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Analysis of Assembly Serial Number Usage in Domestic Light-Water Reactors

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Chemical Technology Division

ANALYSIS OF ASSEMBLY SERIAL NUMBER USAGE IN DOMESTIC LIGHT-WATER REACTORS

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CONTENTS

Page

CONTENTS iii

ACKNOWLEDGEMENTS iv

TABLES v

ABSTRACT 1

1. INTRODUCTION 3

2. BACKGROUND 4
    2.1 SERIAL NUMBER USAGE 4
    2.2 SERIAL NUMBERING SCHEMES 4
    2.3 ASSEMBLY CLASSIFICATION SCHEME FOR LWR FUEL ASSEMBLIES 6

3. SERIAL NUMBER DUPLICATION 9
    3.1 DETERMINING DUPLICATION 9
    3.2 RESULTS OF DUPLICATION STUDY 11
    3.3 DATA ANOMALIES 19

4. CONCLUSIONS 22

5. REFERENCES 24

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TABLES

1. ANSI serial number prefix codes for U.S. fuel fabricators 5
2. Assembly classes for LWR reactors 8
3. Replication ratio for various orders of replication 10
4. Instances of duplication tabulated by assembly class and reactor 12
5. Reactor sites where Oyster Creek serial numbers are duplicated 18

ABSTRACT

Domestic light-water reactor (LWR) fuel assemblies are identified by a serial number that is placed on each assembly. These serial numbers are used as identifiers throughout the life of the fuel. The uniqueness of assembly serial numbers is important in determining their effectiveness as unambiguous identifiers. The purpose of this study is to determine what serial numbering schemes are used, the effectiveness of these schemes, and to quantify how many duplicate serial numbers occur on domestic LWR fuel assemblies.

The serial numbering scheme adopted by the American National Standards Institute (ANSI) ensures uniqueness of assembly serial numbers. The latest numbering scheme adopted by General Electric (GE), which is very similar to the ANSI Standard, was also found to be unique. Most utility numbering schemes are not inherently unique and errors within such schemes accounted for all of the identified serial number duplication except for three isolated instances.

Analysis of 70,971 fuel assembly serial numbers from permanently discharged fuel identified 11,948 serial number duplicates. These duplications resulted from repetition of generic-type serial numbers at different reactor sites. Serial numbers at 50 pressurized-water reactors (PWRs) accounted for 95% of these duplications with the remaining 5% occurring at four boiling-water reactors (BWRs). On average, when a given serial number is duplicated, it is duplicated between five and six times. It was determined that no serial number duplication occurred (except that caused by data entry errors) at any particular reactor site when the comparison was limited to fuel at that site. Thus, the combination of a generic fuel assembly serial number and reactor site identifier is currently unique within the entire domestic spent fuel inventory.

Three duplicate serial numbers were found when analysis focused on duplication within the individual fuel inventory at each reactor site, but these were traced back to data entry errors and will be corrected by the EIA. There were also three instances where the serial numbers used to identify assemblies used for hot cell studies differed from the serial numbers reported to the EIA.

It is recommended that fuel fabricators and utilities adhere to the ANSI serial numbering scheme to ensure serial number uniqueness. In addition, organizations collecting

serial number information, such as the Energy Information Administration (EIA), should request that all known serial numbers (ANSI, utility, and other numbering schemes) physically attached or associated with each assembly be reported and identified by the corresponding numbering scheme.

1. INTRODUCTION

Domestic light-water reactor (LWR) fuel assemblies are identified by a serial number that is placed on each assembly. These serial numbers are used as identifiers throughout the life of the fuel. The uniqueness of assembly serial numbers is important in determining their effectiveness as unambiguous identifiers. The purpose of this study is to determine what serial numbering schemes are used, the effectiveness of these schemes, and to quantify how many duplicate serial numbers occur on domestic LWR fuel assemblies.

The American National Standards Institute (ANSI) has issued a standard for fuel assembly identification.[1] The standard ensures that serial numbers are unique and that they also identify the fuel fabrication facility for each assembly. In addition, several non-ANSI serial numbering schemes have been identified in this study.

The approach taken in this study was to first determine the amount of duplication within the entire fuel inventory and then also by categories such as reactor type (BWR or PWR), Characteristics Data Base (CDB) assembly class, fuel vendor, and at each reactor site. The uniqueness of each identified serial numbering scheme was then determined.

