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Distribution of Characteristics of LWR Spent Fuel

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DISTRIBUTION OF CHARACTERISTICS OF LWR SPENT FUEL

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ABSTRACT

The Materials Characterization Center (MCC) at Battelle Pacific Northwest Laboratory (PNL) has the responsibility to select appropriate spent fuel Approved Testing Materials (ATMs) and to characterize, via hot-cell studies, certain detailed properties of the discharged fuel. The purpose of this report is to develop a collective description of the entire spent fuel inventory in terms of various fuel properties relevant to ATMs using information available from the Characteristics Data Base (CDB), which is sponsored by the U.S. Department of Energy's (DOE's) Office of Civilian Radioactive Waste Management.

A number of light-water reactor (LWR) characteristics were analyzed including assembly class representation, fuel burnup, enrichment, fuel fabrication data, defective fuel quantities, and, at PNL's specific request, linear heat generation rate (LHGR) and the utilization of burnable poisons. A quantitative relationship was developed between burnup and enrichment for BWRs and PWRs. The relationship shows that the existing BWR ATM is near the center of the burnup-enrichment distribution, while the four PWR ATMs bracket the center of the burnup range but are on the low side of the enrichment range. Fuel fabrication data are based on vendor specifications for new fuel. Defective fuel distributions were analyzed in terms of assembly class and vendor design. LHGR values were calculated from utility data on burnup and effective full-power days; these calculations incorporate some unavoidable assumptions which may compromise the value of the results. Only a limited amount of data are available on burnable poisons at this time.

Based on this distribution study, suggestions for additional ATMs are made. These are based on the class and design concepts and include BWR/2,3 barrier fuel, and the WE 17 x 17 class with integral burnable poison. Both should be at relatively high burnups.

1. INTRODUCTION

Determining the distribution of characteristics of light-water reactor (LWR) spent fuel is important to the design of a deep geological repository and the associated waste disposal forms as part of the Federal Waste Management System (FWMS). The Materials Characterization Center (MCC) at Battelle Pacific Northwest Laboratory (PNL) has the responsibility to select spent fuel approved testing materials (ATMs) for use in the investigation of nuclear waste disposal forms and to characterize, via hot-cell studies, certain of their detailed properties after burnup (such as grain size, fission product distribution, and fission gas release). The Characteristics Data Base (CDB),[1] sponsored by the U. S. Department of Energy's (DOE's) Office of Civilian Radioactive Waste Management, provides quantitative and descriptive data on all potential repository wastes, including LWR spent fuel. The purpose of this report is to develop a collective description of the entire spent fuel inventory by characterizing various fuel properties using information available from the CDB. This information will be used to supplement the MCC data and help determine how well the ATMs represent the spent fuel inventory.

The characteristics of fuels from the two types of LWRs, boiling-water reactors (BWRs) and pressurized-water reactors (PWRs), are distinct enough that the distributions are treated separately. The characteristics and properties that were analyzed included the fuel burnup, enrichment, cladding and assembly hardware composition, fuel fabrication data (grain size, density, porosity, and plenum pressurization data), and defective fuel quantities. In addition, at the request of the MCC, the linear heat generation rate (LHGR) was calculated and the utilization of burnable poisons was reviewed. All of these characteristics, with the exception of the last two, are available directly from the CDB. The LHGR calculations required additional data on effective full-power days (EFPDs). The CDB has only limited data on burnable poisons (this is largely vendor-proprietary data).

Data on quantities of discharged fuel, including enrichment, burnup, and EFPD, were obtained from the Energy Information Administration's (EIA's) Nuclear Fuel Data Form RW-859. The EIA compiles the RW-859 Data Base from utility-supplied information on the Nuclear Fuel Data Form. The EIA information used in this report is for spent fuel discharges as of December 31, 1987, except where noted otherwise.[2]

Data on fuel assembly descriptions were obtained directly from the major fuel vendors [Advanced Nuclear Fuels (ANF), Babcock & Wilcox (B&W), Combustion Engineering (CE), and Westinghouse(WE)], except for General Electric (GE). For GE fuel, data were obtained from Nuclear Regulatory Commission (NRC) dockets and other literature sources.[3] Because of the large number of assembly model types, the CDB has developed a classification scheme to group similar assemblies in a systematic manner. This scheme, described in the next chapter, greatly simplifies the tabulation of assembly-related data for a variety of applications.

2. BACKGROUND

2.1 CLASSIFICATION SCHEME FOR LWR FUEL ASSEMBLIES

The CDB has developed an assembly classification scheme to characterize LWR fuels in a well-defined and systematic manner.[4] A two-stage scheme was developed that consists of 22 broad categories, known as assembly classes, that are further divided into approximately 120 assembly types.

The assembly classes are determined by the physical configuration of the fuel rods into assemblies. The configuration is determined by the physical dimensions of the fuel assemblies and the design of the upper and lower core plates and the control elements. Within an assembly class, all assembly types are of a similar size (and, for PWRs, of the same array size), since these factors are controlled by the core configuration. The assembly class of the fuel for a particular reactor is fixed and is independent of fuel vendor or fuel design because it is controlled by the reactor core configuration. There are 9 generic classes (2 BWR and 7 PWR) and 13 reactor-specific classes (i.e., the fuels used by these reactors are unique to those reactors and are not used by any other reactors) which are listed in Table 1.

Characteristics other than the core configuration, such as the fuel vendor, materials of construction, fuel rod diameters, and other fuel assembly characteristics, are the basis for further subdivision into assembly type. Thus, the combination of assembly class, fuel vendor, and fuel design identifies a particular assembly type. Design developments by vendors may be used for more than one class of fuel; however, the combination of class, fuel vendor, and fuel design always specifies a unique assembly type. Determining distributions of fuel characteristics by assembly type is important for some studies, such as the analysis of defective fuels where improved fuel designs have been shown to reduce defective fuel quantities,[5] and is helpful for some aspects of describing the spent fuel inventory to determine how well the ATMs represent this inventory. Therefore, assembly types are used where appropriate, but generally the distribution of the various LWR fuel characteristics is categorized by assembly class in this report.

A more detailed description of the classification scheme as well as a complete listing of spent fuel by assembly class, assembly type, utility, and reactor name can be found in the work by Moore et al.[4]

Table 1. Assembly classes for BWRs and PWRs

Generic assembly classes	
BWR	PWR
GE BWR/2,3	B&W 15 X 15
GE BWR/4,5,6	B&W 17 X 17
	CE 14 X 14
	CE 16 X 16
	WE 14 X 14
	WE 15 X 15
	WE 17 X 17
Reactor-specific classes	
BWR	PWR
Big Rock Point	Fort Calhoun
Dresden 1	Haddam Neck
Elk River	Indian Point 1
Humboldt Bay	Palisades
LaCrosse	San Onofre 1
	St. Lucie 2
	South Texas 1&2
	Yankee Rowe

2.2 IDENTIFICATION OF APPROVED TESTING MATERIALS

The MCC has already selected and examined a number of approved testing materials (ATMs). The detailed characterization of these ATMs consists of performing measurements and developing descriptions for many fuel characteristics and properties including irradiation history, decay history, unusual in-core incidents, fission gas release, fuel cracking, cladding oxidation, fuel burnup, fuel enrichment, radionuclide inventory, radial and axial distributions of individual radionuclides, gap inventories, and other characteristics. The details of the generic characterization plan for MCC spent fuel ATMs can be found in the work by Barner.[6] The extensive information obtained by the MCC for each ATM can be found elsewhere.[7,8,9,10,11]. The H. B. Robinson 2 ATM is assembly type WE 15 X 15 WE LOPAR, Calvert Cliffs 1 ATM is type CE 14 X 14 CE, and Cooper Station is type GE 7 X 7 GE-3. In addition, a number of potential additional ATMs have been identified. The existing and potential ATMs are shown in Table 2.

Table 2. Existing and potential approved testing materials (ATMs)

Existing spent fuel ATMs					
ATM	Reactor	Discharge date	Assembly class	Burnup (MWd/kgM)	Fission gas release (%)
101	H. B. Robinson 2	05/06/74	WE 15 X 15	32	0.2
103	Calvert Cliffs 1	10/18/80	CE 14 X 14	33	0.3
104	Calvert Cliffs 1	04/17/82	CE 14 X 14	44	0.4 to 1.1
105	Cooper Station	05/21/82	GE BWR/4,5,6	34	0.6 to 7.9
106	Calvert Cliffs 1	10/18/80	CE 14 X 14	44	1.4 to 17
108	ATM-105 poisons	05/21/82	GE BWR/4,5,6	<34	Low

Potential spent fuel ATMs				
ATM	Reactor	Assembly class	Burnup (MWd/kgM)	Fission gas release (%)
107	WE PWR	WE 15 X 15	40	Low
109	GE BWR	TBD	High	TBD
110	WE PWR	WE 14 X 14	33	Low
111	WE PWR	WE 17 X 17	High	TBD
112	TBD	TBD	Moderate	Low

2.3 QUANTITIES OF LWR SPENT FUEL

The fuels used in domestic BWRs are represented by seven assembly classes. The spent fuel from the two generic classes (GE BWR/2,3 and GE BWR/4,5,6) represents 97% of current BWR fuel inventory and over 99% of the projected fuel discharges to 2020.

The fuels used in domestic PWRs are represented by 15 assembly classes. The spent fuel from the seven generic classes represents 90% of current PWR fuel inventory and 92% of the projected fuel discharges to 2020.

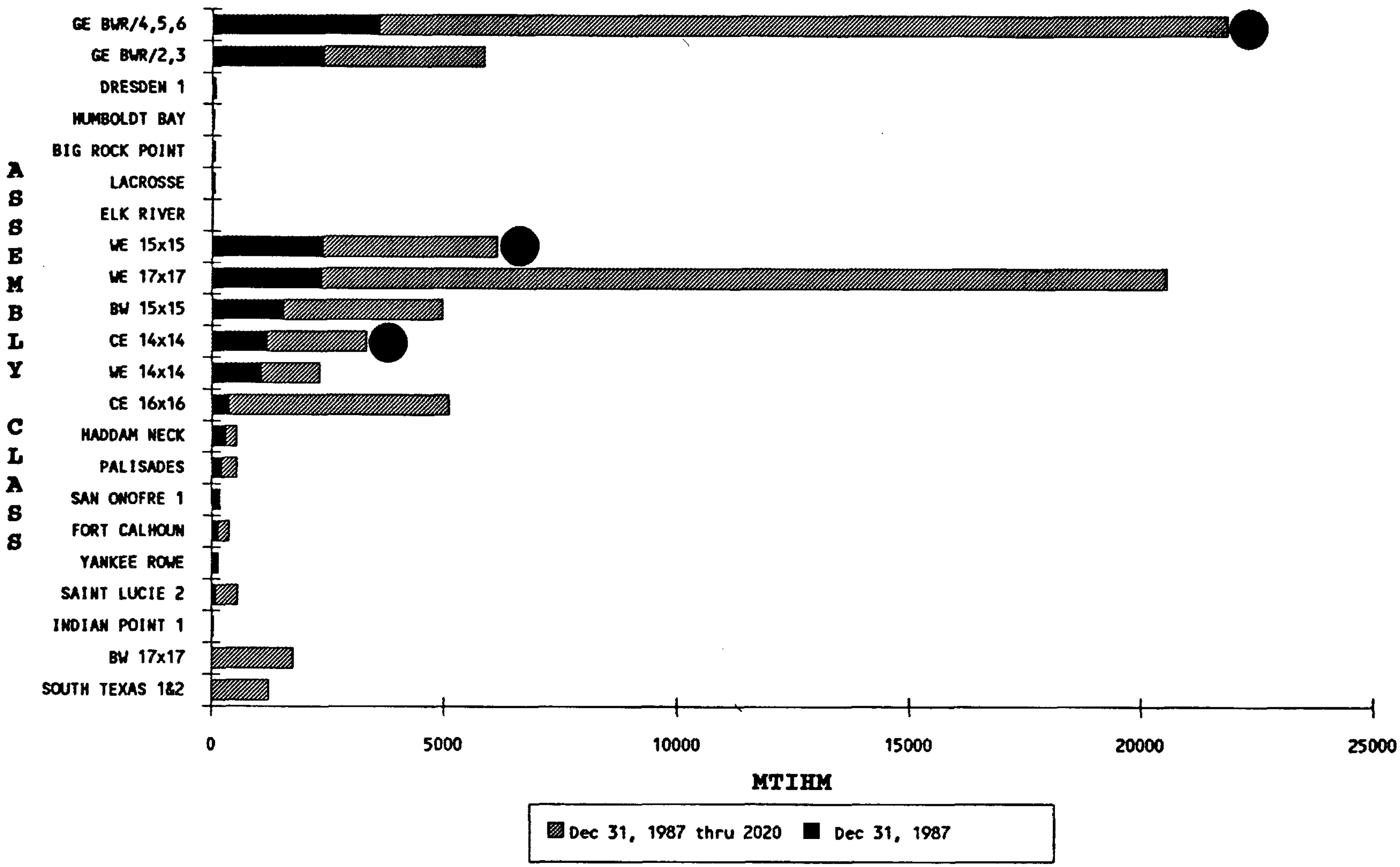
The quantities of LWR spent fuel in each class are shown in Table 3 and Fig. 1 for BWRs and PWRs. Figure 1 shows BWR classes first with PWR classes following. For both BWR and PWR classes, Fig. 1 is ordered from largest to smallest quantity according to historical data as of December 31, 1987. The assembly classes in Fig. 1 represented by one or more ATMs are shown with a large dot after the bar. The primary BWR assembly class, GE BWR 4,5,6, is represented. If additional BWR ATMs are obtained, the GE BWR/2,3 assembly class should be considered. Two large PWR assembly classes, WE 15 X 15 and CE 14 X 14, are represented. PWR class WE 17 X 17 contains the most fuel assemblies but is not represented. Clearly, an ATM for the WE 17 X 17 fuel assembly class should be added. For both BWRs and PWRs, later generation fuels should also be considered (e.g., GE barrier fuel and WE integral burnable poison fuel). These design aspects can probably be incorporated into ATMs from the BWR/2,3 class and the WE 17 x 17 class.

Table 3. Quantities of domestic LWR spent fuel[a]

BWR assembly class	Historical quantities as of Dec. 31, 1987 (MTIHM)	Projected quantities from 1988 to 2020 (MTIHM)
GE BWR/4,5,6	3587	18277
GE BWR/2,3	2406	3464
Dresden 1	87	0
Humboldt Bay	50	0
Big Rock Point	38	28
Lacrosse	38	30
Elk River (reprocessed)	5	0
PWR assembly class	**Historical quantities as of Dec. 31, 1987 (MTIHM)**	**Projected quantities from 1988 to 2020 (MTIHM)**
WE 15x15	2384	3760
WE 17x17	2365	18192
BW 15x15	1542	3429
CE 14x14	1188	2140
WE 14x14	1071	1258
CE 16x16	370	4736
Haddam Neck	304	234
Palisades	219	333
San Onofre 1	152	41
Fort Calhoun	143	233
Yankee Rowe	91	63
Saint Lucie 2	90	489
Indian Point 1	31	0
BW 17x17	2	1748
South Texas 1 & 2	0	1235

[a] R. S. Moore, D. A. Williamson, and K. J. Notz, A Classification Scheme for LWR Fuel Assemblies, ORNL/TM-10901, Oak Ridge National Laboratory, November 1988.

