	228					
R-4-9	L-RA01-03	15633	B	228		57	28			171
R-5-1	L-RB01-07	15634	A	166	166					
R-5-2	L-RB01-04	15635	A	166	166					
R-5-3	L-RB01-06	15636	A	166	166					
R-5-4	L-RB01-08	15637	B	166		37	34			129
R-5-5	LRB01-03 ²	15638	A	166	166					
R-5-6	L-RB01-05	15639	A	166	166					
Total				17288	11690	1046	500	12	17	4523

Table 3-3. (cont'd)

Module ID	Fuel Piece Serial #	Liner #	Liner Type ³	#Rods Initially ⁴	#Rods in "A" liner	#Rods in "C" liner ⁵	# P08 Rods ⁶	# DE Samples ⁷		#Should be in "B" liners A-(C+E+F)
								ANL-W	ANL-E	
FR-B-1	Blanket	15682	C			175				
FR-B2	Blanket	15684	C			144				
FR-B3	Blanket	15685	C			243				
FR-B4	Blanket	15687	C			62				
FR-R1	Reflector	15681	C			127				
FR-R2	Reflector	15683	C			80				
FR-S1	Seed	15686	C			270				
	624sections	15718								
				Total		1101				

¹ The technician actually stated that the serial number was L-G522-01 (mistaking the S for a 5)

² The videotape w/ audio is the only documentation of the serial numbers; videotape in is SNF records @ INTEC (CPP-666). Serial number does not appear on the shipping forms.

³ Reference: Bolton, Christensen and Hallinan (1989). Final Safety Analysis Report. March 1989. WIN-107-4.7A, Rev. 1.

⁴ Reference: WAPD-TM-1326 Table A-17 for seed and blanket WAPD-TM-1 605 for reflector
One flux thimble in each of the following modules: 81-1, 81-2, 82-1, 82-3, R4-7.

⁵ Part B of Fuel Receipt Criteria lists the serial numbers of each rod in Type C liners.

⁶ Reference: WAPD-TM-1612 (Sep 1987) Figures V-2 through V-13. Note: number of rods shown in figures differs from the number of rods accounted for in Table V-i of same report.

⁷ Number of rods destructively evaluated. ANL-W performed DE on 12 rods. ANL-E+A32 performed DE on 17 rods.

Table 3-4. Summary of Masses for Intact and Partially Derodded Assemblies from all Core Regions [Ref. 14, Table 6-3].

Core Region	Assembly Type	Mass [kg (lb)]	
		Intact Assemblies	Partially Derodded Assemblies
Seed	All	750.2 (1654)	913.1 (2013)
Blanket	I	1910.5 (4212)	2140.0 (4718)
Blanket	II	2218.1 (4890)	2453.9 (5410)
Blanket	III	2728.4 (6015) ^a	2634.9 (5809)
Reflector	IV	2237.6 (4933)	2358.7 (5200) ^b
Reflector	V	1827.1 (4028)	1906.9 (4204)

^a This value only appears only once. The two other listed weights of intact assemblies of this type are 2405.4 kg (5303 lb).

^b One of the partially derodded Type IV reflector assemblies has a listed weight of 2237.6 kg (4933 lb), same as the weight of intact assemblies of this type.

^c Partially derodded assemblies have 'installed' fixtures that increase the weight of the individual assemblies.

3.1.1.1 Description of SNF from the Seed Region

Two different enrichments of the same binary ($\text{UO}_2\text{-ThO}_2$) matrix were used in seed rods. Axial and radial zoning of the fissile and fertile material were optimized for breeding. Axial zoning of the seed is shown in Figure 3-7, depicting the varying enrichments of the 619 rods [Ref. 14, Table 3-1] in each of the seed modules. Radial zoning of the fissile material of the seed is shown in Figure 3-3. Each seed was a movable assembly contained within a blanket assembly (Figure 3-1).

The 12 Seed assemblies together initially contained 198.59 kg of fissile material, with 61.28 kg (wt%=4.337; use as 'most conservative' fissile load) [Ref. 14, p. 23, Table 3-4] in rods of the lower fissile concentration (low zone) and 137.31 kg (wt%=5.202; use as 'most conservative' fissile load) [Ref. 14, p. 23, Table 3-4] in rods of the higher fissile concentration (high zone).

3.1.1.1.1 Fuel Pellets from the Seed Region

Seed pellets were right circular cylinders, with chamfers (bevels) on both ends to ease loading into tubing, facilitate movement of the pellet stack in the tubing during power operation, and reduce pellet chipping during fabrication, rod handling, and power operation. The seed pellets had dished ends to reduce axial expansion of the stack. Fuel pellets in the seed region were smaller in diameter than pellets elsewhere in the core. Two types of binary pellets were used in the seed region (Table 3-5). The shorter binary pellets had a lower fissile concentration than the longer binary pellets. Thoria pellets, used near the top and bottom of the fuel stack, were shorter. A spring-bearing thoria pellet with only one dished end was used at the top of each fuel (pin) stack.

During fabrication, the pellets were sintered to a large fraction of their theoretical densities to ensure dimensional stability. The void fraction listed in Table 3-5 and elsewhere is defined as the fraction of the volume of a right circular cylindrical pellet of the nominal dimensions that is missing due to end dishes, chamfers, and pellet chips.

Table 3-5. Characteristics of Pellets in the Seed Region
[Ref. 14, p. 33; Ref. 5, Table 4 (except as noted)]

Property (units)	Seed Region Enrichment Zone		
	High (5.202 wt% U-fissile enriched) ¹	Low (4.337 wt % U-fissile enriched) ¹	ThO ₂
Diameter ^a [mm (in)] ¹	6.4008 (0.2520)	6.4008 (0.2520)	6.49224 (0.2556)
Diameter ^b [mm (in)]	6.4008 ± .0127 (0.252 ± 0.0005)	6.4008 ± .0127 (0.252 ± 0.0005)	6.4897 ± .0127 (0.2555 ± .0005)
Length ^a [mm (in)] ¹	15.621 (0.615)	11.2776 (0.444)	13.462 (0.530)
Length ^b [mm (in)]	15.621 ± .508 (0.615 ± .020)	11.303 ± .508 (0.445 ± .020)	13.462 ± .508 (0.530 ± .020)
Taper or Chamfer Depth ^b [mm (in)] ³	0.381 ± 0.127 (0.015 ± 0.005)	0.381 ± 0.127 (0.015 ± 0.005)	0.381 ± 0.127 (0.015 ± 0.005)
Taper or Chamfer Length ^b [mm (in)] ³	0.381 ± 0.127 (0.015 ± 0.005)	0.381 ± 0.127 (0.015 ± 0.005)	0.381 ± 0.127 (0.015 ± 0.005)
End Dish Spherical Radius ^b [mm (in)] ²	9.144 (0.360)	9.144 (0.360)	7.5692 (0.298)
End Shoulder Width ^b [mm (in)]	1.1684 ± 0.20 (0.046 ± 0.008)	1.1684 ± 0.20 (0.046 ± 0.008)	1.397 ± 0.254 (0.055 ± 0.010)
End Face Dish Depth ^b [mm (in)]	0.2286 ± 0.0762 (0.009 ± 0.003)	0.2286 ± 0.0762 (0.009 ± 0.003)	0.2286 ± 0.0762 (0.009 ± 0.003)
Void Fraction ^a (of chamfers, dishes, and chip defects) ³	0.01172	0.01704	0.01253
Percent Theoretical Density ^{a,3}	97.554	97.712	98.013
Theoretical Density (g/cm ³) ³	10.042	10.035	9.999

^aAverage as built.

^bDesign specification.

1. Ref. 14, Table 3-4; use as 'most conservative' fissile loading

2. Ref. 2, Table 2

3. Ref. 5, p. 20 (Table 4)

3.1.1.1.2 Fuel Rods from the Seed Region

There were eight types of seed rods. Dimensions of the eight types are shown in Figure 3-9. Rods with odd type numbers were fixed to the bottom of the assembly, while even numbered rods were fixed at the top. The diameter of the mounting stems is not precisely known but historical documents imply that it does not exceed 5.7658-mm (0.227-in.) [Ref. 13, Fig. 5 and Ref. 9, Note 1 of Figures II-4, II-5, and II-6]. The seamless cladding tubes were welded at both ends to solid end plugs of Zircaloy-4 [End-plug material is identified in Ref. 9, Table 5, p. 21]. Cladding dimensions are given in Table 3-8. The cladding tubes in the seed region were freestanding; that is, they were designed to withstand operating pressures and temperatures without collapsing onto the pellet stack. However, irradiation of the rods caused a reduction in diameter of 0.03 to 0.06-mm (1.2 to 2.5-mils) [Ref. 2, p. 119]. Within the tube and above the pellet stack there was a 254 ± 2.54-mm (10.0 ± 0.1-in.) plenum at the top of the fuel stack to accommodate fission gases [Ref. 2, p. 50 (Fig. 13)]. The plenum housed an Inconel X-750 [Ref. 2, p. 21, Table 5] wire compression spring (Table 3-9). The approximate weights of unirradiated fuel rod components for all core regions are given in Table 3-10.

Table 3-6. As-Built Characteristics of Seed Fuel Rods.
[Ref. 2, Fig. 3 (except as noted)]

Fuel Rod Type	Number per Assem-bly ^a	Overall Length [mm (in)]	Length of Fixed-end Plug [mm (in)]	Length of Mounting Stem [mm (in)]	Length of Free-end Plug [mm (in)]
01	30	3023.108 (119.02)	52.578 (2.07)	60.96 (2.40)	19.05 (0.75)
02	84	3023.108 (119.02)	44.958 (1.77)	60.96 (2.40)	26.67 (1.05)
03	72	3026.156 (119.14)	52.578 (2.07)	64.008 (2.52)	19.05 (0.75)
04	66	3026.156 (119.14)	44.958 (1.77)	64.008 (2.52)	26.67 (1.05)
05	181	3029.458 (119.27)	52.578 (2.07)	67.31 (2.65)	19.05 (0.75)
06	150	3029.458 (119.27)	44.958 (1.77)	67.31 (2.65)	26.67 (1.05)
07	30	3006.598 (118.37)	52.578 (2.07)	44.45 (1.75)	19.05 (0.75)
08	6	3006.598 (118.37)	44.958 (1.77)	44.45 (1.75)	26.67 (1.05)

^a Ref. 6, Fig. II-4

Table 3-7. Further As-Built Characteristics of Fuel Rods in the Seed Region
[Ref. 14, pgs 23-24]

Rod Type	Initial fissile mass loading (g/rod)	Fissile Concentration of the Binary Stack ^a (wt% fissile)	Length of Binary Stack ^b [mm (in)]
01, 02, 07, 08	14.33	4.337	1066.8 (42)
03	19.14	4.337	1422.4 (56)
04	23.92	4.337	1778 (70)
05,06	34.57	5.202	2133.6 (84)

^aWeight percent fissile (U-233+U-235)/(ThO₂+UO₂). Historical documents give conflicting values. The largest reported as-built values are listed here. The conflicting values, 4.327 and 5.195, are less than 0.3% less.

^bThe bottom 254 mm (10 in) of each stack consisted of thorium pellets. The binary stack began at the 254-mm level. Because there were no binary shim pellets, the length of the binary stack may differ from rod to rod by up to one pellet length. Thorium pellets made up the rest of the stack above the binary stack. Total pellet stack length was 2635.25 mm (103.75 in).

Table 3-8. Average As-Built Cladding Dimensions for all Core Regions
[Ref. 14, p.8]

Core Region	Outside Diameter [mm (in)]	Thickness [mm (in)]
Seed	7.78002 (0.3063)	0.563118 (0.02217)
Standard Blanket	14.52118 (0.5717)	0.713232 (0.02808)
Power Flattening Blanket	13.39596 (0.5274)	0.671068 (0.02642)
Reflector	21.14042 (0.8323)	1.06426 (0.0419)

Table 3-9. Plenum Spring Dimensions for all Core Regions
[Spring dimensions are from Ref. 2, pp. 123-124, Tables 41 & 42]

Core Region	Number of Coils	Wire Diameter [mm (in)]	Spring Diameter [mm (in)]
Seed	190	1.0795 (0.0425)	5.2578 (0.207)
Standard Blanket	125	1.81102 (0.0713)	9.1694 (0.361)
Power Flattening Blanket	135	1.66624 (0.0656)	8.4328 (0.332)
Reflector	33	2.7686 (0.109)	13.3858 (0.527)

Table 3-10. Estimated Masses of Unirradiated Fuel Rod Components for all Core Regions
[company internal document, "Information package from Bettis to ANL LWBR-CE-POB", Table III-F.]

Core Region	Mass per Rod (kg)			
	Fuel Pellets	Cladding and End Caps	Internal Hardware	Total
Seed	0.83	0.27	0.02	1.12
Standard Blanket	3.38	0.69	0.14	4.21
Power Flattening Blanket	2.85	0.59	0.12	3.56
Reflector	6.94	1.47	0.12	8.53

3.1.1.1.3 Seed Modules

There were twelve nominally identical seed modules. Key dimensions of the cross sections of the various types of fuel modules are given in Figure 3-11. Figure 3-3 depicts the radial zoning of the seed modules. The fuel rod in the center of a seed module occupies the first "row". Each successive hexagonal layer of rods wrapping around the central fuel rod forms another consecutively numbered row. Higher-enriched fuel occupied the central eleven rows of the seed assemblies, where the binary stack length was at its maximum. Lower-enriched fuel occupied the remaining four outer rows, which contained decreasing amounts of U-fissile with distance from the center due to shorter binary stack lengths.

Base plates of Inconel 600 alloy held the fuel rods in position axially [Ref. 12, p. 3]. Approximately half of the fuel rods were secured to the top base plate and the others were secured to the bottom base plate. The base plates were 38.1-mm (1.5-in.) thick and were perforated as shown in Figure 3-12 to accept the rod mounting stems and to allow the flow of cooling water [Ref. 12, p. 3 & Fig. 1]. Average as-built fissile masses in assemblies from all core regions are given in Table 3-11. The seed assembly with the maximum fissile loading contained the BOL quantities of thorium and isotopes of uranium as shown in Table 3-12.

Table 3-11. Average As-Built Fissile Loading of Assemblies from All Core Regions
[Ref. 14, p 43]

Core Region	Average As-Built Fissile Loading ^a (kg)		
	Type I	Type II	Type III
Seed	16.53	16.55	16.56
Blanket	16.18	25.00	29.85

^aNo deductions have been made for flux wells, which were present in two Type II and two Type III blanket assemblies. Reflector assemblies had no initial fissile loading

Table 3-12. Composition of the Seed Assembly with Maximum Fissile Loading
[Ref. 14, Table III-1, p. 21 (maximum composite of all seed assemblies)]

Nuclide	Mass (g)
^{232}Th	434.09 kgs
^{232}U	0.12
^{233}U	16568.70
^{234}U	215.20
^{235}U	11.49
^{236}U	2.49
^{238}U	45.85
$^{233}\text{U} + ^{235}\text{U}$	16580.19

A nominal 9.36244-mm (0.3686-in) center-to-center spacing between fuel rods was maintained along the length of each seed assembly by nine stainless steel (AM-350) grids. The uppermost grid was entirely above the fuel, and half of the lowermost grid was below the fuel. Leaving out the portions of the grids above and below pellet stacks, the grids displaced 2.130 cm^3 (0.130 in^3) of cooling water for each fuel rod in the seed assemblies. Grids in the seed region weighed, on average, 1542 g each grid, while the assembly with the most massive grids had an average grid mass of 1557 g. [Ref. 6, Table A-14]

The outer support shell of the seed assemblies was a 2.032-mm (0.080-in) thick hexagonal shell of Zircaloy-4 [Ref. 14, p. 39]. The length of the support shell may be taken to be 3302-mm (130.00-in.), though this length includes that of the bottom cover plate. The distance between the inner surfaces of the top and bottom base plates was 3009.9-mm (118.500-in.). The distance between the bottom of the assembly and the inner surface of the bottom base plate was greater than 111.76-mm (4.4-in.) and less than 254-mm (10-in.); halfway between the bounds is a reasonable approximation [Westinghouse Bettis Atomic Power Laboratory Drawing. LWBR TR-19.4. "Product Dwg Seed Fuel Assembly." July 19, 1998. 927J464]. For top- and bottom-mounted fuel rods, the distance to the bottom of the pellet stack from the inner surface of the bottom base plate is 52.578 mm (2.07-in.) as shown in Fig. 3-9. Therefore, the total distance between the bottom of the fuel assembly and the bottom of the fuel stack is approximately 235 mm. The maximum corner-to-corner width of the seed assemblies shown in Figure 3-10 was 281.432-mm (11.08-in) [Ref. 14, p. 39].

Hardware removed from the seed assembly tops included the support shaft, the uppermost hexagonal portion of the assembly, the cover plate, and the top base plate bolts (Figure 3-11). The removal of mounting hardware from the assemblies necessitated the attachment of shipping plates at the tops so that the assemblies could be picked up [Ref. 15, Figures 2, 10, & 16]. The shipping plates on the seed assemblies consist of 50.8-mm (2.0-in) thick rings of Type 304 stainless steel with inner diameter 155.956-mm (6.140-in.) and outer diameter 244.5512-mm (9.628-in.). There are a number of holes and recessions in the shipping plates. Of the many holes and recessions, 9 holes bear mentioning: 6 holes 14.224-mm (0.560-in.) in diameter and 3 holes 25.4-mm (1.00-in.) in diameter. Records of the total

FIGURE 3-9. SCHEMATIC REPRESENTATION OF SEED FUEL RODS
[Ref. 14, Fig. 3-9]

FIGURE 3-10. CROSS SECTIONAL DIMENSIONS IN INCHES OF THE FUEL ASSEMBLIES
[Ref. 14, p. 39]

weights of intact assemblies in storage are available (Table 3-4). The intact assemblies, including attached shipping plates, are between 3302-mm (130-in.) and 3327.4-mm (131-in.) long, allowing for the 25.4-mm (1-in.) maximum extent that the studs and nuts for attaching the shipping plates were allowed to protrude beyond the Zircaloy-4 support shell [Ref. 15, pp. 18-20 and Westinghouse Bettis Atomic Power Laboratory Drawing. LWBR TR-19.4. "Product Dwg Seed Fuel Assembly." July 19, 1998. 927J464].

FIGURE 3-11. SEED ASSEMBLY CONSTRUCTION
[Ref. 12, p. 4]

3.1.1.2 Description of SNF from the Blanket Regions

Three different binary mixtures were used to fabricate the fuel in the Standard Blanket Region (1.214, 1.668, and 2.005 wt % fissile) [Ref. 6, Table II-2], and three different binary mixtures were used to fabricate the fuel in the Power-Flattening Blanket Region (1.654, 2.009, and 2.739 wt % fissile) [Ref. 6, Table II-2], resulting in six enrichments of binary blanket pellets. As in the Seed Region, the tops and bottoms of the fuel rods were stacked with ThO_2 pellets, and between the two fertile end stacks was a variable length binary ThO_2 - UO_2 stack. The axial zoning for the Type I blanket modules and the standard blanket sides of the Type II and Type III blanket modules is shown in Figure 3-7, and in Figure 3-8 for the power-flattening sides of the Type II and Type III modules.

3.1.1.2.1 Fuel Pellets from the Blanket Regions

There were four types of fuel pellets manufactured for the standard blanket rods, and four types manufactured for the power-flattening blanket rods. A distinction is made here between a chamfer, which extends roughly the same distance axially and radially, and a taper, which extends much farther along the axial direction. The binary pellets were right circular cylinders that were tapered and dished on both ends to discourage ridging of cladding due to pellet hour-glassing and to reduce axial expansion of the fuel (pin) stack. The thoria pellets were chamfered and dished on both ends. Pellets in the blanket regions were roughly twice as large in diameter as the seed pellets (Table 3-13 and Table 3-14). Short shim pellets of thoria were used near the top and bottom of the fuel stack to make up the desired stack length. A spring-bearing thoria pellet with only one dished end was used at the top of the fuel stack [Ref. 14, p.34].

Table 3-13. Characteristics of Pellets in the Standard Blanket
[Ref. 14, p. 33 (except as noted)]

Property (units)	Standard Blanket Region Enrichment Zone			
	High (2.005 wt%) ¹	Medium (1.668 wt %) ¹	Low (1.214 wt%) ¹	Thoria
Diameter ^a [mm (in)] ¹	12.9667 (0.5105)	12.9667 (0.5105)	12.9667 (0.5105)	12.9667 (0.5105)
Diameter ^b [mm (in)]	12.9667 ± .0127 (0.5105 ± .0005)	12.9667 ± .0127 (0.5105 ± .0005)	12.9667 ± .0127 (0.5105 ± .0005)	12.9667 ± .0127 (0.5105 ± .0005)
Length ^a [mm (in)] ¹	19.939 (0.785)	22.0472 (0.868)	13.487 (0.531)	15.6464 (0.616)
Length ^b [mm (in)]	19.939 ± .508 (0.785 ± .020)	22.098 ± .508 (0.870 ± .020)	13.462 ± .508 (0.530 ± .020)	15.621 ± .508 (0.615 ± .020)
Taper or Chamfer Depth ^b [mm (in)] ³	0.0762 ± 0.0508 (0.003 ± 0.002)	0.0762 ± 0.0508 (0.003 ± 0.002)	0.0762 ± 0.0508 (0.003 ± 0.002)	0.1524 ± 0.1016 (0.006 ± 0.004)
Taper or Chamfer Length ^b [mm (in)] ³	3.81 ± 1.27 (0.150 ± 0.050)	3.81 ± 1.27 (0.150 ± 0.050)	3.81 ± 1.27 (0.150 ± 0.050)	0.1524 ± 0.1016 (0.006 ± 0.004)
End Dish Spherical Radius ^b [mm (in)] ²	36.5506 (1.439)	36.5506 (1.439)	36.5506 (1.439)	36.5506 (1.439)
End Shoulder Width ^b [mm (in)]	1.397 ± 0.381 (0.055 ± 0.015)	1.397 ± 0.381 (0.055 ± 0.015)	1.397 ± 0.381 (0.055 ± 0.015)	1.397 ± 0.381 (0.055 ± 0.015)
End Face Dish Depth ^b [mm (in)]	0.3556 ± 0.1016 (0.014 ± 0.004)	0.3556 ± 0.1016 (0.014 ± 0.004)	0.3556 ± 0.1016 (0.014 ± 0.004)	0.3556 ± 0.1016 (0.014 ± 0.004)
Void Fraction ^a (of chamfers, dishes, and chip defects) ³	0.01600	0.01335	0.02494	0.01399
Percent Theoretical Density ^{a3}	98.115	98.224	98.608	97.796
Theoretical Density (g/cm ³) ³	10.016	10.013	10.009	9.999

^aAverage as built.

^bDesign specification.

1. Ref. 14, Table 3-4; use as 'most conservative' fissile loading

2. Ref. 2, Table 2

3. Ref. 5, p. 20 (Table 4)

Table 3-14. Characteristics of Pellets in the Power Flattening Blanket
[Ref. 14, p. 33 (except as noted)]

Property (units)	Power-Flattening Blanket Region Enrichment Zone			
	High (2.739 wt%) ¹	Medium (2.009 wt%) ¹	Low (1.654 wt%) ¹	Thoria
Diameter ^a [mm (in)] ¹	11.9278 (0.4696)	11.9253 (0.4695)	11.9253 (0.4695)	11.9278 (0.4696)
Diameter ^b [mm (in)]	11.9253 ± .0127 (0.4695 ± .0005)	11.9253 ± .0127 (0.4695 ± .0005)	11.9253 ± .0127 (0.4695 ± .0005)	11.9253 ± .0127 (0.4695 ± .0005)
Length ^a [mm (in)] ¹	17.8054 (0.701)	19.9644 (0.786)	22.098 (0.870)	11.3538 (0.447)
Length ^b [mm (in)]	17.78 ± .508 (0.700 ± .020)	19.939 ± .508 (0.785 ± .020)	22.098 ± .508 (0.870 ± .020)	11.303 ± .508 (0.445 ± .020)
Taper or Chamfer Depth ^b [mm (in)] ³	0.06096 ± .03556 (0.0024 ± 0.0014)	0.06096 ± .03556 (0.0024 ± 0.0014)	0.06096 ± .03556 (0.0024 ± 0.0014)	0.1524 ± 0.1016 (0.006 ± 0.004)
Taper or Chamfer Length ^b [mm (in)] ³	3.81 ± 1.27 (0.150 ± 0.050)	3.81 ± 1.27 (0.150 ± 0.050)	3.81 ± 1.27 (0.150 ± 0.050)	0.1524 ± 0.1016 (0.006 ± 0.004)
End Dish Spherical Radius ^b [mm (in)] ²	29.4894 (1.161)	29.4894 (1.161)	29.4894 (1.161)	29.4894 (1.160)
End Shoulder Width ^b [mm (in)]	1.397 ± 0.381 (0.055 ± 0.015)	1.397 ± 0.381 (0.055 ± 0.015)	1.397 ± 0.381 (0.055 ± 0.015)	1.397 ± 0.254 (0.055 ± 0.010)
End Face Dish Depth ^b [mm (in)]	0.3556 ± 0.1016 (0.014 ± 0.004)	0.3556 ± 0.1016 (0.014 ± 0.004)	0.3556 ± 0.1016 (0.014 ± 0.004)	0.3556 ± 0.1016 (0.014 ± 0.004)
Void Fraction ^a (of chamfers, dishes, and chip defects) ³	0.01578	0.01753	0.01998	0.01966
Percent Theoretical Density ^{a,3}	97.906	98.041	98.034	98.057
Theoretical Density (g/cm ³) ³	10.022	10.016	10.013	9.999

^aAverage as built.

^bDesign specification.