Figure 1. Quantities of Domestic LWR Spent Fuel



3. RESULTS

3.1 BURNUP AND ENRICHMENT

The burnup and initial enrichment are the primary characteristics of spent fuel, along with cooling time, that determine the radionuclide inventory. In general, the burnup increases monotonically with increasing enrichment. The weight of spent fuel in metric tons of initial heavy metal, sorted into burnup and enrichment bins, is shown in Figs. 2 and 3 for all domestic BWRs and PWRs, respectively. These figures show the burnup and enrichment distributions for the entire domestic LWR fuel inventory except defective fuels, which are atypical and have been excluded from these distributions.

The values in Fig. 2 with enrichments greater than 3.4% are stainless steel-clad fuels from Big Rock Point and Lacrosse. The values with enrichments less than 1.7% are BWR "first-cycle only" fuels. BWR first-cycle only fuel does not fall within the normal range due to the fact that this fuel tends to be of very low enrichment (as low as 0.72%) and is predominately placed on the core periphery where lower burnup occurs. The values in Fig. 3 with enrichments equal to or greater than 4.0% are high-enrichment stainless steel-clad PWR fuels used at Indian Point 1, Haddam Neck, San Onofre 1 and early use at Yankee Rowe.

Enrichment as a function of burnup for BWRs and PWRs is shown in Figs. 4 and 5, respectively, including projected discharges. For each reactor type (BWR and PWR), an empirical equation was developed by regression analysis to describe the relationship between burnup and initial fuel enrichment.[12] These equations are based on discharged fuel data through December 1988. Low and high enrichments were selected at +/- 0.7%, since this range includes 95% of the discharged fuel. The equations of the curves are:

For BWR reactors:

Low enrichment: $E = -0.5038 + 0.121756B - 0.001018B^2$
Standard enrichment: $E = 0.1962 + 0.121756B - 0.001018B^2$
High enrichment: $E = 0.8962 + 0.121756B - 0.001018B^2$

For PWR reactors:

Low enrichment: $E = 0.1694 + 0.085366B - 0.000351B^2$
Standard enrichment: $E = 0.8694 + 0.085366B - 0.000351B^2$
High enrichment: $E = 1.5694 + 0.085366B - 0.000351B^2$

where E is initial enrichment (% ^{235}U) and B is burnup (MWd/kgU).

Figures 4 and 5 show the five fuel ATMs. The single BWR ATM is near the center of the distribution and nearly on the statistical enrichment/burnup curve. The four PWR ATMs are close to the "standard" burnup and are also into the enhanced burnup region but still below projected maximum values. However, all four are below the lower burnup/enrichment curve; the major effect of this on radionuclide composition is higher actinide and activation product concentrations than population average for the respective burnups.[12] These observations suggest that future ATMs should (1) be at higher burnups, to represent the more radioactive fuels; and (2) have enrichments that place them close to the center curve. These objectives should be attainable concurrent with selection of assemblies that represent Class GE BWR/2,3 and PWR Class WE 17 x 17.

Figure 2. MTIHM Categorized By Burnup And Enrichment For All Historical BWR Assemblies

ENRICHMENT %	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
5.1																																																		
5.0																																																		
4.9																																																		
4.8																																																		
4.7																																																		
4.6																																																		
4.5																																																		
4.4																																																		
4.3																																																		
4.2																																																		
4.1																																																		
4.0																																																		
3.9													1	1	2	2	2	1																																
3.8																										1	1																							
3.7					3							3				5	3	4	2				1	1			1																							
3.6	1						1	1			5	3	3	4		1	1																																	
3.5										1					1			2	2	1	1																													
3.4																																																		
3.3																										2		1	1																					
3.2																							1		1	1																								
3.1																								1			2																							
3.0																							6		3		12	1	35																					
2.9																					5		11	24	39	14	35	90	7	109	34		1																	
2.8										3	1				6	1	6					18	1	11	74	31	81	74	38	142	19	4	8	1																
2.7														3	1		1	2	9	9	10		68	20	75	90	63	166	20	24	4	21	1	1																
2.6									6	1							1	1		13		25	60	8	40	60	28	33	110	43	18	1				20	1		1											
2.5								1			1		4	1	4	2	7	4	80	9	13	17	100	197	153	123	68	144	22	22	5	4																		
2.4					3			2			1		3					3	1	2																														
2.3							1			1		2	1			1	6	9	27	4	30	26	23	21	10	7		4	4	3																				
2.2				2	5	4		3	2	2	29	12	18	4	7	97	31	14	100	91	106	70	22	33	72	1				4																				
2.1	8	34	8	65	26	4	9	13	14	37	10	61	56	52	20	61	184	57	126	43	66	83	86	59	79	30	5		8																					
2.0																		38		45					1		15																							
1.9														3																																				
1.8									7		24		18	71	4	26	12	3	17	5	5				1																									
1.7																																																		
1.6									8																																									
1.5										32		15																																						
1.4																																																		
1.3																																																		
1.2																																																		
1.1							37		26	110	13																																							
1.0																																																		
0.9							24	16																																										
0.8																																																		
0.7			96	34					43																																									

BURNUP (GWd/MTIHM)

Figure 3. MTIHM Categorized By Burnup And Enrichment For All Historical PWR Assemblies

ENRICHMENT %	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
5.1																									
5.0																									
4.9																							9		
4.8																									
4.7																									
4.6																									
4.5																									
4.4																									
4.3																									
4.2					7																				
4.1													8										8		8
4.0																									
3.9																									
3.8																									
3.7																									
3.6																							1		
3.5																									
3.4																			1		1			15	14
3.3																			1	2	1			7	1
3.2																		18	1	3		3	8	3	7
3.1																				9	31	11	20	25	16
3.0																			15	6	2	4		11	18
2.9																				3	8	3	7		10
2.8																		14	5		13	1	1		21
2.7																			4				13	25	14
2.6																1	1	14		14	30	5	23	63	77
2.5																	8	1		1	35	6	12		
2.4												20	27	2		9			1	30		11			91
2.3																3	11	6	82	7		22		17	55
2.2																	26	16	55	10			29	20	6
2.1	30										1	7			21	63	275	67	75	2	19	7	20	19	19
2.0											11	13			2	22	6	41		12	17	9	2	19	
1.9				2						2			22	54	111	58	30	2	4	22	2	8	3	13	
1.8																22	2								
1.7											28	28													
1.6														54											
1.5													27												
1.4									9						6		1								
1.3																									
1.2																									
1.1																									
1.0																5									
0.9																									
0.8																									
0.7																			1						

ENRICHMENT %	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
5.1																									
5.0																									
4.9	9			1	1		1																		
4.8																									
4.7																									
4.6																									
4.5																									
4.4																									
4.3																									
4.2																									
4.1																									
4.0			30	10	45	30	11	94	60	45	1	2			19										
3.9			3		15	1							1												
3.8									12																
3.7		18	29	28	8	28		1	1				14	16			12								
3.6					4			9	52	4	22	39	59	7	3		3								
3.5					1	1		3	5	12	13	20	8	9	13	8	12	12							
3.4	10	3	1	20	24	43	42	88	101	32	67	40	34	33	3	9	5	5		4					
3.3	24	3	22	12	24	29	46	15	147	41	123	97	46	15		7		1							
3.2	19	11	26	13	33	94	109	150	93	113	47	64	49	37	9		2	1							
3.1	42	73	56	79	26	69	102	175	103	122	56	14	11	8	7		4								
3.0	84	5	48	120	152	132	100	135	88	35	51	20	1	15	4					2			1		
2.9	4	72	22	19	24	216	75	32	25	13	5	16	9		3	1									
2.8	74	25	35	94	97	77	49	17	24	9	5			12											
2.7	36	40	7		37	11	24	30	22	36		3		2											
2.6	103	151	194	59	29	17	9	32		6															
2.5		55		5	22	7			1																
2.4	2	3		10							3	9													
2.3	3	30	1	13	1				2																
2.2	2	11																							
2.1		11																							
2.0	16		6																						
1.9	8	2	1																						
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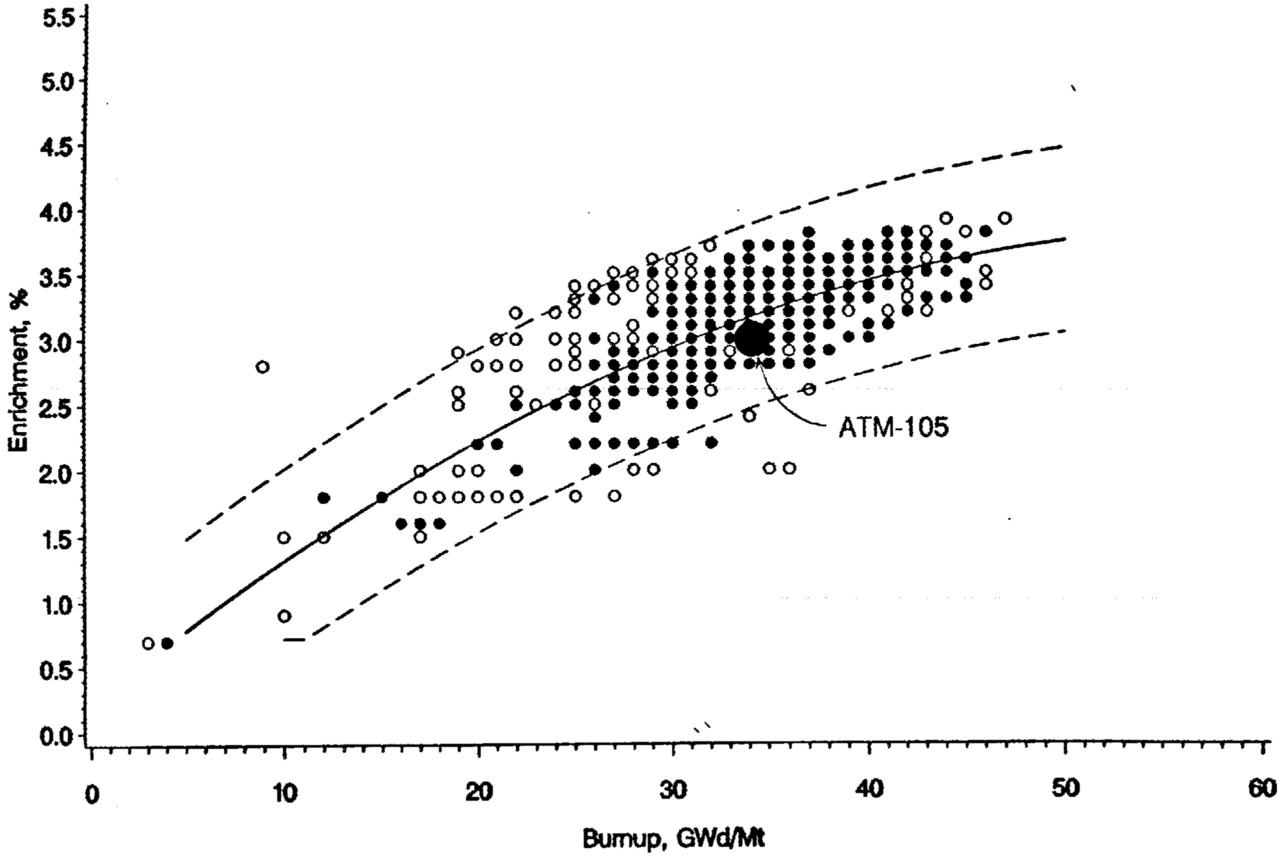
0.7													1												

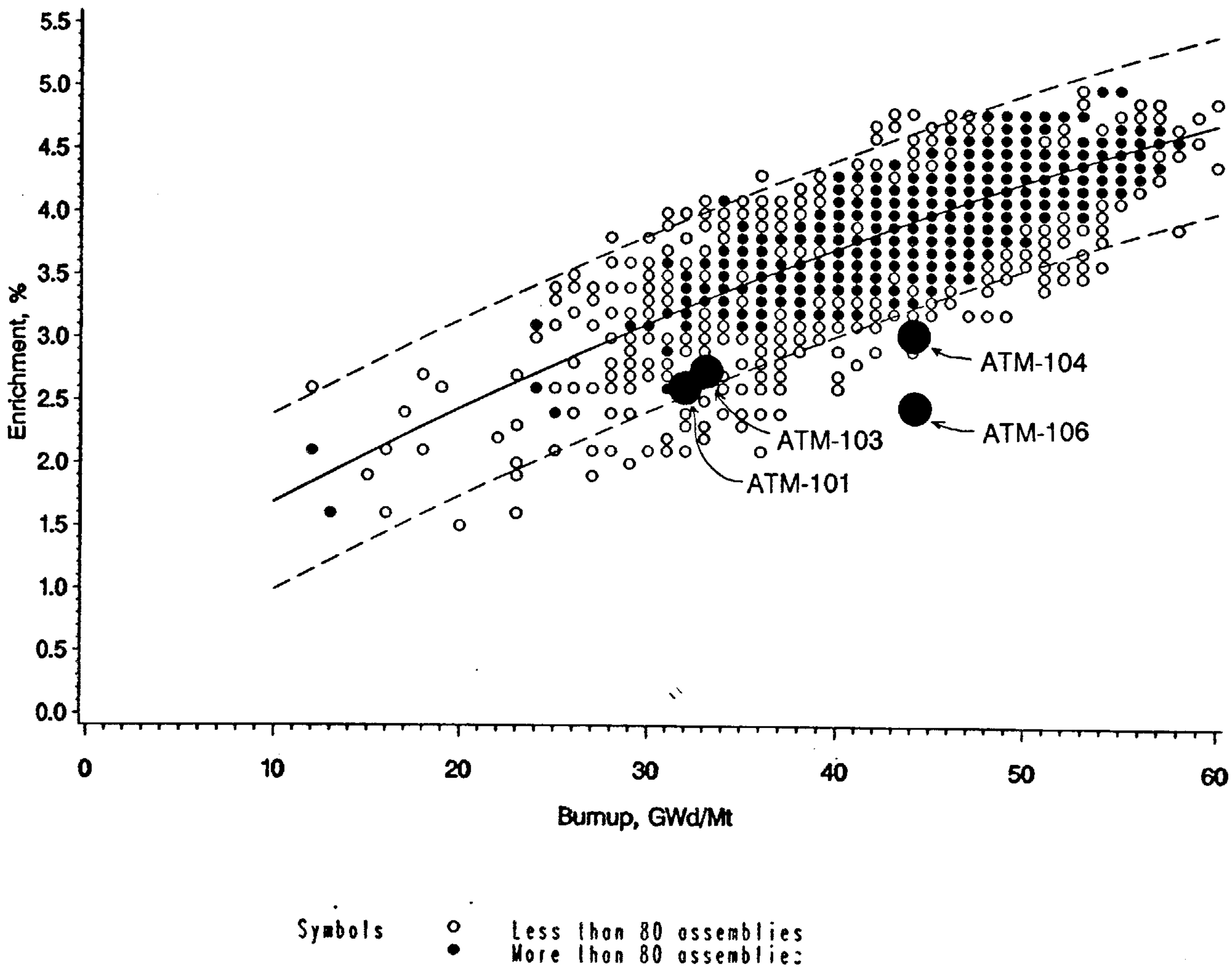
BURNUP (GWd/MTIHM)

Figure 4. Enrichment as a Function of Burnup for BWRs



Symbols ○ Less than 80 assemblies
● More than 80 assemblies

Figure 5. Enrichment as a Function of Burnup for PWRs



3.2 FABRICATION DATA

Fabrication data include some fuel properties (grain size, density, and porosity); plenum pressurization data (fill gas identification, pressure, nitrogen content); assembly hardware composition; and the type of cladding. All of the fabrication data are from the CDB,[1] which obtained them directly from the fuel vendors, except for GE fuel, which was obtained from NRC dockets and other literature sources.[3]

Tables 4 and 5 show the fabrication data for BWRs and PWRs, respectively. Some values were either not obtainable for all assembly classes or else were considered proprietary (shown as "PROP." in Tables 4 and 5). The linear heat rating, plenum pressurization and related data, and fuel property data are given.