1. Ref. 14, Table 3-4; use as 'most conservative' fissile loading

2. Ref. 2, Table 2

3. Ref. 5, p. 20 (Table 4)

3.1.1.2.2 Fuel Rods from the Blanket Regions

There were 13 types of blanket rods (Figure 3-12). The first digit of the rod type number indicates whether a rod is a standard blanket rod (Types 11 through 16) or a power flattening blanket rod (Types 21 through 27). Rods with even type numbers were fixed to the tops of the assemblies; odd numbered rods were fixed to the bottoms of the assemblies. As-built characteristics of the Blanket Region fuel rods are given in Tables 3-14 & 3-15. The diameter of the mounting stems is not precisely known but historical documents imply that it does not exceed the value given in Table 3-16 [Ref. 12, Fig. 5 and Ref. 9, Note 1 of Figures II-4, II-5, and II-6]. The seamless cladding tubes were welded at both ends to solid end plugs of Zircaloy-4 (Table 3-16). Cladding inner and outer diameters are given in Table 3-8. The cladding tubes in the blanket regions were not freestanding; that is, they were not designed to withstand operating pressures and temperatures without collapsing on the pellet stack. Within the tube and above the pellet stack there was a plenum at the top of the fuel stack to accommodate gaseous fission product. The plenum housed an Inconel X-750 wire compression spring (Table 3-9) and a support sleeve of seamless Type 348 stainless steel tubing [support-sleeve material is identified in Ref. 2, Table 5, p. 21]. The spring discouraged the formation of gaps between pellets while the support sleeve prevented collapse of the cladding against the compression spring.

Table 3-15. Characteristics of Fuel Rods in the Blanket Regions
[Ref. 14, pgs. 13, 15, &30 (except as noted)]

Rod Type	Overall Length [mm (in)]	Length of Mounting Stem [mm (in)]	Length of Binary Stack [mm (in)] ¹	Fissile Concentration of Binary Stack ^a (wt% fissile)	Initial Fissile Mass Loading (g/rod)
11	3096.26 (121.9)	107.442 (4.23)	1066.8 (42)	1.214	16.45
12	3096.26 (121.9)	107.442 (4.23)	1066.8 (42)	1.214	16.45
13	3098.8 (122.0)	110.49 (4.35)	1778 (70)	2.005	45.47
14	3098.8 (122.0)	110.49 (4.35)	1422.4 (56)	1.668	30.34
15	3101.34 (122.1)	113.538 (4.47)	2133.6 (84)	1.668	45.66
16	3101.34 (122.1)	113.538 (4.47)	2133.6 (84)	2.005	54.66
21	3096.26 (121.9)	107.442 (4.23)	1066.8 (42)	1.654	18.96
22	3096.26 (121.9)	107.442 (4.23)	1066.8 (42)	1.654	18.96
23	3098.8 (122.0)	110.49 (4.35)	1778 (70)	2.739	52.56
24	3098.8 (122.0)	110.49 (4.35)	1422.4 (56)	2.009	30.74
25	3101.34 (122.1)	113.538 (4.47)	2133.6 (84)	2.739	63.06
26	3101.34 (122.1)	113.538 (4.47)	2133.6 (84)	2.009	46.40
27	3106.42 (122.3)	116.84 (4.60)	2133.6 (84)	2.739	63.06

^aHistorical documents give conflicting values. The largest reported as-built values are listed here. The conflicting values are less than 0.4% less.

1. Ref. 2, Table 5

Table 3-16. Dimensions of Blanket Fuel Rods Parts
[Ref. 9, Fig. II-5]

Dimension [mm (in)]	Bottom Mounted Rods	Top Mounted Rods
Length of Plenum ²	251.46 ± 1.397 (9.9 ± .055)	251.46 ± 1.397 (9.9 ± .055)
Diameter of Mounting Stem	< 8.763 (0.345)	< 8.763 (0.345)
Length of fixed-end plug ¹	67.31 (2.65)	33.02 (1.30)
Length of free-end plug ¹	34.29 (1.350)	41.91 ^a (1.650)
Length of pellet stack ¹	2633.726 (103.69)	2660.396 (104.74)

^aIncludes hemispherical end.

1. Ref.2, Fig. 4

2. Ref. 14, p. 25

3.1.1.2.3 Fuel Assemblies from the Blanket Regions

There were 12 blanket modules, one surrounding each seed module. Blanket modules were categorized as Types I, II or III, depending on their shapes as viewed from above (Figure 3-2). Type I Blanket assemblies contain only Standard Blanket rods (Fig. 3-4), while Types II and III contain separate regions of Standard and Power Flattening Blanket Rods (Figure 3-5 and Figure 3-6). Key dimensions of the horizontal cross sections are given in Figure 3-10 and Table 3-17. Stabilization clamps on partially derodded assemblies alter the dimensions to some extent. [Ref. 12, Figs. A5-1, A5-2, and A5-3]

The as-built fissile concentration varied radially and axially within each assembly. The movable seed assemblies fit into 4.826-mm (0.190-in) thick Zircaloy-4 guide tubes that constituted the inner surfaces of the blanket assemblies. The interior distance between parallel interior faces of the blanket guide tubes was 258.572-mm (10.18-in). The blanket assemblies had 8 grids, the average masses of which are given in Table 3-18. The numbers of fuel rods per blanket assembly are given in Table 3-19. [Ref. 2, Fig. A1-2]

Table 3-17. Dimensions of Blanket Modules.
(see Figure 3-11)

Description (Refer to Figure 3-10)	Value	
	Millimeters	Inches
Type I		
Maximum corner-to-corner dimension	501.396	19.74
Distance between interior faces of guide tube	258.572	10.18
Thickness of the guide tube	4.826	0.190
Type II		
Maximum corner-to-corner dimension	561.848	22.12
Smaller exterior distance between parallel faces	434.4416	17.104
Larger exterior distance between parallel faces	489.996	19.29
Distance between interior faces of guide tube	258.572	10.18
Thickness of the guide tube	4.826	0.190
Type III		
Maximum corner-to-corner dimension	561.848	22.12
Exterior distance between parallel faces	489.996	19.29
Distance between interior faces of guide tube	258.572	10.18
Thickness of the guide tube	4.826	0.190

Table 3-18. Average Masses of Grid Structures in the Blanket Regions
[Ref. 14, Table 3-3]

Assembly Type	Masses of Grids (g/grid)			
	Standard Blanket		Power-Flattening Blanket	
	Core Average	Maximum Assembly Average	Core Average	Maximum Assembly Average
I	2232	2239	Not Applicable	Not Applicable
II	1312	1314	1524	1525
III	933	935	2223	2230

Table 3-19. Maximum Numbers of Rods of Each Type in Blanket and Reflector Modules.
 [Ref. 2, Figs. A1-2, A1-3, A1-4; Ref. 16, Fig. V-10 & V-13]

Rod Type	Assembly Type ^a				
	I	II	III	IV	V
11	60	39	29	0	0
12	66	41	30	0	0
13	78	45	32	0	0
14	72	43	31	0	0
15	84	46	32	0	0
16	84	47	33	0	0
21	0	21	31	0	0
22	0	25	36	0	0
23	0	33	46	0	0
24	0	29	41	0	0
25	0	179	276	0	0
26	0	8	8	0	0
27	0	8	8	0	0
31	0	0	0	115	82
32	0	0	0	113	84
Any	444	564	633	228	166

^aNo deductions made for 16 flux wells occupying selected rod positions in selected assemblies.

FIGURE 3-12. SCHEMATIC REPRESENTATION OF FUEL RODS FROM THE BLANKET REGIONS
[Ref. 14, p. 30]

3.1.1.3 Description of SNF from the Reflector Region

The Reflector Region was initially free of fissile material. There were two types of reflector modules (Type IV and V) based on their shapes (Figure 3-2).

3.1.1.3.1 Fuel Pellets from the Reflector Region

All pellets in reflector rods were thoria (no binary pellets). Pellets were right circular cylinders with square edges and they had dished ends to reduce axial expansion of the fuel stack. Reflector pellets were larger than pellets elsewhere in the core, with average as-built length 18.8214-mm (0.741-in) and diameter 18.83918-mm (0.7417-in). The design specified a spherical radius of curvature of the end dishes of 80.0608-mm (3.152-in) and an end-dish depth of 0.3556 ± 0.1016 -mm (0.014 ± 0.004 -in). The theoretical density of thoria is 9.999 g/cm^3 . The sintering process achieved an as-built density of 97.282 percent of theoretical density. The fraction of the volume of the otherwise right cylindrical pellets that is missing because of tapers, dished ends, and chip defects, that is, the as-built void fraction, is 0.01317. [Ref 14, p. 42]

3.1.1.3.2 Fuel Rods from the Reflector Region

Reflector rods were of two types: 31 and 32 (Figure 3-13). Both types initially contained only thoria pellets. Each reflector rod had a plenum at the top of the fuel stack, which housed an Inconel X-750 wire compression spring (Table 3-9) and a support sleeve of seamless Type 348 stainless steel tubing. The spring discouraged the formation of gaps between pellets while the support sleeve prevented collapse of the cladding against the compression spring. The length of the pellet stack was different for top- and bottom-mounted rods (Table 3-20). Top-mounted rods had hemispherical free-end plugs of Zircaloy-4 (Table 3-20). Bottom-mounted rods had square free-end plugs of Zircaloy-4 (Table 3-20). The diameter of the mounting stems is not precisely known, but historical documents imply that it does not exceed the value given in Table 3-20 [Ref.13, Fig. 5 and Ref. 9, note 1 of Figures II-4, II-5, and II-6]. Inner and outer diameters of the Zircaloy-4 cladding are given in Table 3-8.

Table 3-20. Dimensions of Reflector Fuel Rods

[Overall length, length of mounting stem, and lengths of end plugs are from Ref. 9].

Dimension [mm (in)]	Bottom Mounted Rods (Type 31)	Top Mounted Rods (Type 32)
Overall Length	2813.558 (110.77)	2813.558 (110.77)
Length of Fuel Stack	2563.876 (100.94)	2614.676 (102.94)
Length of Plenum	100.457 ± 1.016 (3.955 $\pm$ 0.040)	100.457 ± 1.016 (3.955 $\pm$ 0.040)
Length of Mounting Stem	75.692 (2.98)	75.692 (2.98)
Diameter of Mounting Stem	< 8.763 (0.345)	< 8.763 (0.345)
Length of fixed-end plug	95.25 (3.75)	53.975 (2.125)
Length of free-end plug	53.975 (2.125)	44.45 ^a (1.75)

^aIncludes hemispherical end.

3.1.1.3.3 Fuel Assemblies from the Reflector Region

There were 15 reflector assemblies. Reflector assemblies are categorized into Types IV and V, depending on their shapes as viewed from above (Figures 3-2, 3-14 and 3-15). The numbering of assemblies by Arabic numerals within each type gives each assembly a unique identifier. Key dimensions of the horizontal cross sections are given in Figure 3-11 and Table 3-21. Stabilization clamps on partially derodded assemblies alter the dimensions to some extent. The numbers of rods of each type in reflector assemblies are given in Table 3-18. Assemblies in the reflector region had six grids composed of AM-350 stainless steel. The volume of the grid metal in the fuel lattice was 6.915 cm³ (0.422in³) per fuel rod, which accounts for 80 percent of the total grid volume in the reflector assemblies. [Ref. 6, Table II-1]

Table 3-21. Dimensions of Reflector Assemblies
[Ref. 12, Fig. 24]

Description	Value	
	Millimeters	Inches
Type IV Assembly (metaphorically considered as a house)		
"Foundation" width	434.4416	17.104
"Rooftop" to "foundation" dimension	350.3676	13.794
Maximum corner-to-corner dimension	489.204	19.26
"Foundation" thickness	16.51	0.65
"Wall" thickness	5.334	0.21
"Roof" thickness	6.35	0.25
Type V Assembly (considered as a trapezoid on its base)		
"Base" width (maximum corner-to-corner dimension)	539.877	21.255
"Height "	229.235	9.025
"Top" width	314.9346	12.399
"Base" thickness	16.51	0.65
"Sides" thickness	14.224	0.56
"Top" thickness	4.62	0.30

FIGURE 3-13. SCHEMATIC REPRESENTATION OF REFLECTOR FUEL RODS
[Ref. 2, Fig. 5]

ROD LOCATION IS TO BE OCCUPIED
BY FLUX WELL IN MODULE IX-7

IDENTIFICATION LEGEND
EXAMPLE:

228 RODS (113 TOP MOUNTED)
832 D.A.
900 PITCH

FIGURE 3-14. LAYOUT OF RODS IN A TYPE IV REFLECTOR ASSEMBLY
[Ref. 14, p. 17]

FIGURE 3-15. LAYOUT OF RODS IN A TYPE V REFLECTOR ASSEMBLY
[Ref. 14, p. 18]

3.1.2 Thermal

Decay heat for intact assemblies can be estimated from predicted decay heat curves that were developed for the Shippingport LWBR. The decay heat curves represent the decay heat generation rates as a function of cooling time for the hottest intact seed, blanket, and reflector assemblies. As documented in Olson, et al. (1999), the maximum estimated heat generation rates for the various assemblies in 1992 (ten years after shutdown) are: [Ref. 14, p. 131]

Seed Assemblies (assuming 619 rods):	630 W (2,150 BTU/hr)
Blanket Assemblies (assuming 564 rods):	527 W (1,800 BTU/hr)
Reflector Assemblies (assuming 228 rods):	175 W (600 BTU/hr).

Further information on decay-heat from LWBR fuel comes from simulations performed with ORIGEN2, a computer program from the Radiation Safety Information Computational Center, which is associated with Oak Ridge National Laboratory. ORIGEN2 has been used to simulate the burn-up and decay of Shippingport LWBR Seed assembly. [Ref. 19] The thermal power due to radioactive decay (Table B-7) can be derived from the isotopic activities (Table B-6). The simulated extent of burn-up was 10,269.14 MWd per seed assembly. The assumed initial fissile loading of the simulated seed assembly was 16,892.84 g, which is approximately 2% greater than the average initial fissile loading reported in Table 3-11. These ORIGEN calculations indicate a slight decrease in heat generation per seed assembly (extrapolated to ~500 W/assembly in 1992 from Figure B-1 vs. 630 W reported above).

Estimates of axial thermal peaking factors can be derived from average and peak burnup data for individual fuel rods (Table 3-22). Estimates of the thermal conductivity of the two components (UO_2

and ThO₂) of the unirradiated fuel at elevated temperatures as a function of temperature [Ref. 5, Table 7] are presented in Table 3-23.

Table 3-22. Axial Peaking Factors Estimated from Peak and Average Burnups
[Ref. 5, p. 13]

Core Region	Peak Burnup (MWd/MTHM)	Maximum Rod Average Burnup (MWd/MTHM)	Estimated Axial Peaking Factor
Seed	53,400	29,800	1.79
Standard Blanket	23,200	13,200	1.76
Power Flattening Blanket	25,200	14,700	1.71
Reflector	4,500	2,200	2.05

Table 3-23. Thermal Conductivity of UO₂ and Thoria Fuel
[Ref. 5, p. 30]

Temperature (°F)	Thermal Conductivity (Btu/hr/ft/°F)	
	UO ₂	ThO ₂
500	3.4	4.1
1000	2.7	3.2
2000	1.8	2.1
3000	1.4	1.6
4000	1.1	1.2

3.1.3 Burn-up Data

Peak burnups (estimated and design) are shown in Table 3-24 for the various module types.

Table 3-24. Peak burnups (MWD/MTM)
[from Ref. 5, Table 1].

Burnup	Seed	Standard Blanket	Power Flattening Blanket	Reflector
Best Estimate at 18,000 EFPH	38,900	15,200	17,000	2,400
Best Estimate at 29,047 EFPH	53,400	23,200	25,200	4,500
Design at 18,000 EFPH	45,300	19,000	20,500	2,800
Design at 29,047 EFPH	62,500	29,600	30,800	5,600

Table 3-25. Fuel Quantities Assumed for the ORIGEN2 Calculations

Assembly Type	Basis of Comparison	Best Estimate (Table 3-11)	Assumed for the ORIGEN2 Calculation	Percent Difference
Seed I	Fissile Loading	16.53	16.89	2.2
Blanket II	Fissile Loading	25.00	25.02	0.1
Blanket III	Fissile Loading	29.85	29.44	-1.4
Reflector IV	Thoria Fuel Mass □	1580 ^a	1637 ^b	3.6

a Calculated as the fuel mass (from Table 3-10) times the number of rods (from Table 3-19)

b Calculated as the thorium mass plus the thorium mass times twice the ratio of the atomic weight of oxygen to that of thorium

3.1.4 Chemical Properties

The LWBR core was fueled with fertile Th-232 and fissile U-233, the relative concentrations of which varied axially and radially across the core to promote high neutron economy. The uranium that was used in fabricating the fuel was very highly enriched in U-233, but some isotopic impurities were present (Table 3-1). The design called for vertical fuel rods on a triangular pitch with the space between taken up by circulating cooling water. The fuel rods featured cladding tubes loaded with cylindrical fuel pellets of thoria (ThO₂) or a binary mixture of thoria and UO₂ and backfilled with helium at one atmosphere during welding [Ref. 14, and Ref. 5, p. 70.] The binary fuel is a solid solution fabricated from the two oxides in powder form. Processing of the well-mixed powder preparation achieved a nearly homogeneous structure owing to diffusion at elevated temperature during sintering [Ref. 18, Section II.C.3, p. II-3.]. Axial variation in fissile material concentration was achieved by loading individual fuel rods such that part of the length bore a binary mixture of fissile and fertile material and the rest bore only fertile material. Radial variation was achieved by the arrangement of fuel rods that differed in their axial loading and by using binary pellets of different binary mixtures, depending on the radial location of the rod. Zircaloy-4 with hafnium content less than 40 ppm was used for the cladding tubes and all other structures in the fuel region, except the grids, which were made of AM-350 stainless steel. The fuel and fuel components suffered minimal damage during operation. Extensive destructive and non-destructive examinations after shutdown confirmed that the fuel was in good condition with minimal deformation of the cladding and minimal cracking of fuel pellets.

4. DOE SNF Canister

A standard canister design has been proposed for use in the packaging, transport, and disposal of DOE SNF fuels [Ref. 17]. The canister design (Figure 4.1) includes nominal lengths of either 10- or 15-feet and diameters of 18- or 24-in. Beyond these basic dimensions, fuel-specific internals will be designed for each canister that provides fuel separation and/or a method of fixing neutron poisons within the package.

Current storage of all LWBR fuels precludes use of either standard canister diameter without some type of repackaging. In the case of LWBR fuel assemblies other than the seed assemblies, dimensional constraints may dictate some form of disassembly to utilize even the 24-in. canister.

4.1 DOE SNF Canister

The following conceptual design for the DOE SNF canister is taken from Reference 17, pages 4-6, and Appendix A. The canister is a right circular cylinder of stainless steel (Type 316L). This canister must be able to stand vertically when placed on a flat surface after being loaded with the SNF. The dimensions for the DOE SNF canister are a 457.2-mm (18.00-in.) outer diameter with a 9.525-mm (0.375-in.) wall thickness. The nominal internal length of the canister is 4117-mm (162.09-in.) and the nominal overall length is 4569-mm (179.92-in.). The canister maximum total weight is 2,721 kg. There is a tapered bottom carbon steel impact plate that varies in thickness from 15.24-mm (0.60-in.) at the edge to 50.8-mm (2.0-in.) in the center at the top and bottom boundaries of the canister. Length dimension of seed assemblies dictates use of the 15-ft long SNF canisters.

FIGURE 4-1. 18-IN. SNF CANISTER SECTION VIEW
[Ref. 17]

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APPENDIX A: Shippingport Fuel Inventories

Table A-1: Shippingport Fuel Inventories

Number of the specific type of fuel assemblies or the quantity of fuel to be canisterized for disposal.

Fuel Compound	Cladding	Site	Fuel Name	No. of Fuel Units	Fuel Unit	EOL Eff Enrich %	EOL Th (kg)	EOL U233 (kg)	U Mass (kg)	Total Mass (kg)	MTHM	Vol (M3)
THO2-UO2 CERAMIC	Zirconium	INEEL LMITCO	SHIPPINGPORT LWBR SEED [380]	12	ASSEMBLY	91.087	4945.000	150.771	165.524	10800.000	5.111	2.192
THO2-UO2 CERAMIC	Zirconium	INEEL LMITCO	SHIPPINGPORT LWBR BLKT III [376]	6	ASSEMBLY	93.020	8532.000	155.180	166.825	17400.000	8.599	3.387
THO2-UO2 CERAMIC	Zirconium	INEEL LMITCO	SHIPPINGPORT LWBR BLKT II [375]	3	ASSEMBLY	92.047	4251.999	73.371	79.710	8700.000	4.332	1.694
THO2-UO2 CERAMIC	Zirconium	INEEL LMITCO	SHIPPINGPORT LWBR BLKT I [374]	3	ASSEMBLY	91.113	3693.000	56.673	62.201	7500.000	3.755	1.212
THO2-UO2 CERAMIC	Zirconium	INEEL LMITCO	SHIPPINGPORT LWBR REFLECT. V [372]	6	ASSEMBLY	98.454	5835.000	9.552	9.702	11700.000	5.945	0.788
THO2-UO2 CERAMIC	Zirconium	INEEL LMITCO	SHIPPINGPORT LWBR REFLECT. IV [371]	9	ASSEMBLY	97.804	11459.997	24.937	25.497	22950.000	11.485	3.997
THO2-UO2 CERAMIC	Zirconium	INEEL LMITCO	SHIPPINGPORT LWBR SCRAP [379]	1	SCRAP	91.833	462.000	0.506	0.551	950.000	0.463	0.042
THO2-UO2 CERAMIC	Zirconium	INEEL LMITCO	SHIPPINGPORT LWBR SCRAP [378]	1	SCRAP	91.190	194.000	5.558	6.095	400.000	0.200	0.007
THO2-UO2 CERAMIC	Zirconium	INEEL LMITCO	S SCRAP [378]	2	SCRAP	97.528	1257.000	3.393	3.479	2600.000	1.260	0.035
THO2-UO2 CERAMIC	Zirconium	INEEL LMITCO	SHIPPINGPORT LWBR SCRAP [377]	4	SCRAP	92.835	1631.000	28.712	30.928	3400.000	1.662	0.149
THO2-UO2 CERAMIC	Zirconium	INEEL LMITCO	R SCRAP [377]									
THO2-UO2 CERAMIC	Zirconium	INEEL LMITCO	SHIPPINGPORT LWBR BLKT SCRAP [373]									
Totals							42260.995	508.653	550.512	86400.000	42.812	13.503

* Effective Enrichment % = $\Sigma (^{233}\text{U} + ^{235}\text{U} + ^{239}\text{Pu}) / \text{U}_{\text{TOT}}$ (in mass units)

Data from INEEL National Spent Nuclear Fuel Database as of: July 7, 1999. The information contained in this database is neither 'qualified' nor has it been validated/verified. It can be used in a qualitative manner for selection of fuels to be evaluated in conceptualized packaging. Specific fuel assemblies information must be gathered from specific, respective WAPD or other referenced documents for any detailed analyses.

All the Shippingport fuels assemblies and the scrap materials employ essentially an identical canister configuration for the dry storage facility. The size of the storage canister at 647.7-mm (25.5-in. OD) and 3718.8-mm (146.41-in) length precludes the use of these packages in a repository disposal package. All Shippingport LWR materials are candidates for repackaging for repository acceptance. Some of the assemblies (blanket and reflector modules) may be subject to derodding or partial disassembly to meet both dimensional constraints and/or fissile limits for existing standard SNF canister design(s). At the present time, only the seed assemblies are candidate for intact disposal in standard SNF canisters.

APPENDIX B: Burnup Data

Time Since Last Irradiation

Operation of the Shippingport LWBR reactor configuration covered five years between 1977 and 1982,

Shielding Source Terms

The gamma sources for the Shippingport seed fuel assemblies are given below in Table B-1 through B-3. These values represent the highest source exhibited by any LWBR assembly; refer to Section 3.1.2 for comparative heat generation rates for other types of assemblies. Photon values are for the years listed.

Table B-1 Photon Spectra for Activation Products
[Ref. 19]

Mean Photon Energy (MeV)	Calculated Photon Spectrum ^a as of Year (Photons/sec)						
	2000	2005	2010	2015	2020	2025	2030
1.50E-02	2.363E+11	1.208E+11	6.521E+10	3.692E+10	2.196E+10	1.383E+10	9.297E+09
2.50E-02	3.312E+11	1.034E+11	3.441E+10	1.262E+10	5.253E+09	2.519E+09	1.380E+09
3.75E-02	1.482E+11	6.585E+10	3.369E+10	1.916E+10	1.165E+10	7.374E+09	4.779E+09
5.75E-02	3.548E+10	1.967E+10	1.129E+10	6.668E+09	4.031E+09	2.492E+09	1.574E+09
8.50E-02	2.319E+10	1.187E+10	6.196E+09	3.297E+09	1.788E+09	9.915E+08	5.642E+08
1.25E-01	8.814E+10	5.647E+10	3.671E+10	2.407E+10	1.586E+10	1.050E+10	6.967E+09
2.25E-01	4.352E+10	1.869E+10	9.490E+09	5.469E+09	3.398E+09	2.196E+09	1.445E+09
3.75E-01	1.623E+11	4.747E+10	1.427E+10	4.534E+09	1.597E+09	6.575E+08	3.222E+08
5.75E-01	2.228E+11	7.054E+10	2.472E+10	1.011E+10	4.917E+09	2.761E+09	1.695E+09
8.50E-01	9.099E+10	6.130E+10	4.148E+10	2.823E+10	1.938E+10	1.347E+10	9.519E+09
1.25E+00	6.152E+12	3.202E+12	1.669E+12	8.714E+11	4.557E+11	2.391E+11	1.259E+11
1.75E+00	2.960E+09	1.979E+09	1.322E+09	8.839E+08	5.906E+08	3.948E+08	2.638E+08
2.25E+00	3.208E+07	1.662E+07	8.612E+06	4.462E+06	2.311E+06	1.197E+06	6.204E+05
2.75E+00	9.928E+04	5.144E+04	2.665E+04	1.381E+04	7.151E+03	3.705E+03	1.920E+03
3.50E+00	1.628E-06	1.468E-06	1.323E-06	1.193E-06	1.076E-06	9.704E-07	8.755E-07
5.00E+00	5.276E-09	5.276E-09	5.276E-09	5.276E-09	5.276E-09	5.276E-09	5.276E-09
7.00E+00	3.423E-10	3.423E-10	3.423E-10	3.423E-10	3.423E-10	3.423E-10	3.423E-10
1.10E+01	2.165E-11	2.165E-11	2.165E-11	2.165E-11	2.165E-11	2.165E-11	2.165E-11
Sum	7.537E+12	3.781E+12	1.948E+12	1.023E+12	5.462E+11	2.963E+11	1.637E+11

^aThe basis for the ORIGEN2 simulation is a Seed assembly. The initial fissile loading of the simulated assembly is 16,892.84 g, which is approximately 2% greater than the actual initial fissile loading. The simulated burnup is 10,269.14 MWd for the assembly.