The linear heat rating is a typical operating average as reported by the utilities or obtained from docket and literature searches, except for the marked values which correspond to the maximum average planar linear heat generation rate. The LHGR values in Tables 4 and 5, reported from the utilities, are to be distinguished from the values in section 3.4, which were calculated as described in that section, based on reported operating data.

The fuel pin fill gas is usually helium, although early fuels were simply backfilled with air. The fill gas improves heat transfer across the pellet-clad gap in the fuel pin and inhibits fuel cladding collapse. The assemblies in which the gas pressure extends down to zero (gage pressure) and the nitrogen content extends up to 78% have used air as a fill gas for some of the fuel pins in that assembly class. Those assembly types that have a nitrogen content of a few percent use prepressurized fuel pins without air evacuation before pressurization. Nitrogen content of a few parts per million indicate that the fuel pins were evacuated before pressurization.

The cladding material for LWR reactors is given in Table 6 for the generic and specific assembly classes. All generic fuels use Zircaloy cladding: Zircaloy-2 for BWRs and Zircaloy-4 for PWRs. Stainless steel cladding is one factor sometimes associated with specific assembly classes. If an assembly class has used more than one type of cladding material, then all these materials are shown. The Haddam Neck reactor, which has historically used SS 304 clad fuel, will begin utilizing Zircaloy-clad fuel beginning in 1991. The quantities of stainless steel-clad fuel are relatively small, but they could be expected to have different long-term behavior than Zircaloy-clad fuel.

Fuel rod diameters, shown in Table 7, are listed by assembly class. Within each class, the fuel rod diameters are listed in order of decreasing size. This ordering also generally places the fuel from oldest to newest design within a class due to the use of smaller fuel rod diameters on newer fuels to improve the heat transfer characteristics. The diameter is a function of assembly type (i.e., fuel design) within each class and is a factor that deserves consideration in the selection of future ATMs.

Table 4. Fabrication Data for BWR Reactors

ASSEMBLY CLASS AND TYPE		Linear Heat Rating (KWt/ft)	Fill Gas	Gas Pressure (psig)	Nitrogen Content (%)	Porosity (%)	Grain Size (microns)	Fuel Density (%)
GE BWR/2,3								
	GE 7x7 GE-1, V4	-	-	-	-	-	-	-
	GE 7x7 GE-2, V1	17.50*	He	-	-	-	-	94-95
	GE 7x7 GE-3, V1	-	He	-	-	-	-	94-95
	GE 8x8 GE-4, V1	13.40*	He	-	-	-	-	95
	GE 8x8 GE-5, V1	13.40*	He	-	-	-	-	95
	GE 8x8 GE-6, V1	-	-	-	-	-	-	-
	GE 8x8 GE-7, V1	-	-	-	-	-	-	-
	GE 8x8 GE-8, V1	-	-	-	-	-	-	-
	GE 8x8 GE-9, V1	-	-	-	-	-	-	-
	EXXON/ANF 7x7 GE	5.98	He	0	0.5	PROP.	PROP.	95
	EXXON/ANF 8x8 JP-3	4.58	He	45	2.0	PROP.	PROP.	95
	EXXON/ANF 9x9 JP-3	3.65	He	60	2.0	PROP.	PROP.	95
GE BWR/4,5,6								
	GE 7x7 GE-2, V2	-	He	-	-	-	-	93-95
	GE 7x7 GE-3, V2	-	He	-	-	-	-	94
	GE 7x7 GE-3, V3	-	-	-	-	-	-	-
	GE 8x8 GE-4, V2	13.40*	He	-	-	-	-	95
	GE 8x8 GE-4, V3	-	-	-	-	-	-	-
	GE 8x8 GE-5, V2	13.40*	He	-	-	-	-	95
	GE 8x8 GE-6, V2	-	-	-	-	-	-	-
	GE 8x8 GE-7, V2	-	-	-	-	-	-	-
	GE 8x8 GE-8, V2	-	-	-	-	-	-	-
	GE 8x8 GE-9, V2	-	-	-	-	-	-	-
	EXXON/ANF 8x8 JP-4,5	5.61	He	30	2.0	PROP.	PROP.	95
	EXXON/ANF 9x9 JP-4,5	4.36	He	60	2.0	PROP.	PROP.	95
BIG ROCK POINT								
	GE 9x9 GE-1, V5	-	He	-	-	-	-	94
	GE 11x11 GE-1, V6	-	He	-	-	-	-	94
	EXXON/ANF 9x9 BRP	-	-	-	-	-	-	-
	EXXON/ANF 11x11 GE	4.19	He	30	2.0	PROP.	PROP.	94
	NFS 11x11 BRP	-	-	-	-	-	-	-
DRESDEN 1								
	GE 6x6 GE-1, V1	15.40*	-	-	-	-	-	-
	EXXON/ANF 6x6 GE	4.79	He	0	0.5	PROP.	PROP.	94
	UN 6x6 DRESDEN-1	-	-	-	-	-	-	-
ELK RIVER								
	ALLIS CHALMERS 5x5	-	-	-	-	-	-	-
HUMBOLDT BAY								
	GE 6x6 GE-1, V2	-	-	-	-	-	-	94
	GE 7x7 GE-1, V3	12.10*	He	-	-	-	-	94
	EXXON/ANF 6x6 HB	-	-	-	-	-	-	-
LACROSSE								
	ALLIS CHALMERS 10x10	-	-	-	-	-	-	95
	EXXON/ANF 10x10 AC	4.30	He	0	2.0	PROP.	PROP.	94

*Maximum Average Planar Linear Heat Generation Rate

Table 5. Fabrication Data for PWR Reactors

ASSEMBLY CLASS AND TYPE	Linear Heat Rating (KWt/ft)	Fill Gas	Gas Pressure (psig)	Nitrogen Content (%)	Porosity (%)	Grain Size (microns)	Fuel Density (%)
BW 15x15 ARRAY							
BW MARK B	6.30	He	415	3.0	<1	10-14	95
BW MARK BZ	6.30	He	415	3.0	<1	10-14	95
BW 17x17 ARRAY							
BW MARK C	5.83	He	435	3.0	<1	10-14	95
CE 14x14 ARRAY							
CE STD	6.30	He	300-450	4-5 ppm	-	>5	94-95
EXXON/ANF CE	6.21	He	375	0.5	PROP.	PROP.	94
WE MODEL C	-	He	275-400	4.0	0-3	8-20	95
CE 16x16 ARRAY							
CE ONOFRE	5.50	He	300-450	4-5 ppm	-	>5	94-95
CE ANO2	5.50	He	300-450	4-5 ppm	-	>5	94-95
CE SYSTEM 80	5.50	He	300-450	4-5 ppm	-	>5	94-95
WE 14x14 ARRAY							
WE STD/ZCA	6.20	He	0-460	4-78	0-3	8-20	91-95
WE STD/ZCB	-	He	0-460	4-78	0-3	8-20	91-95
WE OFA	-	He	250-350	4.0	0-3	8-20	95
EXXON/ANF WE	6.44	He	290	0.5	PROP.	PROP.	94
EXXON/ANF TOP ROD	6.35	He	305	0.5	PROP.	PROP.	94
BW GINNA	-	-	-	-	-	-	-
WE 15x15 ARRAY							
WE STD/ZC	6.70	He	0-475	4-78	0-3	8-20	95
WE STD/ZC, VAR	-	-	-	-	-	-	-
WE OFA	6.70	He	275-350	4.0	0-3	8-20	95
EXXON/ANF WE	5.98	He	290	0.5	PROP.	PROP.	94
WE 17x17 ARRAY							
WE STD	5.44	He	275-500	4.0	0-3	8-20	95
WE OFA	5.44	He	275-350	4.0	0-3	8-20	95
WE VANTAGE 5	-	He	-	-	-	-	95
EXXON/ANF WE	5.58	He	290	0.5	PROP.	PROP.	94
BW MARK BW	-	-	-	-	-	-	-
FORT CALHOUN							
CE 14x14 FC	6.00	He	300-450	4-5 ppm	-	>5	94-95
EXXON/ANF 14x14 FC	-	-	-	-	-	-	-
HADDAM NECK							
BW 15x15 ST. STEEL	5.57	He	40	3.0	<1	10-14	95
WE 15x15 STD/SC	-	AIR	0	78.0	0-3	8-20	93
INDIAN POINT 1							
BW 13x14	-	-	-	-	-	-	-
WE 13x14	-	-	-	-	-	-	-
PALISADES							
CE 15x15 PALISADES	5.30	He	300-450	4-5 ppm	-	>5	94-95
EXXON/ANF 15x15 CE	5.23	He	306	0.5	PROP.	PROP.	94
SAINT LUCIE 2							
CE 16x16 LUCIE 2	5.00	He	300-450	4-5 ppm	-	>5	94-95
SAN ONOFRE 1							
WE 14x14 STD/SC	-	He	0-300	4-78	0-3	8-20	93-95
SOUTH TEXAS 1&2							
WE 17x17 XLR	-	-	-	-	-	-	-
YANKEE ROWE							
CE 15x16 YANKEE ROWE	4.40	He	300-450	4-5 ppm	-	>5	94-95
UN 15x16 YANKEE ROWE	-	-	-	-	-	-	-
EXXON/ANF 15x16 WE	4.51	He	250	0.5	PROP.	PROP.	94
WE 17x18	-	-	-	-	-	-	-

Table 6. Cladding Material for LWR Reactors

PWR CLASSES

GENERIC	CLADDING MATERIAL
BW 15x15 ARRAY	ZIRCALOY-4
BW 17x17 ARRAY	ZIRCALOY-4
CE 14x14 ARRAY	ZIRCALOY-4
CE 16x16 ARRAY	ZIRCALOY-4
WE 14x14 ARRAY	ZIRCALOY-4
WE 15x15 ARRAY	ZIRCALOY-4
WE 17x17 ARRAY	ZIRCALOY-4
SPECIFIC	
FORT CALHOUN	ZIRCALOY-4
HADDAM NECK	SS 304
INDIAN POINT 1	ZIRCALOY-4
PALISADES	ZIRCALOY-4
SAINT LUCIE 2	ZIRCALOY-4
SAN ONOFRE 1	SS 304
SOUTH TEXAS 1&2	ZIRCALOY-4
YANKEE ROWE	ZIRCALOY-4

BWR CLASSES

GENERIC	CLADDING MATERIAL
GE BWR/2,3	ZIRCALOY-2
GE BWR/4,5,6	ZIRCALOY-2
SPECIFIC	
BIG ROCK POINT	ZIRCALOY-2/SS 304
DRESDEN 1	ZIRCALOY-2
ELK RIVER	-
HUMBOLDT BAY	ZIRCALOY-2/SS 304
LACROSSE	SS 348H

Table 7. Fuel Rod Diameters for LWR Reactors

PWR CLASSES

GENERIC	FUEL ROD DIAMETER (INCHES)	QUANTITY OF FUEL (MTIHM)	COMMENTS
BW 15x15 ARRAY	0.430	1,506.6	Mark B/BZ
BW 17x17 ARRAY	0.379	1.8	Mark C
CE 14x14 ARRAY	0.440	952.6	Std
CE 16x16 ARRAY	0.382	359.7	ANO2, SYS80
WE 14x14 ARRAY	0.440	76.8	Model C (Millstone 2)
	0.422	914.4	San Onofre 1, Std/ZCA, Std/ZCB
	0.400	7.3	OFA
WE 15x15 ARRAY	0.422	1,551.1	Std/SC, Std/ZC, OFA
WE 17x17 ARRAY	0.374	2,086.8	Std
	0.360	151.0	OFA, Vant 5
SPECIFIC			
FORT CALHOUN	0.440	138.4	CE, EXA 14x14 Ft. Cal.
HADDAM NECK	0.422	303.2	BW 15x15 St. Stl. (SS304)
INDIAN POINT 1	-	30.6	WE 13x14
PALISADES	0.418	218.9	CE 15x15 Palis., EXA 15x15 CE
SAINT LUCIE 2	0.382	88.9	CE 16x16 Lucie 2
SAN ONOFRE 1	0.422	152.2	WE 14x14 Std/SC (SS 304)
SOUTH TEXAS 1&2	0.374	0.0	WE 17x17 XLR
YANKEE ROWE	0.365	91.4	WE 17x18 Yankee Rowe EXA 15x16 Yankee Rowe

Table 7. Fuel Rod Diameters for LWR Reactors (cont.)

BWR CLASSES	FUEL ROD DIAMETER (INCHES)	QUANTITY OF FUEL (MTIHM)	COMMENTS
GENERIC			
GE BWR/2,3	0.570	712.3	GE 7x7/2,3:V1
	0.563	222.7	GE 7x7/2,3:V2
	0.490	693.9	GE 8x8/2,3
GE BWR/4,5,6	0.563	1,150.6	GE 7x7/4,5,6
	0.490	2,210.5	GE 8x8/4,5,6:V1 & V2
SPECIFIC			
BIG ROCK POINT	0.449-0.563	38.6	EXA 9x9 BRP, EXA 11x11 BRP GE 7x7 & 8x8 BRP-CM GE 9x9 & 11x11 BRP Nuclear Fuel Services 11x11
DRESDEN 1	0.565	6.3	EXA 6x6 GE
	0.562	84.3	GE 6x6 Dres-1
ELK RIVER	-	5.0	Allis Chalmers 5x5
HUMBOLDT BAY	0.565	8.8	EXA 6x6 Hum. Bay
	0.563	13.4	GE 6x6 Hum. Bay
	0.486	6.7	GE 7x7 Hum. Bay
LACROSSE	0.396	18.6	Allis Chalmers 10x10
	0.394	19.3	EXA 10x10 AC

3.3 DEFECTIVE LWR FUEL

The characterization of defective LWR fuel is important to assess the need for special fuel handling and to determine other possible impacts on the FWMS. Two systems to categorize defective fuels have been used.