Table B-2 Calculated Photon Spectra from Actinides and Their Daughters in Seed Fuel
[Ref. 19]

Mean Photon Energy (MeV)	Calculated Photon Spectrum ^a as of Year (Photon/s)						
	2000	2005	2010	2015	2020	2025	2030
1.50E-02	1.618E+13	1.546E+13	1.476E+13	1.410E+13	1.347E+13	1.288E+13	1.230E+13
2.50E-02	1.273E+12	1.215E+12	1.158E+12	1.105E+12	1.054E+12	1.006E+12	9.597E+11
3.75E-02	1.027E+12	9.808E+11	9.359E+11	8.939E+11	8.538E+11	8.157E+11	7.794E+11
5.75E-02	1.210E+12	1.159E+12	1.108E+12	1.061E+12	1.015E+12	9.706E+11	9.283E+11
8.50E-02	7.368E+12	7.029E+12	6.700E+12	6.390E+12	6.095E+12	5.814E+12	5.546E+12
1.25E-01	5.667E+11	5.412E+11	5.163E+11	4.929E+11	4.706E+11	4.494E+11	4.291E+11
2.25E-01	1.034E+13	9.856E+12	9.390E+12	8.953E+12	8.535E+12	8.138E+12	7.759E+12
3.75E-01	7.490E+11	7.169E+11	6.855E+11	6.560E+11	6.279E+11	6.010E+11	5.753E+11
5.75E-01	6.864E+12	6.543E+12	6.231E+12	5.938E+12	5.659E+12	5.394E+12	5.140E+12
8.50E-01	3.190E+12	3.041E+12	2.896E+12	2.761E+12	2.631E+12	2.508E+12	2.390E+12
1.25E+00	1.826E+11	1.741E+11	1.658E+11	1.581E+11	1.507E+11	1.436E+11	1.369E+11
1.75E+00	5.913E+11	5.637E+11	5.369E+11	5.117E+11	4.878E+11	4.649E+11	4.431E+11
2.25E+00	2.965E+05	3.567E+05	4.197E+05	4.855E+05	5.540E+05	6.251E+05	6.988E+05
2.75E+00	5.961E+12	5.682E+12	5.411E+12	5.157E+12	4.914E+12	4.683E+12	4.463E+12
3.50E+00	2.432E+04	2.298E+04	2.180E+04	2.077E+04	1.986E+04	1.907E+04	1.837E+04
5.00E+00	7.566E+03	7.014E+03	6.521E+03	6.085E+03	5.695E+03	5.344E+03	5.028E+03
7.00E+00	5.819E+02	5.310E+02	4.866E+02	4.480E+02	4.141E+02	3.844E+02	3.580E+02
1.10E+01	4.755E+01	4.255E+01	3.827E+01	3.462E+01	3.147E+01	2.876E+01	2.640E+01
Sum	5.550E+13	5.296E+13	5.050E+13	4.818E+13	4.597E+13	4.386E+13	4.185E+13

^aThe basis for the ORIGEN2 simulation is a Seed assembly. The initial fissile loading of the simulated assembly is 16,892.84 g, which is approximately 2% greater than the actual initial fissile loading. The simulated burnup is 10,269 MWd for the assembly.

Table B-3 Calculated Photon Spectra from Fission Products in Seed Fuel
[Ref. 19]

Mean Photon Energy (MeV)	Calculated Photon Spectrum ^a from Fission Products as of Year (Photon/s)						
	2000	2005	2010	2015	2020	2025	2030
1.50E-02	1.268E+15	1.123E+15	9.958E+14	8.831E+14	7.833E+14	6.950E+14	6.168E+14
2.50E-02	2.650E+14	2.340E+14	2.073E+14	1.838E+14	1.630E+14	1.446E+14	1.284E+14
3.75E-02	2.273E+14	2.006E+14	1.774E+14	1.572E+14	1.393E+14	1.236E+14	1.097E+14
5.75E-02	2.467E+14	2.185E+14	1.936E+14	1.717E+14	1.522E+14	1.351E+14	1.199E+14
8.50E-02	1.495E+14	1.322E+14	1.170E+14	1.037E+14	9.200E+13	8.162E+13	7.243E+13
1.25E-01	1.020E+14	8.913E+13	7.820E+13	6.882E+13	6.069E+13	5.362E+13	4.743E+13
2.25E-01	1.291E+14	1.143E+14	1.012E+14	8.970E+13	7.953E+13	7.054E+13	6.258E+13
3.75E-01	5.661E+13	4.979E+13	4.405E+13	3.906E+13	3.465E+13	3.075E+13	2.729E+13
5.75E-01	8.539E+14	7.568E+14	6.732E+14	5.994E+14	5.338E+14	4.754E+14	4.235E+14
8.50E-01	1.828E+13	1.275E+13	1.001E+13	8.202E+12	6.859E+12	5.814E+12	4.979E+12
1.25E+00	1.010E+13	7.310E+12	5.450E+12	4.156E+12	3.236E+12	2.570E+12	2.079E+12
1.75E+00	4.397E+11	3.450E+11	2.759E+11	2.247E+11	1.859E+11	1.560E+11	1.324E+11
2.25E+00	3.738E+07	2.293E+07	2.018E+07	1.791E+07	1.590E+07	1.412E+07	1.253E+07
2.75E+00	5.356E+05	1.706E+04	5.466E+02	1.754E+01	5.626E-01	1.818E-02	6.824E-04
3.50E+00	6.904E+04	2.219E+03	7.131E+01	2.292E+00	7.358E-02	2.437E-03	1.507E-04
5.00E+00	2.226E-05	2.227E-05	2.227E-05	2.227E-05	2.227E-05	2.227E-05	2.227E-05
7.00E+00	1.444E-06	1.445E-06	1.445E-06	1.445E-06	1.445E-06	1.445E-06	1.445E-06
1.10E+01	9.134E-08	9.138E-08	9.139E-08	9.139E-08	9.139E-08	9.139E-08	9.139E-08
Sum	3.327E+15	2.939E+15	2.604E+15	2.309E+15	2.049E+15	1.819E+15	1.615E+15

^aThe basis for the ORIGEN2 simulation is a Seed assembly. The initial fissile loading of the simulated assembly is 16,892.84 g, which is approximately 2% greater than the actual initial fissile loading. The simulated burnup is 10,269.14 MWd for the assembly.

Table B-4 α, n Neutron Sources for a Shippingport LWBR Seed Assembly *
[Ref. 19]

Nuclide	(α, n) Neutron Source ^a as of Year (Neutron/s)						
	2000	2005	2010	2015	2020	2025	2030
²¹² Bi	5.911E+07	5.634E+07	5.366E+07	5.114E+07	4.873E+07	4.644E+07	4.426E+07
²¹² Po	5.131E+08	4.891E+08	4.658E+08	4.439E+08	4.231E+08	4.032E+08	3.842E+08
²¹³ Po	2.337E+05	2.865E+05	3.394E+05	3.922E+05	4.451E+05	4.978E+05	5.506E+05
²¹⁶ Po	2.152E+07	2.052E+07	1.954E+07	1.862E+07	1.775E+07	1.691E+07	1.612E+07
²²⁰ Rn	7.493E+06	7.143E+06	6.802E+06	6.483E+06	6.178E+06	5.888E+06	5.611E+06
²²⁴ Ra	1.822E+06	1.736E+06	1.654E+06	1.576E+06	1.502E+06	1.431E+06	1.364E+06
²²⁸ Th	9.236E+05	8.811E+05	8.398E+05	8.004E+05	7.628E+05	7.269E+05	6.928E+05
²³² U	6.948E+05	6.621E+05	6.310E+05	6.014E+05	5.731E+05	5.462E+05	5.205E+05
Sum	6.052E+08	5.770E+08	5.496E+08	5.239E+08	4.994E+08	4.760E+08	4.537E+08

^aThe basis for the ORIGEN2 simulation is a Seed assembly. The initial fissile loading of the simulated assembly is 16,892.84 g, which is approximately 2% greater than the actual initial fissile loading. The simulated burnup is 10,269.14 MWd for the assembly.

Table B-5 Calculated Spontaneous Fission Neutron Source for Seed Fuel
[Ref. 19]

Nuclide	Spontaneous Fission Neutron Source ^a as of Year (Neutron/s)						
	2000	2005	2010	2015	2020	2025	2030
²³² U	2.327E+01	2.218E+01	2.114E+01	2.015E+01	1.920E+01	1.830E+01	1.744E+01
²³⁸ Pu	7.763E+02	7.464E+02	7.175E+02	6.898E+02	6.632E+02	6.376E+02	6.130E+02
²⁴⁰ Pu	6.623E+02	6.625E+02	6.626E+02	6.626E+02	6.626E+02	6.625E+02	6.623E+02
²⁴² Pu	1.846E+02	1.847E+02	1.847E+02	1.847E+02	1.847E+02	1.847E+02	1.847E+02
²⁴² Cm	8.835E+01	8.638E+01	8.429E+01	8.239E+01	8.054E+01	7.872E+01	7.695E+01
²⁴⁴ Cm	3.883E+04	3.207E+04	2.648E+04	2.187E+04	1.806E+04	1.491E+04	1.232E+04
²⁴⁶ Cm	1.371E+02	1.370E+02	1.369E+02	1.368E+02	1.367E+02	1.366E+02	1.365E+02
Sum	4.072E+04	3.392E+04	2.830E+04	2.366E+04	1.982E+04	1.665E+04	1.402E+04

^aThe basis for the ORIGEN2 simulation is a Seed assembly. The initial fissile loading of the simulated assembly is 16,892.84 g, which is approximately 2% greater than the actual initial fissile loading. The simulated burnup is 10,269.14 MWd for the assembly.

Decay Heat

The estimated isotopic activities through the year 2030 of one SNF canister packed with one LWBR seed fuel assembly [Ref. 6, p. 43] are given in Table B-6. The decay heat output is shown in Table B-7 and portrayed graphically in Figure B-1.

Comparative BOL and EOL fissile loadings (nominal per assembly) are shown in Table B-8 for a single seed assembly. BOL values only are also shown for blanket Type II and III configurations in Tables B-9 and B-10 respectively.

Table B-6 Calculated Isotopic Activity of the Seed Fuel by Year
[Ref. 19]

Nuclide	Isotopic Activity as of Year ^d (Ci)						
	2000	2005	2010	2015	2020	2025	2030
³ H	5.813E+01	4.391E+01	3.317E+01	2.505E+01	1.892E+01	1.429E+01	1.079E+01
¹⁰ Be	2.394E-06	2.394E-06	2.394E-06	2.394E-06	2.394E-06	2.394E-06	2.394E-06
¹⁴ C	8.892E-01	8.886E-01	8.881E-01	8.875E-01	8.870E-01	8.865E-01	8.859E-01
³⁶ Cl	1.859E-02	1.859E-02	1.859E-02	1.859E-02	1.859E-02	1.859E-02	1.859E-02
⁵¹ Cr	3.799E-68	5.515E-88	8.007-108	1.162-127	1.646-147	2.389-167	3.469-187
⁵⁴ Mn	1.768E-05	3.080E-07	5.365E-09	9.345E-11	1.624E-12	2.829E-14	4.928E-16
⁵⁵ Fe	2.141E+00	5.648E-01	1.490E-01	3.928E-02	1.035E-02	2.731E-03	7.202E-04
⁵⁹ Fe	4.746E-43	2.892E-55	1.762E-67	1.074E-79	6.444E-92	3.927-104	2.393-116
⁶⁰ Co	8.183E+01	4.240E+01	2.197E+01	1.138E+01	5.894E+00	3.054E+00	1.582E+00
⁵⁹ Ni	6.359E-02	6.359E-02	6.359E-02	6.358E-02	6.358E-02	6.358E-02	6.358E-02
⁶³ Ni	7.751E+00	7.465E+00	7.189E+00	6.923E+00	6.667E+00	6.421E+00	6.183E+00
⁶⁵ Zn	3.474E-07	1.936E-09	1.078E-11	6.008E-14	3.338E-16	1.860E-18	1.036E-20
⁷⁹ Se	3.637E-01	3.637E-01	3.637E-01	3.637E-01	3.637E-01	3.636E-01	3.636E-01
⁸⁵ Kr	1.985E+03	1.437E+03	1.040E+03	7.528E+02	5.448E+02	3.943E+02	2.854E+02
⁸⁷ Rb	1.429E-05	1.429E-05	1.429E-05	1.429E-05	1.429E-05	1.429E-05	1.429E-05
⁸⁹ Sr	6.909E-34	8.998E-45	1.172E-55	1.526E-66	1.960E-77	2.553E-88	3.325E-99
⁹⁰ Sr	2.321E+04	2.061E+04	1.830E+04	1.624E+04	1.442E+04	1.280E+04	1.137E+04
⁹⁰ Y	2.322E+04	2.061E+04	1.830E+04	1.625E+04	1.442E+04	1.281E+04	1.137E+04
⁹¹ Y	1.401E-28	5.642E-38	2.271E-47	9.145E-57	3.639E-66	1.464E-75	5.897E-85
⁹³ Zr	8.496E-01	8.496E-01	8.496E-01	8.496E-01	8.496E-01	8.496E-01	8.495E-01
⁹⁵ Zr	1.008E-25	2.583E-34	6.620E-43	1.697E-51	4.302E-60	1.103E-68	2.826E-77
^{93M} Nb	5.215E-01	5.857E-01	6.355E-01	6.741E-01	7.040E-01	7.272E-01	7.452E-01
⁹⁴ Nb	2.304E-02	2.304E-02	2.303E-02	2.303E-02	2.303E-02	2.302E-02	2.302E-02
⁹⁵ Nb	2.238E-25	5.734E-34	1.470E-42	3.767E-51	9.551E-60	2.448E-68	6.274E-77
^{95M} Nb	7.477E-28	1.916E-36	4.911E-45	1.259E-53	3.191E-62	8.179E-71	2.097E-79
⁹³ Mo	4.194E-03	4.190E-03	4.186E-03	4.181E-03	4.177E-03	4.173E-03	4.169E-03
⁹⁹ Tc	3.341E+00	3.341E+00	3.341E+00	3.341E+00	3.340E+00	3.340E+00	3.340E+00
¹⁰³ Ru	1.827E-45	1.856E-59	1.886E-73	1.916E-87	1.913-101	1.944-115	1.976-129
¹⁰⁶ Ru	6.643E-02	2.135E-03	6.860E-05	2.205E-06	7.072E-08	2.273E-09	7.303E-11
^{103M} Rh	1.647E-45	1.673E-59	1.700E-73	1.728E-87	1.725-101	1.753-115	1.781-129
¹⁰⁶ Rh	6.643E-02	2.135E-03	6.860E-05	2.205E-06	7.072E-08	2.273E-09	7.303E-11
¹⁰⁷ Pd	3.543E-03	3.543E-03	3.543E-03	3.543E-03	3.543E-03	3.543E-03	3.543E-03
¹¹⁰ Ag	2.311E-08	1.459E-10	9.210E-13	5.814E-15	3.660E-17	2.311E-19	1.459E-21
^{110M} Ag	1.737E-06	1.097E-08	6.924E-11	4.371E-13	2.752E-15	1.738E-17	1.097E-19
¹¹¹ Ag	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
^{113M} Cd	1.967E+00	1.551E+00	1.223E+00	9.646E-01	7.606E-01	5.998E-01	4.730E-01
¹¹³ Cd	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
^{113M} Cd	1.688E-42	7.968E-55	3.760E-67	1.775E-79	8.248E-92	3.892-104	1.837-116
¹¹⁴ In	7.240E-39	5.730E-50	4.536E-61	3.589E-72	2.802E-83	2.218E-94	1.756-105
^{114M} In	7.565E-39	5.987E-50	4.739E-61	3.751E-72	2.928E-83	2.318E-94	1.834-105
^{115M} In	1.186E-46	5.597E-59	2.641E-71	1.247E-83	5.793E-96	2.734-108	1.290-120
^{115M} Sn	2.936E-05	1.676E-07	9.572E-10	5.465E-12	3.111E-14	1.777E-16	1.014E-18
^{121M} Sn	4.719E-01	4.403E-01	4.109E-01	3.833E-01	3.576E-01	3.336E-01	3.113E-01
¹²³ Sn	4.639E-13	2.575E-17	1.429E-21	7.936E-26	4.381E-30	2.433E-34	1.351E-38
¹²⁵ Sn	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
¹²⁶ Sn	4.092E-01	4.092E-01	4.092E-01	4.092E-01	4.092E-01	4.092E-01	4.091E-01
¹²⁴ Sb	8.290E-31	6.126E-40	4.527E-49	3.344E-58	2.443E-67	1.805E-76	1.334E-85
¹²⁵ Sb	6.293E+01	1.801E+01	5.155E+00	1.475E+00	4.220E-01	1.208E-01	3.457E-02
¹²⁶ Sb	5.729E-02	5.729E-02	5.729E-02	5.729E-02	5.728E-02	5.728E-02	5.728E-02

Table B-6 Calculated Isotopic Activity of the Seed Fuel by Year [Ref. 19] (cont'd)

Nuclide	Isotopic Activity as of Year ^a (Ci)						
	2000	2005	2010	2015	2020	2025	2030
^{125m} Sb	4.092E-01	4.092E-01	4.092E-01	4.092E-01	4.092E-01	4.092E-01	4.091E-01
^{123m} Te	1.793E-16	4.577E-21	1.168E-25	2.982E-30	7.565E-35	1.931E-39	4.928E-44
^{125m} Te	1.536E+01	4.395E+00	1.258E+00	3.600E-01	1.030E-01	2.947E-02	8.434E-03
¹²⁷ Te	5.869E-15	5.319E-20	4.821E-25	4.369E-30	3.935E-35	3.566E-40	3.232E-45
^{127m} Te	5.992E-15	5.431E-20	4.922E-25	4.461E-30	4.017E-35	3.641E-40	3.299E-45
¹²⁹ Te	8.233E-55	3.596E-71	1.570E-87	6.858E-104	2.934E-120	1.282E-136	5.597E-153
^{129m} Te	1.265E-54	5.524E-71	2.412E-87	1.054E-103	4.508E-120	1.969E-136	8.598E-153
¹²⁹ I	1.628E-02	1.628E-02	1.628E-02	1.628E-02	1.628E-02	1.628E-02	1.628E-02
¹³¹ I	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
^{131m} Xe	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
¹³³ Xe	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
¹³⁴ Xe	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
¹³⁴ Cs	9.226E+01	1.719E+01	3.201E+00	5.962E-01	1.110E-01	2.067E-02	3.850E-03
¹³⁵ Cs	2.941E-01	2.941E-01	2.941E-01	2.941E-01	2.941E-01	2.941E-01	2.941E-01
¹³⁶ Cs	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
¹³⁷ Cs	2.270E+04	2.022E+04	1.802E+04	1.605E+04	1.430E+04	1.274E+04	1.135E+04
^{136m} Ba	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
^{137m} Ba	2.147E+04	1.913E+04	1.704E+04	1.518E+04	1.353E+04	1.205E+04	1.074E+04
¹⁴⁰ Ba	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
¹⁴⁰ La	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
¹⁴¹ Ce	3.199E-55	3.961E-72	4.904E-89	6.072E-106	7.360E-123	9.112E-140	1.128E-156
¹⁴² Ce	1.019E-05	1.019E-05	1.019E-05	1.019E-05	1.019E-05	1.019E-05	1.019E-05
¹⁴⁴ Ce	2.905E-02	3.384E-04	3.941E-06	4.591E-08	5.335E-10	6.214E-12	7.239E-14
¹⁴³ Pr	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
¹⁴⁴ Pr	2.905E-02	3.384E-04	3.942E-06	4.591E-08	5.335E-10	6.215E-12	7.239E-14
^{144m} Pr	3.486E-04	4.060E-06	4.730E-08	5.510E-10	6.402E-12	7.458E-14	8.687E-16
¹⁴⁴ Nd	4.220E-10	4.220E-10	4.220E-10	4.220E-10	4.220E-10	4.220E-10	4.220E-10
¹⁴⁷ Nd	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
¹⁴⁵ Pm	5.451E-03	4.482E-03	3.685E-03	3.030E-03	2.491E-03	2.048E-03	1.684E-03
¹⁴⁷ Pm	2.696E+02	7.195E+01	1.920E+01	5.125E+00	1.367E+00	3.648E-01	9.738E-02
^{148m} Pm	7.680E-44	3.756E-57	1.837E-70	8.982E-84	4.319E-97	2.112E-110	1.033E-123
¹⁴⁸ Pm	4.326E-45	2.115E-58	1.035E-71	5.059E-85	2.433E-98	1.190E-111	5.819E-125
¹⁴⁹ Sm	1.043E-07	2.523E-09	6.102E-11	1.476E-12	3.561E-14	8.613E-16	2.083E-17
¹⁴⁷ Sm	1.297E-06	1.301E-06	1.303E-06	1.303E-06	1.303E-06	1.303E-06	1.303E-06
¹⁵¹ Sm	1.273E+02	1.225E+02	1.179E+02	1.134E+02	1.091E+02	1.050E+02	1.011E+02
¹⁵² Eu	1.088E+00	8.431E-01	6.535E-01	5.065E-01	3.925E-01	3.043E-01	2.358E-01
¹⁵⁴ Eu	3.590E+02	2.399E+02	1.604E+02	1.072E+02	7.162E+01	4.787E+01	3.199E+01
¹⁵⁵ Eu	7.735E+01	3.846E+01	1.912E+01	9.507E+00	4.725E+00	2.349E+00	1.168E+00
¹⁵⁶ Eu	2.049E-125	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
¹⁵³ Gd	4.010E-07	2.147E-09	1.150E-11	6.156E-14	3.286E-16	1.760E-18	9.422E-21
¹⁶⁰ Tb	2.632E-26	6.574E-34	1.642E-41	4.102E-49	1.015E-56	2.534E-64	6.331E-72
²⁰⁶ Tl	1.459E-12	1.459E-12	1.459E-12	1.459E-12	1.459E-12	1.459E-12	1.459E-12
²⁰⁷ Tl	5.762E-01	6.728E-01	7.551E-01	8.254E-01	8.854E-01	9.365E-01	9.801E-01
²⁰⁸ Tl	1.698E+02	1.619E+02	1.541E+02	1.469E+02	1.400E+02	1.334E+02	1.271E+02
²¹⁰ Pb	1.288E-04	1.224E-04	1.200E-04	1.210E-04	1.250E-04	1.318E-04	1.410E-04
²¹¹ Pb	5.778E-01	6.747E-01	7.572E-01	8.277E-01	8.879E-01	9.391E-01	9.828E-01
²¹² Pb	4.726E+02	4.505E+02	4.290E+02	4.089E+02	3.896E+02	3.713E+02	3.539E+02
²¹¹ Bi	5.778E-01	6.747E-01	7.572E-01	8.277E-01	8.879E-01	9.391E-01	9.828E-01
²¹² Bi	4.726E+02	4.505E+02	4.290E+02	4.089E+02	3.896E+02	3.713E+02	3.539E+02
²¹² Po	3.028E+02	2.886E+02	2.749E+02	2.620E+02	2.496E+02	2.379E+02	2.267E+02

Table B-6 Calculated Isotopic Activity of the Seed Fuel by Year [Ref. 19] (cont'd)