The first system is found in Appendix E of the Standard Contract for Disposal of Spent Nuclear Fuel and/or High-level Radioactive Waste (10 CFR 961), which identifies three categories of defective fuel:

Class F-1: Visual Failure or Damage
Class F-2: Radioactive Leakage
Class F-3: Encapsulated

A second system, used by the EIA for a while but now discontinued, identifies seven categories (or codes) of defective fuel:

Code 1: Visually Observed Failure or Damage
Code 2: Encapsulated or Other Remedial Action Taken
Code 3: Require Special Handling
Code 4: Cannot Be Consolidated
Code 5: Physically Deformed
Code 6: Does Not Fit in Pool Rack
Code 7: Clad Damage (Mechanical, Chemical, or other)

Lawson[13] developed a modified system that merged the 10 CFR 961 defect categories and the EIA defect codes and also allowed for reporting in multiple categories (which occurred for only two assemblies). The relationship between the three systems is shown in Table 8. The merged system was needed in order to assemble data that had been reported under one or the other of the two systems.

Table 8. Defective fuel classification schemes

Lawson's defect category	10 CFR 961 Category	EIA defect codes
F-1	Class F-1	1, 3, 4, 5, 6
F-2	Class F-2	7
F-3	Class F-3	2
F-1,2	Classes F-1 & F-2	1, 3, 4, 5, 6, 7

Table 9 shows the number of defective assemblies by assembly class and in terms of the 10 CFR 961 categories.[5] All data on defective fuel include spent fuel discharges as of December 31, 1988, as reported on the EIA's Nuclear Fuel Data Form RW-859.[14]

Fuel design is an important consideration when analyzing defective fuel. New fuel designs are continuously being introduced to improve fuel performance and reduce fuel defects. By categorizing defective fuels by fuel design, a trend is revealed that shows how newer designs have reduced the number of defective fuel assemblies. As the causes of fuel failures are identified and new fuel designs are developed to correct these deficiencies, continued improvement in fuel performance should be expected.

Defective fuel data are reported on an assembly basis. Frequently, there are only one or two defective pins in an assembly. Assuming one defective pin per assembly, the pin failure rate for BWRs would thus be about 1/60 the assembly failure rate, and for PWRs about 1/250 the assembly failure rate.

The number of defective LWR fuel assemblies has steadily declined over the years as improved fuel designs correct past deficiencies. Recent reports to the EIA indicate that very few failures are occurring with the latest designed fuels. This has been the case even though burnups have been increasing. It remains to be seen if even higher burnups and longer cycle times have any effect on failure rates.

3.3.1 BWR FUELS

The spent fuel from the two generic classes of BWRs (BWR/2,3 and BWR/4,5,6) represents 97% of current BWR fuel inventory and over 99% of the projected BWR fuel discharges to 2020. Within these two generic classes are eight BWR fuel designs, six GE and two ANFs. Table 10 shows the number of defective BWR fuel assemblies categorized by assembly class and fuel design. This table clearly shows that improved fuel designs have substantially reduced the number of defective BWR assemblies. It should be noted that the average linear heat generation rate (LHGR) for the GE BWR/2,3 assembly class ranges from 4.6 to 5.9 kW/ft, depending on the fuel design, whereas for the GE BWR/4,5,6 assembly class, the average LHGR ranges from 5.8 to 7.4 kW/ft. This increased LHGR for the latter assembly class may explain the higher defect rate.

GE Model 3 fuel, designed to correct the high failure rate of Model 2 fuel, was designed with a plenum region hydrogen getter and stricter control on the amount of water vapor allowed in the fuel rod. GE Model 4 fuel was designed with an increased array size and water rods to reduce the linear heat generation rate. GE Model 5 fuel added another water rod and natural uranium axial blankets. Prepressurized fuel used 3 atm of helium as the fuel rod fill gas. Finally, GE barrier fuel has an interior clad lining of pure zirconium to reduce clad failures. No ANF 7 X 7 or 8 X 8 fuel has reported fuel failures. The latest GE and ANF fuel designs used in many BWRs are too recent for any data on defective fuel quantities to be available.

3.3.2 PWR FUELS

The spent fuel from the seven generic classes of PWRs represents 90% of current PWR fuel inventory and 92% of the projected PWR fuel discharges to 2020. The remaining assembly classes are either reactor-specific or have no reactors in the class under active construction.

Fuel for B&W 15 X 15 class PWRs has two existing fuel designs: assemblies with Inconel grid spacers and assemblies with Zircaloy grid spacers. Sixty-seven defective assemblies (with the earlier Inconel grid spacers) of the 3564 assemblies discharged (1.9% defective) have been reported.

Fuels for the CE 14 X 14 class PWRs are manufactured by three vendors. For the CE-supplied fuel, 1 of the 2817 assemblies is defective, none of the 323 ANF-supplied assemblies are defective, and 5 of the 189 Westinghouse-supplied assemblies are defective. Fuel for the CE 16 X 16 class PWRs has reported 23 defective assemblies out of 1223 discharged (1.9% defective).

Two manufacturers, Westinghouse and ANF, supply most of the fuel for the three remaining PWR assembly classes (WE 14 X 14, WE 15 X 15, and WE 17 X 17). There are six fuel designs for these three assembly classes. Table 11 shows the number of defective Westinghouse PWR fuel assemblies categorized by assembly class and fuel design. Again, this table shows that improved fuel designs have reduced the number of defective PWR assemblies, though not as dramatically as with the BWRs. The WE standard design had Zircaloy cladding and stainless steel guide tubes. The LOPAR (Low Parasitic) improved design replaced the SS guide tubes with Zircaloy. The higher failure rate for the LOPAR was due to the collapse of unpressurized fuel rods. The Westinghouse OFA (Optimized Fuel Assembly) design had a smaller fuel rod diameter and used Zircaloy instead of Inconel spacer grids. Westinghouse Vantage 5 fuel design had several improvements including integral fuel burnable absorbers and an increased discharge burnup. ANF fuels have only had 1 reported failed fuel assembly out of 1740 assemblies. The TOPROD ANF design uses slightly thicker cladding and gadolinia burnable absorbers.

Table 9. Number of defective assemblies by assembly class and defect category[a]

Assembly class	Total	Defect category		
		F-1	F-2	F-3
GE BWR/2,3	14809	0	1478	0
GE BWR/4,5,6	20470	162[b]	784[b]	0
Big Rock Point	315	10	42	0
Dresden 1	891	0	159	0
Humboldt Bay	390	0	0	0
LaCrosse	333	50	54	0
BWR Fuels	**37208**	**222**	**2517**	**0**
BW 15 X 15	3564	3	37	27
CE 14 X 14	3329	0	6	0
CE 16 X 16	1231	4	19	0
WE 14 X 14	2949	13	67	0
WE 15 X 15	5557	29	102	0
WE 17 X 17	5873	21	61	0
Fort Calhoun	426	0	0	0
Haddam Neck	734	0	43	0
Indian Point 1	160	0	0	0
Palisades	597	1	20	0
St. Lucie 2	236	0	0	0
San Onofre 1	468	5	0	0
Yankee Rowe	417	0	0	0
PWR fuels	**25541**	**76**	**355**	**27**
All fuels	**62749**	**298**	**2872**	**27**

[a] R. S. Moore, K. J. Notz, and C. G. Lawson, "Classification of LWR Defective Fuel Data," Oak Ridge National Laboratory, June 1990, paper to be given at Spectrum '90 and published in the proceedings of September 1990.

[b] Includes 2 fuel assemblies that are in both defect categories F-1 and F-2. (these two assemblies are thus counted twice).

Table 10. Defective BWR fuels by assembly class and fuel design[a]

Fuel design	GE BWR/2,3 (9 reactors)			GE BWR/4,5,6 (28 reactors)		
	Discharged assemblies	Defective assemblies	Percent defective	Discharged assemblies	Defective assemblies	Percent defective
GE Model 2 7 X 7 fuel	6719	1469	21.90	1142	385	33.70
GE Model 3 Improved 7 X 7 fuel	394	7	1.78	4936	130	2.63
GE Model 4 Original 8 X 8 fuel	3876	1	0.03	3571	185	5.18
GE Model 5 8 X 8 retrofit fuel	792	1	0.13	3455	104	3.01
GE prepressurized fuel	1836	0	0.00	6591	144	2.18
GE barrier fuel	248	0	0.00	775	1	0.13
ANF 7 X 7 fuel	260	0	0.00	Not applicable		
ANF 8 X 8 fuel	684	0	0.00	Not yet discharged		

[a] R. S. Moore, K. J. Notz, and C. G. Lawson, "Classification of LWR Defective Fuel Data," Oak Ridge National Laboratory, June 1990, paper to be given at Spectrum '90 and published in the proceedings of September 1990.

Table 11. Defective Westinghouse PWR fuels by assembly class and fuel design[a]

Fuel design	WE 14 X 14 (6 reactors)			WE 15 X 15 (10 reactors)			WE 17 X 17 (33 reactors)		
	Discharged assemblies	Defective assemblies	Percent defective	Discharged assemblies	Defective assemblies	Percent defective	Discharged assemblies	Defective assemblies	Percent defective
WE standard	592	1	0.2	1457	103	7.1	Not applicable		
WE LOPAR	1409	77	5.5	3087	16	0.5	5102	99	1.9
WE OFA	88	1	1.1	266	1	0.4	628	1	0.2
WE VANTAGE 5	Not yet discharged			Not yet discharged			4	0	0.0
ANF for WE	559	0	0.0	743	12	1.6	139	0	0.0
ANF TOPROD	299	1	0.3	Not applicable			Not applicable		

[a] R. S. Moore, K. J. Notz, and C. G. Lawson, "Classification of LWR Defective Fuel Data," Oak Ridge National Laboratory, June 1990, paper to be given at Spectrum '90 and published in the proceedings of September 1990.

3.4 LINEAR HEAT GENERATION RATE

The linear heat generation rate (LHGR) is defined as the amount of thermal power generated per unit length of the fuel rod or assembly. It is essentially a value representative of the linear power density of the fuel. It might be expected to bear a relationship to fission gas release, a parameter of high importance to the MCC, because higher power densities promote fuel restructuring that leads to fission gas release. The calculation of LHGR requires a knowledge of the fuel burnup, cycle length, quantity of uranium, and the active length of the fuel rod or assembly. The LHGR is calculated as follows:

$$LHGR = (BU/t) \times (W/L) \times F,$$

where: LHGR = cycle-average LHGR (kW/m),
BU = cycle burnup for fuel assembly (MWd/MTIHM),
t = cycle length or EFPD (d),
W = uranium mass per fuel rod (g),
= uranium mass per assembly/fueled rods per assembly,
L = active (fueled) length of assembly (in.),
F = conversion factor,
= (39.37 in./m) (MT/10^6 g) (10^3 kW/MW).

Unfortunately, the cycle length is not a value recorded in EIA or CDB records, and it would require exhaustive effort to obtain this information for all discharged fuel assemblies. However, the EIA does request the utilities to submit actual, estimated, or forecasted values for the EFPD of each fuel cycle. The EFPD can be used in lieu of cycle-length data under the assumption that the reactor is at full power during the entire fuel assembly irradiation, in which case the cycle length is equivalent to the EFPD for that assembly. Any error generated from this substitution will generally be conservative (i.e., yielding an overestimate of the actual LHGR, since reactors are, on occasion, below full power).

Obtaining the necessary information to compute the LHGR required extracting data from three separate sources. Cycle-by-cycle burnup data and the uranium mass were available from EIA record 13, utility estimates of the EFPD were obtained from EIA record 12, and the physical dimensions where found in the CDB. Obviously, an absence of data from any of the three sources will prevent the LHGR from being determined. The data from the CDB were relatively complete for all reactors. However, a substantial amount of EIA data was incomplete. Between the three data sources, a total of 126 reactors were represented. Information sufficient to allow calculation of the LHGR on a batch-by-batch basis was available for only 60 of these reactors. These data are available for the three reactors that were the source of the present ATMs (and are given in the Appendix).

For some reactors, the EFPD or cycle-by-cycle burnup data were missing, incomplete, or inconsistent. Two types of data where consistently unavailable. The cycle-by-cycle burnup data as reported to the EIA were frequently reported only as assembly totals (for all cycles). For some reactors, the EIA has reported only the total burnup for the entire lifespan of the assemblies and recorded this as an entry for the last reactor cycle. (Thus, an assembly may appear to have obtained a burnup of 35,000 MWd/MTIHM in only one reactor cycle.) This loss of cycle-by-cycle data is presumably the result of the utilities not reporting the information to the EIA.

The average LHGR per cycle, in kW/m, for BWRs and PWRs is shown in Tables 12 and 13, respectively. The average LHGR, organized by fuel assembly class, is given along with the average fuel burnup and average EFPD per fuel cycle. The number of reactors and assemblies in each class for which average LHGR data are available is also shown. The same average LHGR data are presented in Tables 14 and 15, by assembly class and reactor name. Obviously, these average values will obscure individual perturbations. They do reflect that the older (one-of-a-kind) reactors ran at somewhat lower power densities than the newer, generic class designs.

The Appendix shows the LHGR data, in kW/m, on a fuel-batch basis for those reactors that provided ATMs. The equivalent data were provided to PNL for all 60 reactors for which cycle-by-cycle data were available. It should be recognized that even these highly detailed data are still an average value, for individual cycles, and will probably not reflect short-term perturbations in power density. A statistical analysis of these data was done by PNL and will be reported by them.[15] However, it can be noted that a few cycles were well above the reactor cycle-by-cycle average, for example:

Calvert Cliffs: avg 22.2 kW/m highs of 27.07 and 27.97 kW/m

Cooper Station: avg 20.2 kW/m highs of 29.45 and 30.68 kW/m

Whether or not these highs are statistically significant is outside the scope of this report.

Table 12. Linear heat generation rate data per cycle for BWRs

Assembly class	Number of reactors[a]	Number of assemblies	Average burnup (MWd/MT)	Average EFPD	Average LHGR[b]
GE BWR/2,3	4	5,956	6,350	348	16.9
GE BWR/4,5,6	13	10,590	7,512	335	19.4
Big Rock Point	1	289	6,382	293	14.5
Dresden 1	0	--	--	--	--
Elk River	0	--	--	--	--
Humboldt Bay	0	--	--	--	--
LaCrosse	0	--	--	--	--

[a] Represents the number of reactors in this class for which LHGR data are available.

[b] Average LHGR is given in units of thermal kilowatts per meter.

Table 13. Linear heat generation rate data per cycle for PWRs

Assembly class	Number of reactors[a]	Number of assemblies	Average burnup (MWd/MT)	Average EFPD	Average LHGR[b]
B&W 15 X 15	4	1,443	10,077	324	19.5
B&W 17 X 17	0	--	--	--	--
CE 14 X 14	5	3,105	12,361	384	20.9
CE 16 X 16	3	460	12,444	321	18.6
WE 14 X 14	1	444	10,878	313	20.8
WE 15 X 15	5	2,530	11,637	347	20.4
WE 17 X 17	20	4,628	12,646	330	18.1
Fort Calhoun	0	--	--	--	--
Haddam Neck	1	736	11,239	405	18.4
Indian Point 1	0	--	--	--	--
Palisades	1	545	11,600	400	16.4
San Onofre 1	0	--	--	--	--
St. Lucie 2	1	240	12,928	418	14.9
South Texas 1&2	0	--	--	--	--
Yankee Rowe	1	377	13,623	420	13.9

[a] Represents the number of reactors in this class for which LHGR data are available.

[b] Average LHGR is given in units of thermal kilowatts per meter.

Table 14. Cycle-Average Linear Heat Generation Rate Data by BWR Reactor Name

ASSEMBLY CLASS: GE BWR 2,3

Reactor Name	Number of Assemblies	Average Burnup	Avg. EFPD	Avg. LHGR
Millstone 1	1732	6899	376	16.8
Monticello	1512	5919	327	16.4
Oyster Creek	1392	5360	290	17.6
Pilgrim	1320	7191	400	16.5
	5956	6350	348	16.9

ASSEMBLY CLASS: GE BWR 4,5,6

Reactor Name	Number of Assemblies	Average Burnup	Avg. EFPD	Avg. LHGR
Browns Ferry 1	1328	8269	367	20.9
Browns Ferry 2	1188	8844	397	21.1
Browns Ferry 3	1004	7628	340	17.9
Brunswick 1	872	8697	385	18.1
Cooper Station	1116	6276	277	20.2
Duane Arnold	824	6899	303	19.7
Grand Gulf 1	552	7982	317	20.3
LaSalle 2	764	7714	497	12.4
Limerick 1	268	5780	464	10.2
River Bend 1	164	5683	364	12.7
Susquehanna 1	728	8682	387	18.0
Susquehanna 2	324	10885	513	17.1
Vermont Yankee	1458	6192	266	19.3
	10590	7512	335	19.4

ASSEMBLY CLASS: Big Rock Point

Reactor Name	Number of Assemblies	Average Burnup	Avg. EFPD	Avg. LHGR
Big Rock Point	289	6382	293	14.5
	289	6382	293	14.5

Table 15. Cycle-Average Linear Heat Generation Rate Data by PWR Reactor Name

ASSEMBLY CLASS: B&W 15 X 15

Reactor Name	Number of Assemblies	Average Burnup	Avg. EFPD	Avg. LHGR
Arkansas 1	448	11668	376	19.2
Crystal River 3	395	8483	282	19.1
Rancho Seco	316	10799	318	21.0
Three Mile Island 1	284	9999	335	18.7
	1443	10077	324	19.5

ASSEMBLY CLASS: CE 14 X 14

Reactor Name	Number of Assemblies	Average Burnup	Avg. EFPD	Avg. LHGR
Calvert Cliffs 1	620	12682	384	22.2
Calvert Cliffs 2	520	13484	415	21.6
Maine Yankee	857	12789	392	20.8
Millstone 2	580	11460	361	21.3
St. Lucie 1	528	11400	371	18.5
	3105	12361	384	20.9

ASSEMBLY CLASS: CE 16 X 16

Reactor Name	Number of Assemblies	Average Burnup	Avg. EFPD	Avg. LHGR
Arkansas 2	288	11510	299	18.4
Palo Verde 1	80	17275	447	19.5
Waterford 3	92	15438	380	19.2
	460	12444	321	18.6

ASSEMBLY CLASS: WE 14 X 14

Reactor Name	Number of Assemblies	Average Burnup	Avg. EFPD	Avg. LHGR
Kewaunee	444	10878	313	20.8
	444	10878	313	20.8

Table 15. Cycle-Average Linear Heat Generation Rate Data by PWR Reactor Name (continued)

ASSEMBLY CLASS: WE 15 X 15

Reactor Name	Number of Assemblies	Average Burnup	Avg. EFPD	Avg. LHGR
Cook 1	626	12047	314	22.6
Indian Point 2	532	12175	389	19.1
Surry 1	516	12072	360	20.6
Surry 2	409	13146	380	21.2
Turkey Point 4	447	9518	313	18.8
	2530	11637	347	20.4

ASSEMBLY CLASS: WE 17 X 17

Reactor Name	Number of Assemblies	Average Burnup	Avg. EFPD	Avg. LHGR
Beaver Valley 1	356	12768	352	17.3
Byron 1	88	19261	431	19.6
Callaway	180	15606	405	18.4
Catawba 1	132	12863	309	18.1
Catawba 2	193	14000	336	18.3
Cook 2	424	14997	384	18.2
Diablo Canyon 1	68	18559	456	19.4
Diablo Canyon 2	68	15985	373	20.4
Farley 1	410	11167	301	17.6
Farley 2	320	13595	373	17.4
McGuire 2	184	12103	313	18.5
Millstone 3	84	20170	470	20.5
North Anna 1	369	13376	352	18.1
Salem 1	464	11530	303	18.1
Salem 2	224	12823	333	18.4
Sequoyah 1	212	13568	352	18.3
Sequoyah 2	136	14583	358	19.2
Summer	176	13040	351	17.7
Trojan	436	9607	252	18.2
Wolf Creek	104	14116	321	20.6
	4628	12646	330	18.1

ASSEMBLY CLASS: Haddam Neck

Reactor Name	Number of Assemblies	Average Burnup	Avg. EFPD	Avg. LHGR
Haddam Neck	736	11239	405	18.4
	736	11239	405	18.4

Table 15. Cycle-Average Linear Heat Generation Rate Data by PWR Reactor Name (continued)

ASSEMBLY CLASS: Palisades

Reactor Name	Number of Assemblies	Average Burnup	Avg. EFPD	Avg. LHGR
Palisades	545	11600	400	16.4
	545	11600	400	16.4

ASSEMBLY CLASS: St. Lucie 2

Reactor Name	Number of Assemblies	Average Burnup	Avg. EFPD	Avg. LHGR
St. Lucie 2	240	12928	418	14.9
	240	12928	418	14.9

ASSEMBLY CLASS: Yankee Rowe

Reactor Name	Number of Assemblies	Average Burnup	Avg. EFPD	Avg. LHGR
Yankee-Rowe	377	13623	420	13.9
	377	13623	420	13.9

3.5 BURNABLE ABSORBERS[16]

Burnable absorbers, also called neutron absorbers or burnable poisons, are used in both BWRs and PWRs to control power peaking early in the fuel cycle and to assist in power shaping and fuel burnup optimization. Absorbers have been placed both external and internal to the fuel assembly. The internal absorbers may be either fueled or unfueled rods. An external absorber is defined as any absorber that is not integrally attached to the assembly (i.e., it is non-fuel-assembly hardware). Thus, the absorber may be physically inside the assembly, as in the case of PWR burnable absorbers located in control-rod positions, but still be defined as an external absorber, since it is not an integral part of the fuel assembly and can be removed. Internal absorbers are defined as any absorber that is an integral part of the fuel assembly and therefore will be in-core for the entire fuel assembly lifetime and will remain as an integral part of the assembly after discharge.

The chemical form of absorbers may vary. PWRs typically use Al_2O_3-B_4C pellets in Zircaloy-4 tubes or borosilicate glass rods in stainless steel tubes. These tubes are located either in a fuel-rod position (internal) or a control-rod guide thimble (external) depending upon the fuel design. More recently, UO_2-Gd_2O_3 pellets have been used in PWRs. The Gd_2O_3 forms a solid solution with the UO_2. The latest PWR burnable poison, introduced by Westinghouse, is a zirconium boride coating on the fuel pellets. BWRs typically use UO_2-Gd_2O_3 in a fuel-rod (internal) position. The gadolinia content reduces the thermal conductivity of the pellet, and thus lower fuel enrichments are sometimes used. More detailed descriptions follow.

Neither internal or external burnable poisons are uniformly distributed throughout assemblies. The explanation for this nonuniform distribution is that the neutron flux is not uniform across an assembly, and the burnable poisons are used only where needed. The external type is commonly used only for cycle one of an assembly. With recognition of this variability, it is clear that characterizing the postirradiation properties of all the burnable poison types would be a very complex and extensive task. It would therefore seem appropriate to identify worst-case or bounding-case situations and characterize these for appropriate behavioral factors (e.g., solubility rate, clad failure, fission gas release) to see if they warrant more detailed examination.

3.5.1 BWR BURNABLE ABSORBERS

Early uses of burnable absorbers in BWRs began with "poison curtains," which were actually borated stainless steel plates hung between the fuel channels. This external burnable absorber provided control of excess reactivity during initial reactor startup. It appears that the first application of an internal (integral with the fuel assembly) burnable absorber was begun by GE during the second reload fuel for the Dresden-1 reactor by the inclusion of 36 fuel rods of GE 6 X 6 type III-B uranium oxide fuel doped with 0.15% erbium oxide. The third Dresden-1 reload consisted of 35 fuel rods of type III-F fuel and a single, nonfueled burnable absorber rod made from 95.3% Al_2O_3 - 4.7% Gd_2O_3. The fourth reload fuel, type V, again used 36 fueled rods with some rods containing UO_2-Gd_2O_3 pellets.

Data on recent uses of burnable absorbers in BWRs are very limited. This kind of information is treated as proprietary by GE. In the "GESTAR" (General Electric Standard Application for Reactor Fuel), NEDO-24011-A-8, it is stated that the gadolinia concentrations for all GE BWR fuel are considered proprietary. Gadolinia distributions within the assembly are also considered proprietary for all but the Original 8 X 8 fuel design. For this design, it is known that for a fuel enrichment of 2.19%, three fueled absorber rods are used. Enrichments of 2.19%-2.62% have four absorber rods; higher enrichments use five absorber rods per assembly. Most of the information on GE fuel has been obtained from searches of the federal docket.

Available data on 7 X 7, Improved 7 X 7, and Original 8 X 8 fuel designs suggest that the gadolinia tends to be utilized in the highest enrichment fuels. Most of the numerical data show the gadolinia concentration to be between 2 and 4% with three to five fueled absorber rods per assembly. The gadolinia concentration and the number of fuel rods with burnable absorbers tend to increase with increasing fuel enrichment. GE prepressurized fuel is thought to have up to 8 absorber rods per assembly with up to 171 g of Gd_2O_3 per rod (approx. 4%).

GE experience with optimizing fuel performance has resulted in more complex BWR fuel management concepts including radial and axial enrichment variations within assemblies and fuel rods. It would be reasonable to assume that the gadolinia distributions have also become more complex. Though only limited data exist, it does appear that the latest GE fuel designs (such as GE-8 & GE-9 extended burnup fuel) utilize axial variations as well as radial variations in gadolinia concentrations.

Data from ANF show that gadolinia concentrations in its BWR fuels vary from 1.8% to 5% with the number of fueled burnable absorber rods varying from 1 to 10 per assembly. The ANF 8 X 8 XN-3 fuel design has two water rods with five or six fueled absorber rods containing 2 wt % Gd_2O_3. The ANF 9 X 9 fuel design with two water rods has seven to ten fueled absorber rods containing 4 to 5 wt % Gd_2O_3. The ANF 9 X 9 IX and 9X fuel designs have a water channel (that displaces nine fuel rod locations) and six fueled absorber rods (five rods with 1.8% Gd_2O_3 and one rod with 4.5% Gd_2O_3). The 9 X 9 designs contain 2% Gd_2O_3 per fuel rod. ANF uses only fueled burnable absorbers for BWR fuel.

3.5.2 PWR BURNABLE ABSORBERS

PWRs have used integral burnable absorbers in fuel rods (WE & ANF), in nonfueled rods (CE & ANF), and as NFA hardware (B&W & WE).

Fueled burnable absorbers of the type used in BWRs are becoming increasingly popular for PWRs. ANF uses approximately 80 g/rod of 4-10 wt % UO_2-Gd_2O_3 in some of its fuel designs. The use of gadolinia has become a standard feature on ANF fuels. Typically, 2 to 12 absorber rods/assembly are used. The Gd_2O_3 reduces the thermal conductivity, and thus lower enrichments are used. ANF uses these types of absorbers on most of its reload fuel for CE and WE fuel designs.

Fueled burnable absorbers are used by WE on its Vantage 5 fuel design (production started in 1984). This fuel introduced what WE calls an Integral Fuel Burnable Absorber (IFBA), which integrates the burnable absorber material directly onto the fuel pellet in the form of a thin zirconium diboride coating. Detailed data on the IFBA (material, thickness, etc.) appear to be proprietary. It is known that this type of absorber is used in approximately 80% of current WE fuel production. It is believed that approximately 120 rods/assembly are coated (45% of the rods/assembly), and that the amount of ZrB_2 is around 3 g/rod (0.2 wt % ZrB_2).

Internal burnable absorbers are used by CE in all of its fuel. This is dictated by the CE core design, which uses only five large guide tubes per assembly for control rods; therefore, the use of external burnable absorbers is not feasible. Unfueled rods containing 0.8-1.0 kg/rod of Al_2O_3-B_4C are used with the number of absorber rods varying up to 16 per assembly. ANF uses unfueled burnable absorbers in fuels for the CE 14 X 14 assembly class.

This is the only fuel ANF manufactured that contains unfueled rods. ANF uses Al_2O_3-B_4C as the absorber with 652 g B_4C/rod and a maximum of 4 rods/assembly. In some cases, this is supplemented with gadolinia in fueled absorber rods.

External burnable absorbers are used by B&W in all of its fuel. These external rods fit into the guide tubes of selected assemblies. At a given time, these external rods are used in 30-40% of in-core assemblies, with two designs currently being used. The first B&W design uses an alloy of Ag-In-Cd contained in Inconel 600 tubes. Burnable poison assemblies with these absorbers are known as axial power shaping assemblies (APSAs). Usually the usage rate is about 2.5 to 5.0 APSAs per 100 fuel assemblies. The second B&W design uses Al_2O_3-B_4C, and burnable poison assemblies with this absorber are known as burnable absorber assemblies (BAAs). Pre-1979 core loadings used 20 BAA per 100 fuel assemblies; current usage (1979-1986) is 94 BAA per 100 fuel assemblies.

The majority of external burnable absorbers used in older Westinghouse assemblies were either burnable poison assemblies (BPAs) or wet annular burnable absorbers (WABAs). These absorbers were used in all three generic Westinghouse assembly classes. The older design, BPA, consisted of approximately 0.8 lb of borosilicate glass per stainless steel absorber rod with 2 to 24 rods per assembly. The WABA design used approximately 0.2 lb of Al_2O_3-B_4C per absorber rod with 3 to 24 rods per assembly. The BPA and WABA designs were also used in neutron source assemblies. It is not known how many of these assemblies were used per core.

4. CONCLUSIONS

A number of LWR fuel characteristics of possible importance to the MCC were tabulated and analyzed, including assembly class representation, fuel burnup, enrichment, fuel fabrication data, defective fuel quantities, linear heat generation rate (LHGR), and the utilization of burnable poisons. The following conclusions were drawn:

1. In terms of quantities of LWR spent fuel, as distributed over 22 fuel assembly classes, the existing ATMs represent the largest BWR class (class BWR/4,5,6) and two of the larger PWR classes (WE 15 x 15 and CE 14 x 14). The second-largest BWR class (BWR/2,3) and the largest PWR class (WE 17 x 17) are not represented, nor are two other large PWR classes (BW 15 x 15 and CE 16 x 16).