Nuclide	Isotopic Activity as of Year: ^a (Ci)						
	2000	2005	2010	2015	2020	2025	2030
²¹⁵ Po	5.778E-01	6.747E-01	7.572E-01	8.277E-01	8.879E-01	9.391E-01	9.828E-01
²¹⁶ Po	4.726E+02	4.505E+02	4.290E+02	4.089E+02	3.896E+02	3.713E+02	3.539E+02
²¹⁹ Rn	5.778E-01	6.747E-01	7.572E-01	8.277E-01	8.879E-01	9.391E-01	9.828E-01
²²⁰ Rn	4.726E+02	4.505E+02	4.290E+02	4.089E+02	3.896E+02	3.713E+02	3.539E+02
²²³ Fr	7.957E-03	9.293E-03	1.043E-02	1.140E-02	1.223E-02	1.294E-02	1.354E-02
²²³ Ra	5.778E-01	6.747E-01	7.572E-01	8.277E-01	8.879E-01	9.391E-01	9.828E-01
²²⁴ Ra	4.726E+02	4.505E+02	4.290E+02	4.089E+02	3.896E+02	3.713E+02	3.539E+02
²²⁶ Ra	7.430E-05	9.464E-05	1.158E-04	1.376E-04	1.603E-04	1.837E-04	2.079E-04
²²⁸ Ra	4.303E-02	4.489E-02	4.600E-02	4.666E-02	4.706E-02	4.729E-02	4.743E-02
²²⁷ Ac	5.766E-01	6.734E-01	7.559E-01	8.262E-01	8.862E-01	9.374E-01	9.810E-01
²²⁷ Th	5.698E-01	6.654E-01	7.468E-01	8.163E-01	8.757E-01	9.262E-01	9.693E-01
²²⁸ Th	4.714E+02	4.497E+02	4.286E+02	4.085E+02	3.893E+02	3.710E+02	3.536E+02
²²⁹ Th	2.689E-01	3.298E-01	3.906E-01	4.514E-01	5.122E-01	5.730E-01	6.337E-01
²³⁰ Th	9.288E-03	9.665E-03	1.004E-02	1.042E-02	1.080E-02	1.118E-02	1.155E-02
²³¹ Th	6.271E-04	6.271E-04	6.271E-04	6.271E-04	6.271E-04	6.271E-04	6.271E-04
²³² Th	4.764E-02	4.764E-02	4.764E-02	4.764E-02	4.764E-02	4.764E-02	4.764E-02
²³⁴ Th	1.814E-05	1.814E-05	1.814E-05	1.814E-05	1.814E-05	1.814E-05	1.814E-05
²³¹ Pa	1.234E+00	1.234E+00	1.234E+00	1.234E+00	1.234E+00	1.234E+00	1.234E+00
²³³ Pa	1.273E-03	1.276E-03	1.279E-03	1.283E-03	1.286E-03	1.290E-03	1.294E-03
^{234m} Pa	1.814E-05	1.814E-05	1.814E-05	1.814E-05	1.814E-05	1.814E-05	1.814E-05
²³⁴ Pa	2.358E-08	2.358E-08	2.358E-08	2.358E-08	2.358E-08	2.358E-08	2.358E-08
²³² U	4.593E+02	4.378E+02	4.172E+02	3.976E+02	3.789E+02	3.611E+02	3.441E+02
²³³ U	1.292E+02	1.292E+02	1.292E+02	1.292E+02	1.292E+02	1.292E+02	1.292E+02
²³⁴ U	8.397E+00	8.397E+00	8.397E+00	8.397E+00	8.397E+00	8.397E+00	8.397E+00
²³⁵ U	6.271E-04	6.271E-04	6.271E-04	6.271E-04	6.271E-04	6.271E-04	6.271E-04
²³⁶ U	1.363E-03	1.363E-03	1.363E-03	1.363E-03	1.363E-03	1.363E-03	1.363E-03
²³⁷ U	8.553E-06	6.723E-06	5.285E-06	4.155E-06	3.266E-06	2.567E-06	2.018E-06
²³⁸ U	1.814E-05	1.814E-05	1.814E-05	1.814E-05	1.814E-05	1.814E-05	1.814E-05
²³⁷ Np	1.273E-03	1.276E-03	1.279E-03	1.283E-03	1.286E-03	1.290E-03	1.294E-03
²³⁶ Pu	7.883E-06	2.340E-06	6.959E-07	2.083E-07	6.364E-08	2.078E-08	8.072E-09
²³⁷ Pu	8.632E-46	7.615E-58	6.719E-70	5.928E-82	5.151E-94	4.544E-106	4.009E-118
²³⁸ Pu	5.004E+00	4.810E+00	4.625E+00	4.446E+00	4.274E+00	4.109E+00	3.951E+00
²³⁹ Pu	2.823E-01	2.822E-01	2.822E-01	2.822E-01	2.821E-01	2.821E-01	2.820E-01
²⁴⁰ Pu	1.658E-01	1.659E-01	1.659E-01	1.659E-01	1.659E-01	1.659E-01	1.658E-01
²⁴¹ Pu	3.486E+01	2.741E+01	2.154E+01	1.694E+01	1.331E+01	1.046E+01	8.227E+00
²⁴² Pu	4.184E-04	4.184E-04	4.184E-04	4.185E-04	4.185E-04	4.185E-04	4.185E-04
²⁴⁴ Pu	5.389E-11	5.389E-11	5.389E-11	5.389E-11	5.389E-11	5.389E-11	5.389E-11
²⁴¹ Am	1.692E+00	1.926E+00	2.105E+00	2.241E+00	2.344E+00	2.420E+00	2.474E+00
^{242m} Am	1.645E-02	1.608E-02	1.572E-02	1.537E-02	1.502E-02	1.468E-02	1.435E-02
²⁴² Am	1.637E-02	1.600E-02	1.564E-02	1.529E-02	1.494E-02	1.461E-02	1.428E-02
²⁴³ Am	3.198E-03	3.197E-03	3.195E-03	3.194E-03	3.192E-03	3.191E-03	3.189E-03
²⁴² Cm	1.356E-02	1.326E-02	1.294E-02	1.265E-02	1.236E-02	1.209E-02	1.181E-02
²⁴³ Cm	4.793E-03	4.244E-03	3.758E-03	3.328E-03	2.947E-03	2.609E-03	2.311E-03
²⁴⁴ Cm	2.826E-01	2.334E-01	1.927E-01	1.592E-01	1.314E-01	1.085E-01	8.964E-02
²⁴⁵ Cm	7.142E-05	7.139E-05	7.136E-05	7.134E-05	7.131E-05	7.128E-05	7.125E-05
²⁴⁶ Cm	4.734E-06	4.730E-06	4.727E-06	4.723E-06	4.720E-06	4.716E-06	4.713E-06
²⁴⁷ Cm	1.674E-11	1.674E-11	1.674E-11	1.674E-11	1.674E-11	1.674E-11	1.674E-11
Sum	9.771E+04	8.640E+04	7.669E+04	6.820E+04	6.072E+04	5.411E+04	4.826E+04

^aThe basis for the ORIGEN2 simulation is a Seed assembly. The initial fissile loading of the simulated assembly is 16,892.84 g, which is approximately 2% greater than the actual initial fissile loading. The simulated burnup is 10,269.14 MWd for the assembly.

Seed Decay Heat

FIGURE B-1. SEED DECAY HEAT
[calculated from Table B-7 data]

Table B-7 Thermal Output for a Single LWBR Seed Assembly
(calculated from Table B-7 Ci inputs; * Ref. 20)

Nuclide	W/Ci*	Isotopic Activities for Each Year: (Ci)	Thermal Output for Each Year: (W)	2005	W	2010	W	2015	W	2020	W	2025	W	2030	W
(Ci)	W/Ci	2000	W	2005	W	2010	W	2015	W	2020	W	2025	W	2030	W
3H	3.37E-05	5.81E+01	1.96E-03	4.39E+01	1.48E-03	3.32E+01	1.12E-03	2.51E+01	8.43E-04	1.89E+01	6.37E-04	1.43E+01	4.81E-04	1.08E+01	3.63E-04
10Be	1.20E-03	2.39E-06	2.88E-09	2.39E-06	2.88E-09	2.39E-06	2.88E-09	2.39E-06	2.88E-09	2.39E-06	2.88E-09	2.39E-06	2.88E-09	2.39E-06	2.88E-09
14C	2.93E-04	8.89E-01	2.61E-04	8.89E-01	2.61E-04	8.88E-01	2.60E-04	8.88E-01	2.60E-04	8.87E-01	2.60E-04	8.87E-01	2.60E-04	8.86E-01	2.60E-04
36Cl	1.46E-03	1.86E-02	2.72E-05	1.86E-02	2.72E-05	1.86E-02	2.72E-05	1.86E-02	2.72E-05	1.86E-02	2.72E-05	1.86E-02	2.72E-05	1.86E-02	2.72E-05
54Mn	4.98E-03	1.77E-05	8.80E-08	3.08E-07	1.53E-09	5.37E-09	2.67E-11	9.35E-11	4.65E-13	1.62E-12	8.09E-15	2.83E-14	1.41E-16	4.93E-16	2.45E-18
55Fe	1.38E-03	2.14E-00	2.94E-03	5.65E-01	7.77E-04	1.49E-01	2.05E-04	3.93E-02	5.40E-05	1.04E-02	1.42E-05	2.73E-03	3.76E-06	7.20E-04	9.90E-07
60Co	1.54E-02	8.18E+01	1.26E-00	4.24E+01	6.54E-01	2.20E+01	3.39E-01	1.14E+01	1.75E-01	5.89E-00	9.09E-02	3.05E-00	4.71E-02	1.58E-00	2.44E-02
59Ni	3.37E-03	6.36E-02	2.14E-04	6.36E-02	2.14E-04	6.36E-02	2.14E-04	6.36E-02	2.14E-04	6.36E-02	2.14E-04	6.36E-02	2.14E-04	6.36E-02	2.14E-04
63Ni	3.97E-04	7.75E-00	3.08E-03	7.47E-00	2.96E-03	7.19E-00	2.85E-03	6.92E-00	2.75E-03	6.67E-00	2.65E-03	6.42E-00	2.55E-03	6.18E-00	2.46E-03
65Zn	3.51E-03	3.47E-07	1.22E-09	1.94E-09	6.79E-12	1.08E-11	3.78E-14	6.01E-14	2.11E-16	3.34E-16	1.17E-18	1.86E-18	6.52E-21	1.04E-20	3.63E-23
79Se	2.49E-04	3.64E-01	9.05E-05	3.64E-01	9.05E-05	3.64E-01	9.05E-05	3.64E-01	9.05E-05	3.64E-01	9.05E-05	3.64E-01	9.05E-05	3.64E-01	9.05E-05
85Kr	1.50E-03	1.99E+03	2.97E-00	1.44E+03	2.15E-00	1.04E+03	1.56E-00	7.53E+02	1.13E-00	5.45E+02	8.16E-01	3.94E+02	5.90E-01	2.85E+02	4.27E-01
87Rb	8.36E-04	1.43E-05	1.19E-08	1.43E-05	1.19E-08	1.43E-05	1.19E-08	1.43E-05	1.19E-08	1.43E-05	1.19E-08	1.43E-05	1.19E-08	1.43E-05	1.19E-08
90Sr	1.16E-03	2.32E+04	2.69E+01	2.06E+04	1.14E+02	1.83E+04	2.12E+01	1.62E+04	1.89E+01	1.44E+04	1.67E+01	1.28E+04	1.49E+01	1.14E+04	1.32E+01
90Y	5.54E-03	2.32E+04	1.29E+02	2.06E+04	1.14E+02	1.83E+04	2.12E+01	1.62E+04	1.89E+01	1.44E+04	1.67E+01	1.28E+04	1.49E+01	1.14E+04	1.32E+01
93Zr	1.16E-04	8.50E-01	9.87E-05	8.50E-01	9.87E-05	8.50E-01	9.87E-05	8.50E-01	9.87E-05	8.50E-01	9.87E-05	8.50E-01	9.87E-05	8.50E-01	9.87E-05
93Mo	1.77E-04	5.22E-01	9.24E-05	5.86E-01	1.04E-04	6.36E-01	1.13E-04	6.74E-01	1.19E-04	7.04E-01	1.25E-04	7.27E-01	1.29E-04	7.45E-01	1.32E-04
94Nb	1.02E-02	2.30E-02	2.35E-04	2.30E-02	2.35E-04	2.30E-02	2.35E-04	2.30E-02	2.35E-04	2.30E-02	2.35E-04	2.30E-02	2.35E-04	2.30E-02	2.35E-04
95Mo	1.39E-03	7.48E-28	1.04E-30	1.92E-36	2.66E-39	4.91E-45	6.82E-48	1.26E-53	1.75E-56	3.19E-62	4.43E-65	8.18E-71	1.14E-73	2.10E-79	2.91E-82
93Mo	9.34E-05	4.19E-03	3.92E-07	4.19E-03	3.92E-07	4.19E-03	3.91E-07	4.18E-03	3.91E-07	4.18E-03	3.90E-07	4.17E-03	3.90E-07	4.17E-03	3.90E-07
99Tc	5.01E-04	3.34E-00	1.68E-03	3.34E-00	1.68E-03	3.34E-00	1.68E-03	3.34E-00	1.68E-03	3.34E-00	1.67E-03	3.34E-00	1.67E-03	3.34E-00	1.67E-03
106Ru	5.95E-05	6.64E-02	3.95E-06	2.14E-03	1.27E-07	6.86E-05	4.08E-09	2.21E-06	1.31E-10	7.07E-08	4.21E-12	2.27E-09	1.35E-13	7.30E-11	4.34E-15
106Rh	5.99E-03	6.64E-02	6.37E-04	2.14E-03	1.27E-07	6.86E-05	4.08E-09	2.21E-06	1.31E-10	7.07E-08	4.21E-12	2.27E-09	1.35E-13	7.30E-11	4.34E-15
107Pd	5.93E-05	3.54E-03	2.10E-07	3.54E-03	2.10E-07	3.54E-03	2.10E-07	3.54E-03	2.10E-07	3.54E-03	2.10E-07	3.54E-03	2.10E-07	3.54E-03	2.10E-07
110Ag	7.18E-02	2.31E-08	1.66E-10	1.46E-10	1.05E-12	9.21E-13	6.62E-15	5.81E-15	4.18E-17	3.66E-17	2.63E-19	2.31E-19	1.66E-21	1.46E-21	1.05E-23
110Mg	1.67E-02	1.74E-06	2.90E-08	1.10E-08	1.83E-10	6.92E-11	1.16E-12	4.37E-13	7.30E-15	2.75E-15	4.60E-17	1.74E-17	2.90E-19	1.10E-19	1.83E-21
113Mg	1.68E-03	1.97E-00	3.31E-03	1.55E-00	2.61E-03	1.22E-00	2.06E-03	9.65E-01	1.62E-03	7.61E-01	1.28E-03	6.00E-01	1.01E-03	4.73E-01	7.96E-04
119MSn	5.17E-04	2.94E-05	1.52E-08	1.68E-07	8.66E-11	9.57E-10	4.95E-13	5.47E-12	2.82E-15	3.11E-14	1.61E-17	1.78E-16	9.18E-20	1.01E-18	5.24E-22
121MSn	2.00E-04	4.72E-01	9.46E-05	4.40E-01	8.82E-05	4.11E-01	8.23E-05	3.83E-01	7.68E-05	3.58E-01	7.17E-05	3.34E-01	6.69E-05	3.11E-01	6.24E-05
123Sn	3.12E-03	4.64E-13	1.45E-15	2.58E-17	8.04E-20	1.43E-21	4.46E-24	7.94E-26	2.48E-28	4.36E-30	1.37E-32	2.43E-34	7.60E-37	1.35E-38	4.22E-41
126Sn	1.25E-03	4.09E-01	5.10E-04	4.09E-01	5.10E-04	4.09E-01	5.10E-04	4.09E-01	5.10E-04	4.09E-01	5.10E-04	4.09E-01	5.10E-04	4.09E-01	5.10E-04
125Sb	3.13E-03	6.29E+01	1.97E-01	1.80E+01	5.63E-02	5.16E-00	1.61E-02	1.48E-00	4.61E-03	4.22E-01	1.32E-03	1.21E-01	3.78E-04	3.46E-02	1.08E-04