2. In terms of burnup and enrichment (and these two factors were shown to be functionally related), the single BWR ATM is somewhat higher than standard burnup and close to the average enrichment for that burnup. The four PWR ATMs are either at standard burnup or about 30% higher; however, all are relatively low in enrichment, and one is quite low.

3. In terms of vendor-specific assembly fuel design (which can overlay more than one class), two recent and widespread innovations are not represented by the existing ATMs: GE barrier fuel and WE fuel with integral burnable poison. Barrier fuel includes a thin lining of pure zirconium inside the Zircaloy cladding to minimize pellet-clad interaction (PCI). Integral burnable poison consists of a thin coating of zirconium boride on the outer periphery of fuel pellets (to provide a more uniform distribution of burnable poison within the assembly).

4. Failed fuel is a different characteristic in the sense that this is an exception rather than a common characteristic. None of the ATMs were failed. Analysis of CDB data shows the failure rates to be very low and to be decreasing with time as improved fuel designs are being introduced, even though burnups are increasing.

5. In terms of LHGR, data were developed for use by PNL, who will be reporting on this. (The reason for this type analysis is that LHGR may bear a relationship to fission gas release, which, in turn, is related to certain spent fuel properties that relate to dissolution rate.)

6. Burnable absorbers (poisons), both external and internal to assemblies, and either integral or nonintegral if internal, represent a degree of variation not dealt with on a total basis by the CDB. To do so on an "open" basis would be impossible because much - perhaps most - of these data are proprietary. It would also increase the complexity of fuel assembly descriptions, now based on class, design, and type, by about an order of magnitude. It is suggested that this aspect of ATMs be held in abeyance until, a clear need is shown for this degree of detail.

7. Zircaloy cladding is used for all BWR and PWR fuel except seven early, one-of-a-kind reactors. These use, or used, stainless steel cladding. Two of these seven are still in operation, but all seven represent only 1.2% of projected discharges to 2020. Even so, in view of the 10^{-5}-per-year regulation, as applied to repositories, they cannot be dismissed arbitrarily as being irrelevant.

8. Fuel pin diameters have been decreasing steadily over the years to permit higher core power levels without raising LHGR excessively. The newer sizes should be taken into account in selecting any future ATMs. This can be done within the context of criteria specified above (items 1 and 3) since the WE 17 x 17 class has later designs (OFA and Vantage 5) that employ the smaller pins (0.360-in. diameter), and both of the GE generic classes (2,3 and 4,5,6) have employed their smallest (0.490-in. diameter) pin size for some time. New BWR fuel designs by both ANF and GE utilize 9 x 9 arrays. The fuel pins in these arrays are approximately 0.43 in. in diameter.

9. Other fuel fabrication parameters, such as fill gas (pressure and nitrogen content) and fuel pellets (porosity, density, and grain size), are incomplete and, where provided, usually just duplicate the specifications. These parameters are valid for fresh

(unirradiated) fuel and will not necessarily apply to discharged fuel. For the latter, the burnup and specific operating conditions will, in large measure, control the final properties. These could, to some degree, be estimated from fission gas release, but this is not a directly known property and is highly dependent on actual position in an assembly and on short-term thermal upsets. This information is not available through the CDB.

10. Based on this study, two additional ATMs are recommended:

    WE 17 x 17, design OFA or Vantage 5, with integral burnable poison, and

    GE/BWR 2,3, barrier fuel, using 0.490-in.-diameter pins.

    Both of the above should be at relatively high burnups (45 GWd/MTU for BWR and 55 GWd/MTU for PWR) and, if possible, close to the statistical burnup/enrichment curve.

11. Overall, the PNL selection of ATMs quite effectively represents the broad spectrum of fuel types extant. The two additions suggested above will effectively expand this coverage to projected fuel discharges. It can, of course, always be argued that a single assembly is statistically inadequate for characterizing any group or class, but this is really dependent on the importance of individual variations to the eventual performance of the spent fuel in a repository. These effects are still under study at PNL, Lawrence Livermore National Laboratory, and elsewhere.

12. Because of the 10^{-5}-per-year release fraction regulation, it is not necessarily safe to ignore even a very small contributing group (e.g., defective fuel or stainless steel cladding). Their possible contribution to annual repository releases must be considered via appropriate analyses. In some cases, where a group can be identified and segregated (e.g. stainless steel clad), it might be more cost-effective to provide special treatment or packaging for this group, rather than applying more stringent requirements to all spent fuel.

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APPENDIX: Batch LHGR for ATMs

Reactor Name	INIS Number	Batch	Cycle	Cycle Burnup	EFPD	Cycle LHGR
Calvert Cliffs 1	0501	01A0X	1	18135	549	22.85
Calvert Cliffs 1	0501	01A0X	3	7650	297	17.81
Calvert Cliffs 1	0501	02A0X	1	17801	549	22.44
Calvert Cliffs 1	0501	03B0X	1	18911	549	22.21
Calvert Cliffs 1	0501	03B0X	2	7772	261	19.20
Calvert Cliffs 1	0501	04B0X	1	19636	549	22.86
Calvert Cliffs 1	0501	05B0X	1	19696	549	22.60
Calvert Cliffs 1	0501	05B0X	2	7261	261	17.52
Calvert Cliffs 1	0501	05B0X	3	7458	297	15.82
Calvert Cliffs 1	0501	05B0X	4	8555	367	14.68
Calvert Cliffs 1	0501	06C0X	1	10813	549	13.64
Calvert Cliffs 1	0501	06C0X	2	9333	261	24.76
Calvert Cliffs 1	0501	06C0X	3	9386	297	21.88
Calvert Cliffs 1	0501	07C0X	1	13167	549	16.59
Calvert Cliffs 1	0501	07C0X	2	9141	261	24.23
Calvert Cliffs 1	0501	08C1X	1	17311	549	20.34
Calvert Cliffs 1	0501	08C1X	2	8925	261	22.05
Calvert Cliffs 1	0501	09C2X	1	17546	549	20.64
Calvert Cliffs 1	0501	09C2X	2	8790	261	21.75
Calvert Cliffs 1	0501	10D0X	2	7499	261	19.53
Calvert Cliffs 1	0501	10D0X	3	10447	297	23.91
Calvert Cliffs 1	0501	10D0X	4	12060	367	22.34
Calvert Cliffs 1	0501	11D0X	2	9466	261	24.70
Calvert Cliffs 1	0501	11D0X	3	11429	297	26.21
Calvert Cliffs 1	0501	11D0X	4	11422	367	21.19
Calvert Cliffs 1	0501	11D0X	5	9464	402	16.03
Calvert Cliffs 1	0501	11D0Y	6	12219	407	20.48
Calvert Cliffs 1	0501	12D0X	2	9466	261	24.77
Calvert Cliffs 1	0501	12D0X	3	11429	297	26.28
Calvert Cliffs 1	0501	12D0X	4	11422	367	21.25
Calvert Cliffs 1	0501	12D0X	6	9815	407	16.47
Calvert Cliffs 1	0501	13D1X	2	10388	261	27.07
Calvert Cliffs 1	0501	13D1X	3	10546	297	24.15
Calvert Cliffs 1	0501	13D1X	4	10473	367	19.41
Calvert Cliffs 1	0501	13D1X	2	10045	261	26.13
Calvert Cliffs 1	0501	13D1X	3	10659	297	24.36
Calvert Cliffs 1	0501	13D1X	4	10646	367	19.69
Calvert Cliffs 1	0501	14E0X	3	7928	297	18.13
Calvert Cliffs 1	0501	14E0X	4	12801	367	23.70
Calvert Cliffs 1	0501	14E0X	5	12605	402	21.30
Calvert Cliffs 1	0501	15E1X	3	11620	297	26.55
Calvert Cliffs 1	0501	15E1X	4	12277	367	22.70
Calvert Cliffs 1	0501	15E1X	7	11066	409	18.36
Calvert Cliffs 1	0501	16E1X	3	12274	297	27.97
Calvert Cliffs 1	0501	16E1X	4	12294	367	22.68
Calvert Cliffs 1	0501	17E1X	3	9936	297	22.78
Calvert Cliffs 1	0501	17E1X	4	12267	367	22.76
Calvert Cliffs 1	0501	17E1X	5	11494	402	19.47
Calvert Cliffs 1	0501	18F0X	4	9943	367	18.45

Reactor Name	INIS Number	Batch	Cycle	Cycle Burnup	EFPD	Cycle LHGR
Calvert Cliffs 1	0501	18F0X	5	13901	402	23.55
Calvert Cliffs 1	0501	18F0X	6	11640	407	19.48
Calvert Cliffs 1	0501	19F0X	4	11044	367	20.52
Calvert Cliffs 1	0501	19F0X	5	14454	402	24.52
Calvert Cliffs 1	0501	19F0X	7	8853	409	14.76
Calvert Cliffs 1	0501	20F0X	4	8318	367	15.23
Calvert Cliffs 1	0501	20F0X	5	13226	402	22.11
Calvert Cliffs 1	0501	20F0X	6	12863	407	21.24
Calvert Cliffs 1	0501	20F0X	7	9044	409	14.86
Calvert Cliffs 1	0501	20F0X	8	7306	401	12.25
Calvert Cliffs 1	0501	21F1X	4	13812	367	25.69
Calvert Cliffs 1	0501	21F1X	5	12838	402	21.80
Calvert Cliffs 1	0501	22G0X	5	10523	402	17.82
Calvert Cliffs 1	0501	22G0X	6	15087	407	25.24
Calvert Cliffs 1	0501	22G0X	7	12485	409	20.78
Calvert Cliffs 1	0501	24G1X	5	15469	402	25.04
Calvert Cliffs 1	0501	24G1X	6	13361	407	21.36
Calvert Cliffs 1	0501	25H0X	6	11365	407	19.02
Calvert Cliffs 1	0501	25H0X	7	15362	409	25.58
Calvert Cliffs 1	0501	25H0X	8	1086	401	1.84
Calvert Cliffs 1	0501	26H1X	6	16065	407	25.71
Calvert Cliffs 1	0501	26H1X	7	14003	409	22.30
Calvert Cliffs 1	0501	26H1X	8	12761	401	20.72
Cooper Station	3001	1A	2	6405	235	21.80
Cooper Station	3001	1A	3	3600	121	23.80
Cooper Station	3001	1A	4	7996	287	22.29
Cooper Station	3001	1A	5	6643	245	21.69
Cooper Station	3001	1A	2	6273	235	21.31
Cooper Station	3001	1A	3	3398	121	22.41
Cooper Station	3001	1A	4	6048	287	16.82
Cooper Station	3001	1A	5	6090	245	19.84
Cooper Station	3001	1A	2	6191	235	21.04
Cooper Station	3001	1A	3	3510	121	23.17
Cooper Station	3001	1A	4	6674	287	18.57
Cooper Station	3001	1A	5	6376	245	20.78
Cooper Station	3001	1B	2	6183	235	20.95
Cooper Station	3001	1B	3	3328	121	21.91
Cooper Station	3001	1B	4	5872	287	16.30
Cooper Station	3001	1B	5	6387	245	20.76
Cooper Station	3001	1B	6	6971	287	19.34
Cooper Station	3001	1B	2	6493	235	22.04
Cooper Station	3001	1B	3	3353	121	22.10
Cooper Station	3001	1B	4	5119	287	14.23
Cooper Station	3001	1B	5	4050	245	13.19
Cooper Station	3001	1B	6	7224	287	20.08
Cooper Station	3001	1B	2	5897	235	20.03
Cooper Station	3001	1B	3	3167	121	20.90
Cooper Station	3001	1B	4	6929	287	19.28
Cooper Station	3001	1B	5	5661	245	18.45

Reactor Name	INIS Number	Batch	Cycle	Cycle Burnup	EFPD	Cycle LHGR
Cooper Station	3001	1B	6	6966	287	19.38
Cooper Station	3001	1C	2	5409	235	18.39
Cooper Station	3001	1C	3	2806	121	18.52
Cooper Station	3001	1C	4	7466	287	20.78
Cooper Station	3001	1C	5	5701	245	18.59
Cooper Station	3001	1C	6	6529	287	18.17
Cooper Station	3001	1C	2	5951	235	20.25
Cooper Station	3001	1C	3	3569	121	23.59
Cooper Station	3001	1C	4	7922	287	22.07
Cooper Station	3001	1C	5	6065	245	19.79
Cooper Station	3001	1C	6	6633	287	18.48
Cooper Station	3001	1C	2	6169	235	20.98
Cooper Station	3001	1C	3	3218	121	21.26
Cooper Station	3001	1C	4	7825	287	21.79
Cooper Station	3001	1C	5	5890	245	19.21
Cooper Station	3001	1C	6	6723	287	18.72
Cooper Station	3001	1C	2	5706	235	19.38
Cooper Station	3001	1C	3	3356	121	22.14
Cooper Station	3001	1C	4	7278	287	20.24
Cooper Station	3001	1C	5	5918	245	19.28
Cooper Station	3001	1C	6	6750	287	18.77
Cooper Station	3001	1D	2	6243	235	21.18
Cooper Station	3001	1D	3	3306	121	21.79
Cooper Station	3001	1D	4	7497	287	20.83
Cooper Station	3001	1D	5	2844	245	9.26
Cooper Station	3001	1D	6	7029	287	19.53
Cooper Station	3001	1D	7	2331	268	6.94
Cooper Station	3001	1D	2	5970	235	20.28
Cooper Station	3001	1D	3	3681	121	24.28
Cooper Station	3001	1D	4	7769	287	21.61
Cooper Station	3001	1D	5	3381	245	11.01
Cooper Station	3001	1D	6	6518	287	18.13
Cooper Station	3001	1D	7	2625	268	7.82
Cooper Station	3001	2A	3	3318	121	21.95
Cooper Station	3001	2A	4	8495	287	23.70
Cooper Station	3001	2A	5	5971	245	19.51
Cooper Station	3001	2A	6	6593	287	18.39
Cooper Station	3001	2A	7	6956	268	20.78
Cooper Station	3001	2A	3	3152	121	20.86
Cooper Station	3001	2A	4	8388	287	23.40
Cooper Station	3001	2A	5	4994	245	16.32
Cooper Station	3001	2A	6	7216	287	20.13
Cooper Station	3001	2A	7	6427	268	19.20
Cooper Station	3001	2B	3	2866	121	18.93
Cooper Station	3001	2B	4	8086	287	22.52
Cooper Station	3001	2B	5	5874	245	19.16
Cooper Station	3001	2B	6	5606	287	15.61
Cooper Station	3001	2B	7	5142	268	15.34
Cooper Station	3001	2B	8	2825	268	8.43