227Ac	4.84E-04	5.77E-01	2.79E-04	6.73E-01	3.26E-04	7.56E-01	3.66E-04	8.26E-01	4.00E-04	8.86E-01	4.29E-04	9.37E-01	4.54E-04	9.81E-01	4.75E-04
227Th	3.65E-02	5.70E-01	2.08E-02	6.65E-01	2.43E-02	7.47E-01	2.73E-02	8.16E-01	2.98E-02	8.76E-01	3.20E-02	9.26E-01	3.38E-02	9.69E-01	3.54E-02
228Th	3.27E-02	4.71E+02	1.54E+01	4.50E+02	1.47E+01	4.29E+02	1.40E+01	4.09E+02	1.34E+01	3.89E+02	1.27E+01	3.71E+02	1.21E+01	3.54E+02	1.16E+01
229Th	3.06E-02	2.69E-01	8.23E-03	3.30E-01	1.01E-02	3.91E-01	1.20E-02	4.51E-01	1.38E-02	5.12E-01	1.57E-02	5.73E-01	1.75E-02	6.34E-01	1.94E-02
230Th	2.83E-02	9.29E-03	2.63E-04	9.67E-03	2.74E-04	1.00E-02	2.84E-04	1.04E-02	2.95E-04	1.08E-02	3.06E-04	1.12E-02	3.17E-04	1.16E-02	3.27E-04
231Th	5.61E-04	6.27E-04	3.52E-07	6.27E-04	3.52E-07	6.27E-04	3.52E-07	6.27E-04	3.52E-07	6.27E-04	3.52E-07	6.27E-04	3.52E-07	6.27E-04	3.52E-07
232Th	2.42E-02	4.76E-02	1.15E-03	4.76E-02	1.15E-03	4.76E-02	1.15E-03	4.76E-02	1.15E-03	4.76E-02	1.15E-03	4.76E-02	1.15E-03	4.76E-02	1.15E-03
234Th	4.05E-04	1.81E-05	7.35E-09	1.81E-05	7.35E-09	1.81E-05	7.35E-09	1.81E-05	7.35E-09	1.81E-05	7.35E-09	1.81E-05	7.35E-09	1.81E-05	7.35E-09
231Pa	3.01E-02	1.23E-00	3.72E-02	1.23E-00	3.72E-02	1.23E-00	3.72E-02	1.23E-00	3.72E-02	1.23E-00	3.72E-02	1.23E-00	3.72E-02	1.23E-00	3.72E-02
233Pa	2.27E-03	1.27E-03	2.89E-06	1.28E-03	2.90E-06	1.28E-03	2.90E-06	1.28E-03	2.91E-06	1.29E-03	2.92E-06	1.29E-03	2.93E-06	1.29E-03	2.94E-06
234MPa	4.94E-03	1.81E-05	8.97E-08	1.81E-05	8.97E-08	1.81E-05	8.97E-08	1.81E-05	8.97E-08	1.81E-05	8.97E-08	1.81E-05	8.97E-08	1.81E-05	8.97E-08
234Pa	1.44E-02	2.36E-08	3.39E-10	2.36E-08	3.39E-10	2.36E-08	3.39E-10	2.36E-08	3.39E-10	2.36E-08	3.39E-10	2.36E-08	3.39E-10	2.36E-08	3.39E-10
232U	3.21E-02	4.59E+02	1.47E+01	4.38E+02	1.41E+01	4.17E+02	1.34E+01	3.98E+02	1.28E+01	3.79E+02	1.22E+01	3.61E+02	1.16E+01	3.44E+02	1.10E+01
233U	2.91E-02	1.29E+02	3.76E-00	1.29E+02	3.76E-00	1.29E+02	3.76E-00	1.29E+02	3.76E-00	1.29E+02	3.76E-00	1.29E+02	3.76E-00	1.29E+02	3.76E-00
234U	2.88E-02	8.40E-00	2.42E-01	8.40E-00	2.42E-01	8.40E-00	2.42E-01	8.40E-00	2.42E-01	8.40E-00	2.42E-01	8.40E-00	2.42E-01	8.40E-00	2.42E-01
235U	2.62E-02	6.27E-04	1.64E-05	6.27E-04	1.64E-05	6.27E-04	1.64E-05	6.27E-04	1.64E-05	6.27E-04	1.64E-05	6.27E-04	1.64E-05	6.27E-04	1.64E-05
236U	2.71E-02	1.36E-03	3.69E-05	1.36E-03	3.69E-05	1.36E-03	3.69E-05	1.36E-03	3.69E-05	1.36E-03	3.69E-05	1.36E-03	3.69E-05	1.36E-03	3.69E-05
237U	1.89E-03	8.55E-06	1.62E-08	6.72E-06	1.27E-08	5.29E-06	1.00E-08	4.16E-06	7.87E-09	3.27E-06	6.18E-09	2.57E-06	4.86E-09	2.02E-06	3.82E-09
238U	2.54E-02	1.81E-05	4.60E-07	1.81E-05	4.60E-07	1.81E-05	4.60E-07	1.81E-05	4.60E-07	1.81E-05	4.60E-07	1.81E-05	4.60E-07	1.81E-05	4.60E-07
237Np	3.06E-02	1.27E-03	3.89E-05	1.28E-03	3.90E-05	1.28E-03	3.91E-05	1.28E-03	3.92E-05	1.29E-03	3.93E-05	1.29E-03	3.94E-05	1.29E-03	3.95E-05
236Pu	3.48E-02	7.88E-06	2.74E-07	2.34E-06	8.15E-08	6.96E-07	2.42E-08	2.08E-07	7.25E-09	6.36E-08	2.22E-09	2.08E-08	7.23E-10	8.07E-09	2.81E-10
238Pu	3.32E-02	5.00E-00	1.66E-01	4.81E-00	4.63E-01	4.63E-01	1.53E-01	4.45E-00	1.47E-01	4.27E-00	1.42E-01	4.11E-00	1.36E-01	3.95E-00	1.31E-01
239Pu	3.08E-02	2.82E-01	8.70E-03	2.82E-01	8.70E-03	2.82E-01	8.70E-03	2.82E-01	8.70E-03	2.82E-01	8.69E-03	2.82E-01	8.69E-03	2.82E-01	8.69E-03
240Pu	3.11E-02	1.66E-01	5.16E-03	1.66E-01	5.16E-03	1.66E-01	5.16E-03	1.66E-01	5.16E-03	1.66E-01	5.16E-03	1.66E-01	5.16E-03	1.66E-01	5.16E-03
241Pu	3.10E-05	3.49E+01	1.08E-03	2.74E+01	8.50E-04	2.15E+01	6.68E-04	1.69E+01	5.25E-04	1.33E+01	4.13E-04	1.05E+01	3.24E-04	8.23E-00	2.55E-04
242Pu	2.95E-02	4.18E-04	1.24E-05	4.18E-04	1.24E-05	4.18E-04	1.24E-05	4.19E-04	1.24E-05	4.19E-04	1.24E-05	4.19E-04	1.24E-05	4.19E-04	1.24E-05
244Pu	2.90E-02	5.39E-11	1.56E-12	5.39E-11	1.56E-12	5.39E-11	1.56E-12	5.39E-11	1.56E-12	5.39E-11	1.56E-12	5.39E-11	1.56E-12	5.39E-11	1.56E-12
241Am	3.32E-02	1.69E-00	5.62E-02	1.93E-00	6.40E-02	2.11E-00	6.99E-02	2.24E-00	7.44E-02	2.34E-00	7.79E-02	2.42E-00	8.04E-02	2.47E-00	8.22E-02
242MAm	3.95E-04	1.65E-02	6.50E-06	1.61E-02	6.35E-06	1.57E-02	6.21E-06	1.54E-02	6.07E-06	1.50E-02	5.93E-06	1.47E-02	5.80E-06	1.44E-02	5.67E-06
242Am	1.16E-03	1.64E-02	1.90E-05	1.60E-02	1.86E-05	1.56E-02	1.82E-05	1.53E-02	1.78E-05	1.49E-02	1.74E-05	1.46E-02	1.70E-05	1.43E-02	1.66E-05
243Am	3.21E-02	3.20E-03	1.03E-04	3.20E-03	1.03E-04	3.20E-03	1.03E-04	3.19E-03	1.03E-04	3.19E-03	1.03E-04	3.19E-03	1.03E-04	3.19E-03	1.02E-04
242Cm	1.16E-03	1.36E-02	1.58E-05	1.33E-02	1.54E-05	1.29E-02	1.50E-05	1.27E-02	1.47E-05	1.24E-02	1.44E-05	1.21E-02	1.40E-05	1.18E-02	1.37E-05
243Cm	3.67E-02	4.79E-03	1.76E-04	4.24E-03	1.56E-04	3.76E-03	1.38E-04	3.33E-03	1.22E-04	2.95E-03	1.08E-04	2.61E-03	9.58E-05	2.31E-03	8.48E-05
244Cm	3.50E-02	2.83E-01	9.89E-03	2.33E-01	8.16E-03	1.93E-01	6.74E-03	1.59E-01	5.57E-03	1.31E-01	4.60E-03	1.09E-01	3.80E-03	8.96E-02	3.14E-03
245Cm	3.32E-02	7.14E-05	2.37E-06	7.14E-05	2.37E-06	7.14E-05	2.37E-06	7.13E-05	2.37E-06	7.13E-05	2.37E-06	7.13E-05	2.36E-06	7.13E-05	2.36E-06
246Cm	3.27E-02	4.73E-06	1.55E-07	4.73E-06	1.55E-07	4.73E-06	1.55E-07	4.72E-06	1.55E-07	4.72E-06	1.54E-07	4.72E-06	1.54E-07	4.71E-06	1.54E-07
247Cm	3.20E-02	1.67E-11	5.35E-13	1.67E-11	5.35E-13	1.67E-11	5.35E-13	1.67E-11	5.35E-13	1.67E-11	5.35E-13	1.67E-11	5.35E-13	1.67E-11	5.35E-13
Sum (Ci)		9.77E+04		8.64E+04		7.67E+04		6.82E+04		6.07E+04		5.41E+04		4.83E+04	
Sum (W)			391	353		320		291		265		241		221	

Table B-8 Isotopic Activity Concentrations in Curies for a single seed LWBR

SEED Module (TYPE I).

Burnup:	10269.14 MWd (max)				
Burnup:	27749.70 MWd/MTHM				
BOL U-233:	16877.36 grams U-233 per element	EOL U-233:	1.292E+02	gms/Ci	13344.35
BOL U-234:	221.64 grams U-234 per element	EOL U-234:	8.397E+00		1343.31
BOL U-235:	15.46 grams U-235 per element	EOL U-235:	6.271E-04		289.92
BOL U-236:	3.44 grams U-236 per element	EOL U-236:	1.363E-03		21.06
BOL U-238:	63.57 grams U-238 per element	EOL U-238:	1.814E-05		53.92
BOL Th-232:	442731 grams Th-232 per element	EOL Th-232:	4.764E-02		434275.30
Fuel Meat:	UO ₂ -ThO ₂ (Urania-Thoria)				
Fuel Enrichment:	98.23 wt% U-233				
Clad:	Zircaloy-4				

Table B-9 Isotopic Activity Concentrations in Curies for a single Type II LWBR blanket

Standard/Power Flattening (PF) Blanket Module (TYPE II).

Burnup:	15098.75 MWd (max)
Burnup:	9682.70 MWd/MTHM
BOL U-233:	25020.61 grams U-233 per element
BOL U-234:	328.58 grams U-234 per element
BOL U-235:	22.92 grams U-235 per element
BOL U-236:	5.10 grams U-236 per element
BOL U-238:	94.24 grams U-238 per element
BOL Th-232:	1533876.10 grams Th-232 per element
Fuel Meat:	UO2-ThO2 (Urania-Thoria)
Fuel Enrichment:	98.23 wt% U-233
Clad:	Zircaloy-4

Table B-10 Isotopic Activity Concentrations in Curies for a single Type III LWBR blanket

Standard/Power Flattening (PF) Blanket Module (TYPE III).

Burnup:	14558.84 MWd (max)
Burnup:	8555.73 MWd/MTHM
BOL U-233:	29415.81 grams U-233 per element
BOL U-234:	386.30 grams U-234 per element
BOL U-235:	26.95 grams U-235 per element
BOL U-236:	5.99 grams U-236 per element
BOL U-238:	110.80 grams U-238 per element
BOL Th-232:	1671701.60 grams Th-232 per element
Fuel Meat:	UO ₂ -ThO ₂ (Urania-Thoria)
Fuel Enrichment:	98.23 wt% U-233
Clad:	Zircaloy-4