Reactor Name	INIS Number	Batch	Cycle	Cycle Burnup	EFPD	Cycle LHGR
Cooper Station	3001	2B	3	2898	121	19.19
Cooper Station	3001	2B	4	7910	287	22.08
Cooper Station	3001	2B	5	5151	245	16.84
Cooper Station	3001	2B	6	6330	287	17.67
Cooper Station	3001	2B	7	5020	268	15.01
Cooper Station	3001	2B	8	5014	268	14.99
Cooper Station	3001	2B	3	2881	121	19.05
Cooper Station	3001	2B	4	8022	287	22.37
Cooper Station	3001	2B	5	6050	245	19.76
Cooper Station	3001	2B	6	6454	287	18.00
Cooper Station	3001	2B	7	4302	268	12.85
Cooper Station	3001	2B	8	2334	268	6.97
Cooper Station	3001	2B	3	2581	121	17.08
Cooper Station	3001	2B	4	7556	287	21.08
Cooper Station	3001	2B	5	5546	245	18.12
Cooper Station	3001	2B	6	6668	287	18.60
Cooper Station	3001	2B	7	5612	268	16.77
Cooper Station	3001	2B	8	3839	268	11.47
Cooper Station	3001	2C	3	2369	121	15.67
Cooper Station	3001	2C	4	6552	287	18.28
Cooper Station	3001	2C	5	6847	245	22.37
Cooper Station	3001	2C	6	6849	287	19.11
Cooper Station	3001	2C	7	2713	268	8.10
Cooper Station	3001	2C	8	2998	268	8.96
Cooper Station	3001	2C	9	2668	265	8.06
Cooper Station	3001	3A	4	8601	287	24.00
Cooper Station	3001	3A	5	7333	245	23.97
Cooper Station	3001	3A	6	7858	287	21.93
Cooper Station	3001	3A	7	6705	268	20.03
Cooper Station	3001	3B	4	6139	287	17.08
Cooper Station	3001	3B	5	6169	245	20.11
Cooper Station	3001	3B	6	7204	287	20.04
Cooper Station	3001	3B	7	6644	268	19.80
Cooper Station	3001	3B	8	6579	268	19.60
Cooper Station	3001	3B	4	7070	287	19.70
Cooper Station	3001	3B	5	7155	245	23.35
Cooper Station	3001	3B	6	4530	287	12.62
Cooper Station	3001	3B	7	6793	268	20.27
Cooper Station	3001	3B	8	6048	268	18.04
Cooper Station	3001	3B	4	6827	287	19.02
Cooper Station	3001	3B	5	7035	245	22.95
Cooper Station	3001	3B	6	5901	287	16.44
Cooper Station	3001	3B	7	6768	268	20.19
Cooper Station	3001	3B	8	3811	268	11.37
Cooper Station	3001	3C	4	8309	287	23.18
Cooper Station	3001	3C	5	6827	245	22.31
Cooper Station	3001	3C	6	6596	287	18.40
Cooper Station	3001	3C	7	5928	268	17.71
Cooper Station	3001	3C	8	5014	268	14.98

Reactor Name	INIS Number	Batch	Cycle	Cycle Burnup	EFPD	Cycle LHGR
Cooper Station	3001	3D	4	7454	287	20.76
Cooper Station	3001	3D	5	6799	245	22.18
Cooper Station	3001	3D	6	5096	287	14.19
Cooper Station	3001	3D	7	6713	268	20.02
Cooper Station	3001	3D	8	2513	268	7.49
Cooper Station	3001	3D	9	2861	265	8.63
Cooper Station	3001	3E	4	9675	287	27.00
Cooper Station	3001	3E	5	7362	245	24.07
Cooper Station	3001	3E	6	7680	287	21.43
Cooper Station	3001	3E	7	2454	268	7.33
Cooper Station	3001	3E	8	2747	268	8.21
Cooper Station	3001	3E	9	2357	265	7.12
Cooper Station	3001	4A	5	7133	245	23.27
Cooper Station	3001	4A	6	8207	287	22.86
Cooper Station	3001	4A	7	7449	268	22.22
Cooper Station	3001	4A	8	7429	268	22.16
Cooper Station	3001	4B	5	7086	245	23.12
Cooper Station	3001	4B	6	7714	287	21.48
Cooper Station	3001	4B	7	6223	268	18.56
Cooper Station	3001	4B	8	6026	268	17.97
Cooper Station	3001	4B	9	3625	265	10.93
Cooper Station	3001	4C	5	7047	245	22.99
Cooper Station	3001	4C	6	8465	287	23.58
Cooper Station	3001	4C	7	6311	268	18.82
Cooper Station	3001	4C	8	3714	268	11.08
Cooper Station	3001	4C	9	2692	265	8.12
Cooper Station	3001	4C	10	2477	280	7.07
Cooper Station	3001	5A	6	8203	287	22.88
Cooper Station	3001	5A	7	7989	268	23.86
Cooper Station	3001	5A	8	6781	268	20.25
Cooper Station	3001	5A	9	6575	265	19.86
Cooper Station	3001	5B	6	8490	287	23.67
Cooper Station	3001	5B	7	7580	268	22.63
Cooper Station	3001	5B	8	7793	268	23.27
Cooper Station	3001	5B	9	7234	265	21.85
Cooper Station	3001	5C	6	6382	287	17.80
Cooper Station	3001	5C	7	8334	268	24.90
Cooper Station	3001	5C	8	4073	268	12.17
Cooper Station	3001	5C	9	4402	265	13.30
Cooper Station	3001	5C	10	4907	280	14.03
Cooper Station	3001	5D	6	8389	287	23.39
Cooper Station	3001	5D	7	6205	268	18.52
Cooper Station	3001	5D	8	6631	268	19.80
Cooper Station	3001	5D	9	6081	265	18.36
Cooper Station	3001	5D	10	3123	280	8.92
Cooper Station	3001	6A	7	7758	268	23.21
Cooper Station	3001	6A	8	8349	268	24.98
Cooper Station	3001	6A	9	7326	265	22.16
Cooper Station	3001	6A	10	6151	280	17.61

Reactor Name	INIS Number	Batch	Cycle	Cycle Burnup	EFPD	Cycle LHGR
Cooper Station	3001	6B	7	8091	268	24.17
Cooper Station	3001	6B	8	7677	268	22.93
Cooper Station	3001	6B	9	7241	265	21.87
Cooper Station	3001	6B	10	6831	280	19.53
Cooper Station	3001	IA	1	10674	510	22.89
Cooper Station	3001	IA	1	9771	510	20.98
Cooper Station	3001	IA	1	10670	510	22.89
Cooper Station	3001	IA	1	9165	510	19.67
Cooper Station	3001	IA	1	9930	510	21.31
Cooper Station	3001	IA	1	10207	510	21.89
Cooper Station	3001	IA	1	9770	510	20.98
Cooper Station	3001	IB	1	8535	510	18.25
Cooper Station	3001	IB	2	3132	235	14.54
Cooper Station	3001	IB	1	8570	510	18.34
Cooper Station	3001	IB	2	2110	235	9.80
Cooper Station	3001	IB	1	8546	510	18.36
Cooper Station	3001	IB	2	2782	235	12.97
Cooper Station	3001	IB	1	8216	510	17.65
Cooper Station	3001	IB	2	1809	235	8.43
Cooper Station	3001	IB	1	8302	510	17.81
Cooper Station	3001	IB	2	2789	235	12.98
Cooper Station	3001	IIA	1	13436	510	27.51
Cooper Station	3001	IIA	2	5602	235	24.89
Cooper Station	3001	IIA	3	2730	121	23.56
Cooper Station	3001	IIA	1	13494	510	27.66
Cooper Station	3001	IIA	2	5977	235	26.59
Cooper Station	3001	IIA	3	2732	121	23.61
Cooper Station	3001	IIA	1	13025	510	26.69
Cooper Station	3001	IIA	2	6005	235	26.71
Cooper Station	3001	IIA	3	2943	121	25.42
Cooper Station	3001	IIB	1	8768	510	17.99
Cooper Station	3001	IIB	2	4601	235	20.48
Cooper Station	3001	IIB	3	3048	121	26.36
Cooper Station	3001	IIB	4	5580	287	20.34
Cooper Station	3001	IIB	1	12049	510	24.71
Cooper Station	3001	IIB	2	5426	235	24.15
Cooper Station	3001	IIB	3	2170	121	18.76
Cooper Station	3001	IIB	4	3108	287	11.33
Cooper Station	3001	IIB	1	11933	510	24.51
Cooper Station	3001	IIB	2	5799	235	25.85
Cooper Station	3001	IIB	3	2881	121	24.94
Cooper Station	3001	IIB	4	6199	287	22.62
Cooper Station	3001	IIB	1	11070	510	22.71
Cooper Station	3001	IIB	2	5626	235	25.04
Cooper Station	3001	IIB	3	2587	121	22.36
Cooper Station	3001	IIB	4	4101	287	14.95
Cooper Station	3001	IIB	1	10619	510	21.80
Cooper Station	3001	IIB	2	5622	235	25.04
Cooper Station	3001	IIB	3	2684	121	23.22

Reactor Name	INIS Number	Batch	Cycle	Cycle Burnup	EFPD	Cycle LHGR
Cooper Station	3001	IIB	4	4745	287	17.31
Cooper Station	3001	IIB	1	11570	510	23.70
Cooper Station	3001	IIB	2	5555	235	24.70
Cooper Station	3001	IIB	3	2322	121	20.05
Cooper Station	3001	IIB	4	6080	287	22.14
Cooper Station	3001	IIB	1	11033	510	22.65
Cooper Station	3001	IIB	2	5508	235	24.54
Cooper Station	3001	IIB	3	2627	121	22.73
Cooper Station	3001	IIB	4	6363	287	23.21
Cooper Station	3001	IIC	1	6551	510	13.40
Cooper Station	3001	IIC	2	6111	235	27.13
Cooper Station	3001	IIC	3	2923	121	25.21
Cooper Station	3001	IIC	4	7068	287	25.70
Cooper Station	3001	IIC	5	5946	245	25.32
Cooper Station	3001	IIC	1	9383	510	19.31
Cooper Station	3001	IIC	2	3605	235	16.10
Cooper Station	3001	IIC	3	3537	121	30.68
Cooper Station	3001	IIC	4	6796	287	24.86
Cooper Station	3001	IIC	5	5330	245	22.84
Cooper Station	3001	IIC	1	12730	510	26.17
Cooper Station	3001	IIC	2	5769	235	25.74
Cooper Station	3001	IIC	3	2528	121	21.90
Cooper Station	3001	IIC	4	2123	287	7.76
Cooper Station	3001	IIC	5	3534	245	15.12
Cooper Station	3001	IIC	1	7665	510	15.71
Cooper Station	3001	IIC	2	4569	235	20.32
Cooper Station	3001	IIC	3	2767	121	23.90
Cooper Station	3001	IIC	4	7181	287	26.15
Cooper Station	3001	IIC	5	2626	245	11.20
Cooper Station	3001	IIC	1	6703	510	13.76
Cooper Station	3001	IIC	2	4074	235	18.15
Cooper Station	3001	IIC	3	2743	121	23.73
Cooper Station	3001	IIC	4	7609	287	27.76
Cooper Station	3001	IIC	5	2984	245	12.75
Cooper Station	3001	IIC	1	6692	510	13.73
Cooper Station	3001	IIC	2	3729	235	16.60
Cooper Station	3001	IIC	3	2786	121	24.09
Cooper Station	3001	IIC	4	7442	287	27.13
Cooper Station	3001	IIC	5	3187	245	13.61
Cooper Station	3001	IIC	1	7744	510	15.88
Cooper Station	3001	IIC	2	5079	235	22.60
Cooper Station	3001	IIC	3	3064	121	26.48
Cooper Station	3001	IIC	4	6885	287	25.08
Cooper Station	3001	IIC	5	2614	245	11.16
Cooper Station	3001	IIC	1	8593	510	17.63
Cooper Station	3001	IIC	2	5660	235	25.20
Cooper Station	3001	IIC	3	3072	121	26.57
Cooper Station	3001	IIC	4	5930	287	21.62
Cooper Station	3001	IIC	5	5523	245	23.59

Reactor Name	INIS Number	Batch	Cycle	Cycle Burnup	EFPD	Cycle LHGR
Cooper Station	3001	IID	1	6571	510	13.47
Cooper Station	3001	IID	2	3170	235	14.11
Cooper Station	3001	IID	3	2112	121	18.25
Cooper Station	3001	IID	4	6155	287	22.42
Cooper Station	3001	IID	5	2911	245	12.42
Cooper Station	3001	IID	6	2588	287	9.43
Cooper Station	3001	IID	1	6370	510	13.07
Cooper Station	3001	IID	2	2859	235	12.73
Cooper Station	3001	IID	3	3110	121	26.90
Cooper Station	3001	IID	4	6121	287	22.32
Cooper Station	3001	IID	5	2895	245	12.37
Cooper Station	3001	IID	6	2577	287	9.40
Cooper Station	3001	IID	1	7274	510	14.94
Cooper Station	3001	IID	2	3295	235	14.69
Cooper Station	3001	IID	3	2522	121	21.84
Cooper Station	3001	IID	4	8067	287	29.45
Cooper Station	3001	IID	5	2334	245	9.98
Cooper Station	3001	IID	6	3031	287	11.07
Cooper Station	3001	IIE	1	12355	510	25.36
Cooper Station	3001	IIE	2	5848	235	26.05
Cooper Station	3001	IIE	3	2974	121	25.73
Cooper Station	3001	IIE	6	2782	287	10.15
Cooper Station	3001	IIE	7	2513	268	9.82
Cooper Station	3001	IIIA	1	13360	510	27.37
Cooper Station	3001	IIIA	1	13156	510	26.99
Cooper Station	3001	IIIB	1	13627	510	28.02
Cooper Station	3001	IIIB	2	6019	235	26.85
Cooper Station	3001	IIIC	1	12874	510	26.45
Cooper Station	3001	IIIC	2	5457	235	24.33
Cooper Station	3001	IIIC	3	3001	121	25.98
Cooper Station	3001	IIIC	1	13110	510	26.90
Cooper Station	3001	IIIC	2	5512	235	24.55
Cooper Station	3001	IIIC	3	3055	121	26.42
Cooper Station	3001	IIIC	1	13813	510	28.35
Cooper Station	3001	IIIC	2	5638	235	25.11
Cooper Station	3001	IIIC	3	2901	121	25.10
Cooper Station	3001	IIIC	1	13599	510	27.88
Cooper Station	3001	IIIC	2	5552	235	24.70
Cooper Station	3001	IIIC	3	3180	121	27.48
Cooper Station	3001	IIIC	1	13833	510	28.37
Cooper Station	3001	IIIC	2	5441	235	24.22
Cooper Station	3001	IIIC	3	2968	121	25.66
Cooper Station	3001	IIIC	1	13634	510	27.96
Cooper Station	3001	IIIC	2	5646	235	25.13
Cooper Station	3001	IIIC	3	3144	121	27.18
Cooper Station	3001	IIIC	1	13530	510	27.75
Cooper Station	3001	IIIC	2	5332	235	23.73
Cooper Station	3001	IIIC	3	2888	121	24.97
Cooper Station	3001	IIID	1	13917	510	28.53

Reactor Name	INIS Number	Batch	Cycle	Cycle Burnup	EFPD	Cycle LHGR
Cooper Station	3001	IIID	2	3109	235	13.83
Cooper Station	3001	IIID	3	2247	121	19.41
Cooper Station	3001	IIID	4	6963	287	25.36
Cooper Station	3001	IIID	1	13662	510	28.13
Cooper Station	3001	IIID	2	6006	235	26.83
Cooper Station	3001	IIID	3	1324	121	11.49
Cooper Station	3001	IIID	4	6760	287	24.73
Cooper Station	3001	IIID	1	13832	510	28.33
Cooper Station	3001	IIID	2	2839	235	12.62
Cooper Station	3001	IIID	3	3229	121	27.88
Cooper Station	3001	IIID	4	2933	287	10.68
Cooper Station	3001	IIID	1	13535	510	27.75
Cooper Station	3001	IIID	2	4654	235	20.70
Cooper Station	3001	IIID	3	2144	121	18.52
Cooper Station	3001	IIID	4	3398	287	12.38
Cooper Station	3001	IIID	1	13426	510	27.51
Cooper Station	3001	IIID	2	5413	235	24.07
Cooper Station	3001	IIID	3	1413	121	12.20
Cooper Station	3001	IIID	4	4940	287	17.98
Cooper Station	3001	IIID	1	13380	510	27.42
Cooper Station	3001	IIID	2	5538	235	24.63
Cooper Station	3001	IIID	3	1373	121	11.86
Cooper Station	3001	IIID	4	4781	287	17.41
Cooper Station	3001	IIID	1	13855	510	28.43
Cooper Station	3001	IIID	2	4022	235	17.91
Cooper Station	3001	IIID	3	2220	121	19.20
Cooper Station	3001	IIID	4	6360	287	23.19
Cooper Station	3001	IIID	1	13636	510	27.96
Cooper Station	3001	IIID	2	4351	235	19.36
Cooper Station	3001	IIID	3	2238	121	19.34
Cooper Station	3001	IIID	4	3315	287	12.08
Cooper Station	3001	IIID	1	13604	510	27.90
Cooper Station	3001	IIID	2	4781	235	21.28
Cooper Station	3001	IIID	3	1834	121	15.85
Cooper Station	3001	IIID	4	5783	287	21.08
Cooper Station	3001	IIIE	1	13478	510	27.63
Cooper Station	3001	IIIE	2	5210	235	23.18
Cooper Station	3001	IIIE	3	1570	121	13.57
Cooper Station	3001	IIIE	4	2314	287	8.43
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Cooper Station	3001	IIIE	1	13558	510	27.80
Cooper Station	3001	IIIE	2	4922	235	21.91
Cooper Station	3001	IIIE	3	1853	121	16.02
Cooper Station	3001	IIIE	4	2642	287	9.63
Cooper Station	3001	IIIE	5	4764	245	20.34
Cooper Station	3001	IIIF	1	14117	510	28.94
Cooper Station	3001	IIIF	2	5926	235	26.36
Cooper Station	3001	IIIF	5	6584	245	28.10
Cooper Station	3001	IIIF	1	14081	510	28.85

Reactor Name	INIS Number	Batch	Cycle	Cycle Burnup	EFPD	Cycle LHGR
Cooper Station	3001	IIIF	2	5888	235	26.18
Cooper Station	3001	IIIF	5	3975	245	16.95
Cooper Station	3001	IIIF	1	13850	510	28.40
Cooper Station	3001	IIIF	2	5606	235	24.95
Cooper Station	3001	IIIF	5	4639	245	19.80
Cooper Station	3001	IIIG	1	14254	510	29.25
Cooper Station	3001	IIIG	2	5031	235	22.40
Cooper Station	3001	IIIG	5	2442	245	10.43
Cooper Station	3001	IIIG	6	2866	287	10.45
Cooper Station	3001	IIIG	1	13986	510	28.67
Cooper Station	3001	IIIG	2	5817	235	25.87
Cooper Station	3001	IIIG	5	2257	245	9.63
Cooper Station	3001	IIIG	6	3293	287	11.99
Cooper Station	3001	IIIG	1	13952	510	28.55
Cooper Station	3001	IIIG	2	5869	235	26.07
Cooper Station	3001	IIIG	5	2460	245	10.48
Cooper Station	3001	IIIG	6	3170	287	11.53
Cooper Station	3001	IIIG	1	13741	510	28.19
Cooper Station	3001	IIIG	2	5788	235	25.77
Cooper Station	3001	IIIG	5	2169	245	9.26
Cooper Station	3001	IIIG	6	2960	287	10.79
Cooper Station	3001	IIIG	1	13751	510	28.17
Cooper Station	3001	IIIG	2	5732	235	25.48
Cooper Station	3001	IIIG	5	1974	245	8.42
Cooper Station	3001	IIIG	6	3258	287	11.86
Cooper Station	3001	IIIG	1	13991	510	28.71
Cooper Station	3001	IIIG	2	5716	235	25.46
Cooper Station	3001	IIIG	5	2606	245	11.13
Cooper Station	3001	IIIG	6	3770	287	13.75
Cooper Station	3001	IIIH	1	12516	510	25.72
Cooper Station	3001	IIIH	2	5668	235	25.28
Cooper Station	3001	IIIH	3	2827	121	24.49
Cooper Station	3001	IIIH	6	3004	287	10.97
Cooper Station	3001	IIIH	1	12821	510	26.30
Cooper Station	3001	IIIH	2	5687	235	25.32
Cooper Station	3001	IIIH	3	3099	121	26.80
Cooper Station	3001	IIIH	6	2974	287	10.84
Cooper Station	3001	IIIJ	1	13324	510	27.36
Cooper Station	3001	IIIJ	2	5499	235	24.51
Cooper Station	3001	IIIJ	3	3094	121	26.78
Cooper Station	3001	IIIJ	6	3123	287	11.40
Cooper Station	3001	IIIJ	7	2724	268	10.65
Cooper Station	3001	IIIJ	1	13088	510	26.84
Cooper Station	3001	IIIJ	2	5677	235	25.26
Cooper Station	3001	IIIJ	3	2757	121	23.83
Cooper Station	3001	IIIJ	6	2725	287	9.93
Cooper Station	3001	IIIJ	7	2405	268	9.38
Robinson 2	0705	R 0010	1	16907	487	21.36
Robinson 2	0705	R 0010	1	16728	487	21.14

Reactor Name	INIS Number	Batch	Cycle	Cycle Burnup	EFPD	Cycle LHGR
Robinson 2	0705	R 0010	1	16007	487	20.23
Robinson 2	0705	R 0010	1	15640	487	19.76
Robinson 2	0705	R 0010	1	15913	487	20.11
Robinson 2	0705	R 0010	1	15687	487	19.82
Robinson 2	0705	R 0040	2	10324	312	20.23
Robinson 2	0705	R 0040	3	13687	406	20.61
Robinson 2	0705	R 0040	2	7812	312	15.47
Robinson 2	0705	R 0040	3	14370	406	21.86
Robinson 2	0705	R 0040	2	9547	312	18.71
Robinson 2	0705	R 0040	3	14055	406	21.16
Robinson 2	0705	R 0040	2	9336	312	18.29
Robinson 2	0705	R 0040	3	14290	406	21.52
Robinson 2	0705	R 0040	2	9313	312	18.25
Robinson 2	0705	R 0040	3	14146	406	21.30
Robinson 2	0705	R 0040	2	9521	312	18.66
Robinson 2	0705	R 0040	3	14098	406	21.23
Robinson 2	0705	R 004A	2	7532	312	14.89
Robinson 2	0705	R 004A	3	14098	406	21.42
Robinson 2	0705	R 004A	4	8592	302	17.55
Robinson 2	0705	R 0050	3	15027	406	22.78
Robinson 2	0705	R 0050	4	8344	302	17.01
Robinson 2	0705	R 0050	3	14310	406	21.68
Robinson 2	0705	R 0050	4	8409	302	17.13
Robinson 2	0705	R 0050	3	14697	406	22.23
Robinson 2	0705	R 0050	4	8492	302	17.26
Robinson 2	0705	R 0050	3	14169	406	21.46
Robinson 2	0705	R 0050	4	8596	302	17.50
Robinson 2	0705	R 0060	3	8502	406	12.87
Robinson 2	0705	R 0060	4	10811	302	22.00
Robinson 2	0705	R 0060	5	9756	310	19.34
Robinson 2	0705	R 0060	3	8469	406	12.82
Robinson 2	0705	R 0060	4	10778	302	21.94
Robinson 2	0705	R 0060	5	9505	310	18.85
Robinson 2	0705	R 0060	3	10094	406	15.31
Robinson 2	0705	R 0060	4	10728	302	21.87
Robinson 2	0705	R 0060	5	9464	310	18.79
Robinson 2	0705	R 0060	3	12128	406	18.39
Robinson 2	0705	R 0060	4	10527	302	21.46
Robinson 2	0705	R 0060	5	9461	310	18.79
Robinson 2	0705	R 0060	3	7975	406	12.08
Robinson 2	0705	R 0060	4	10676	302	21.74
Robinson 2	0705	R 0060	5	9323	310	18.49
Robinson 2	0705	R 0060	3	11751	406	17.81
Robinson 2	0705	R 0060	4	10500	302	21.40
Robinson 2	0705	R 0060	5	9326	310	18.51
Robinson 2	0705	R 006A	3	12169	406	18.41
Robinson 2	0705	R 006A	4	8546	302	17.38
Robinson 2	0705	R 006A	5	8207	310	16.26
Robinson 2	0705	R 0070	4	8102	302	15.42

Reactor Name	INIS Number	Batch	Cycle	Cycle Burnup	EFPD	Cycle LHGR
Robinson 2	0705	R 0070	5	11895	310	22.05
Robinson 2	0705	R 0070	6	8946	306	16.80
Robinson 2	0705	R 0070	4	9165	302	17.45
Robinson 2	0705	R 0070	5	11302	310	20.96
Robinson 2	0705	R 0070	6	10306	306	19.36
Robinson 2	0705	R 007A	4	11816	302	22.48
Robinson 2	0705	R 007A	5	11146	310	20.66
Robinson 2	0705	R 007A	6	9865	306	18.52
Robinson 2	0705	R 007A	7	7908	296	15.35
Robinson 2	0705	R 007B	4	11466	302	21.88
Robinson 2	0705	R 007B	5	11200	310	20.82
Robinson 2	0705	R 007B	6	9896	306	18.64
Robinson 2	0705	R 007B	7	7661	296	14.92
Robinson 2	0705	R 007B	8	7292	305	13.78
Robinson 2	0705	R 0080	5	9000	310	16.64
Robinson 2	0705	R 0080	6	12090	306	22.64
Robinson 2	0705	R 0080	7	10084	296	19.52
Robinson 2	0705	R 008A	5	9924	310	18.32
Robinson 2	0705	R 008A	6	12485	306	23.35
Robinson 2	0705	R 008A	8	9686	305	18.17
Robinson 2	0705	R 008B	5	9885	310	18.27
Robinson 2	0705	R 008B	6	12524	306	23.45
Robinson 2	0705	R 008B	9	2122	162	7.50
Robinson 2	0705	R 008B	9	2122	151	8.05
Robinson 2	0705	R 008B	9	2590	162	9.16
Robinson 2	0705	R 008B	9	2590	151	9.83
Robinson 2	0705	R 009A	6	10364	306	19.43
Robinson 2	0705	R 009A	7	9934	296	19.25
Robinson 2	0705	R 009B	6	9927	306	18.65
Robinson 2	0705	R 009B	7	10863	296	21.10
Robinson 2	0705	R 009C	6	9541	306	17.91
Robinson 2	0705	R 009C	7	11386	296	22.09
Robinson 2	0705	R 009C	8	10331	305	19.45
Robinson 2	0705	R 009D	6	7152	306	13.43
Robinson 2	0705	R 009D	7	11944	296	23.18
Robinson 2	0705	R 009D	8	10128	305	19.08
Robinson 2	0705	R 009D	9	1633	162	5.79
Robinson 2	0705	R 009D	9	1633	151	6.21
Robinson 2	0705	R 009D	9	1983	162	7.03
Robinson 2	0705	R 009D	9	1983	151	7.54
Robinson 2	0705	R 010A	7	11403	296	22.25
Robinson 2	0705	R 010A	8	9711	305	18.39
Robinson 2	0705	R 010B	7	8895	296	17.37
Robinson 2	0705	R 010B	8	11756	305	22.28
Robinson 2	0705	R 010B	9	5591	162	19.95
Robinson 2	0705	R 010B	9	5591	151	21.40
Robinson 2	0705	R 010B	9	5014	162	17.89
Robinson 2	0705	R 010B	9	5014	151	19.19
Robinson 2	0705	R 0110	8	11785	305	22.27

Reactor Name	INIS Number	Batch	Cycle	Cycle Burnup	EFPD	Cycle LHGR
Robinson 2	0705	R 0110	9	6361	162	22.63
Robinson 2	0705	R 0110	9	6361	151	24.28
Robinson 2	0705	R 0110	9	5635	162	20.05
Robinson 2	0705	R 0110	9	5635	151	21.51
Robinson 2	0705	R 0110	10	10199	318	18.48
Robinson 2	0705	R 0110	8	8935	305	16.93
Robinson 2	0705	R 0110	9	6585	162	23.49
Robinson 2	0705	R 0110	9	6585	151	25.20
Robinson 2	0705	R 0110	9	5744	162	20.49
Robinson 2	0705	R 0110	9	5744	151	21.99
Robinson 2	0705	R 0110	10	10107	318	18.37
Robinson 2	0705	R 011A	8	11893	305	22.54
Robinson 2	0705	R 011A	9	6341	162	22.62
Robinson 2	0705	R 011A	9	6341	151	24.27
Robinson 2	0705	R 011A	9	5402	162	19.27
Robinson 2	0705	R 011A	9	5402	151	20.68
Robinson 2	0705	R 011A	11	10364	335	17.88
Robinson 2	0705	R 012A	9	4922	162	17.47
Robinson 2	0705	R 012A	9	4922	151	18.74
Robinson 2	0705	R 012A	9	5236	162	18.58
Robinson 2	0705	R 012A	9	5236	151	19.94
Robinson 2	0705	R 012A	10	12694	318	22.95
Robinson 2	0705	R 012A	11	10148	335	17.42
Robinson 2	0705	R 012A	9	5119	162	18.26
Robinson 2	0705	R 012A	9	5119	151	19.59
Robinson 2	0705	R 012A	9	5361	162	19.12
Robinson 2	0705	R 012A	9	5361	151	20.51
Robinson 2	0705	R 012A	10	12397	318	22.53
Robinson 2	0705	R 012A	11	10123	335	17.46
Robinson 2	0705	R 012C	10	10962	318	19.96
Robinson 2	0705	R 012C	11	14038	335	24.26
Robinson 2	0705	R 013B	10	12923	318	23.38
Robinson 2	0705	R 013B	11	12077	335	20.74

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