The CDB[2] Program, sponsored by the U. S. Department of Energy's (DOE's) Office of Civilian Radioactive Waste Management (OCRWM) and developed and maintained by Oak Ridge National Laboratory (ORNL), provides quantitative and descriptive data on all potential repository wastes, including LWR spent fuel. The Serial Number Data Base (SNDB), one of six CDB menu-driven data base programs, contains all the serial number identifiers used for domestic spent fuel. Assembly serial number data are initially obtained from the nuclear utilities by the Energy Information Administration (EIA) using Nuclear Fuel Data Form RW-859. The EIA compiles the RW-859 Data Base annually from utility-supplied information. The assembly serial number information used in the SNDB and this report were obtained directly from the EIA via data tape F19952 dated October, 1990.[3]

2. BACKGROUND

2.1 SERIAL NUMBER USAGE

A system for the unique identification of each nuclear fuel assembly is necessary due to the reporting requirements and record keeping associated with the use of such assemblies at domestic LWRs. The assembly serial numbers are used by fuel fabrication vendors to record which assemblies are shipped to each reactor, by utilities to track the fuel within their fuel management system, and by the DOE, U.S. Nuclear Regulatory Commission (NRC), and International Atomic Energy Agency (IAEA) to meet their requirements for nuclear material control and accountability (NMC&A). Reporting and record keeping, a necessary part of any NMC&A system, are handled by DOE's Nuclear Materials Management and Safeguards System (NMMSS), which is responsible for implementing DOE and NRC regulatory requirements for an NMC&A system. When DOE accepts title to LWR spent fuel at some future date, they must also accept responsibility for physical control and accountability. An unambiguous method for the identification of LWR assemblies is an essential component of any such system.

2.2 SERIAL NUMBERING SCHEMES

ANSI has issued a standard for fuel assembly identification.[1] The standard (N18.3-1972) was originally developed for the Safeguards Program of the U.S. Atomic Energy Commission (AEC), now the U.S. NRC, by Subcommittee 13 of the Standards Committee of the American Nuclear Society. A revised version (ANSI/ANS-57.8-1978) of the original N18.3-1972 Standard was approved by ANSI on November 8, 1978. This revised Standard describes a system for the unique identification of commercial LWR fuel assemblies, based on assigning each fuel assembly a six character serial number. The serial number consists of a prefix code composed of two alphabetic characters that identify the fuel fabrication facility, followed by four alphanumeric characters. The prefix code consists of the last two characters of the three-character code assigned to each fabrication facility by the former U.S. AEC. The fabrication facility codes and the two character prefix codes are shown in Table 1. The last four characters of the serial number are sequentially assigned using a base-34 numbering scheme where characters are selected from the Arabic numerals 0 through 9 and all the

letters of the English alphabet, excluding "I" and "O" (to avoid confusion with the numerals 1 and 0). This base-34 serial numbering scheme provides 1,336,336 unique serial numbers (34^4) for each U.S. fuel fabrication facility.

Table 1. ANSI serial number prefix codes for U.S. fuel fabricators[4]

Fuel Fabricator	U.S. AEC Fabricator Code	ANSI Serial Number Prefix Code
Advanced Nuclear Fuels (formerly Exxon)	YUD	UD
Babcock & Wilcox	YNJ	NJ
Combustion Engineering	ZEF	EF
General Electric	YLJ	LJ
Westinghouse	YLM	LM

Obviously, fuel manufactured before the ANSI Standard will not bear an ANSI serial number, although some pre-1978 fuel did use ANSI-type numbers based on the earlier AEC Standard. Additionally, the utilities may request that a different set of serial numbers be placed on the fuel. Examples have been found where vendor documents clearly showed that ANSI serial numbers were assigned to certain fuels and yet EIA records received from the utilities show that a different numbering scheme had been used. An example of this is found at the Callaway Nuclear Plant, which is known to use only Westinghouse-manufactured 17 x 17 Standard and optimized fuel assembly (OFA) type fuels.[5] EIA records dated October, 1990 show that all 268 fuel assemblies discharged from Callaway used non-ANSI serial numbers. However, a fuel vendor document[6] shows that all Westinghouse-manufactured 17 x 17 fuel assemblies (Standard and OFA type) have been assigned ANSI serial numbers. The use of multiple identification markings, permissible according to the ANSI Standard, is probably requested by utilities to allow internal continuation of a numbering scheme familiar to their operators, and numbers from this scheme may then be reported to the EIA.

Though no national standard exists for non-ANSI numbering schemes, an attempt has been made to understand and describe these other schemes, hereafter referred to as utility

numbering schemes. Vendor documents[6,7] indicate that the vast majority of the fuel manufactured by Babcock & Wilcox (B&W) and Westinghouse that was shipped to utilities after 1974 had ANSI serial numbers assigned. Similar documents from Combustion Engineering[8] indicate that some fuel shipped after 1974 used ANSI serial numbers but that a number of assemblies used only utility numbering schemes.

From examining the EIA serial number data, it is obvious that utilities using fuel manufactured by Advanced Nuclear Fuels, Inc. (formerly Exxon Nuclear Company) and General Electric (GE) have not reported ANSI Standard serial numbers to the EIA. It does appear that serial numbers used on GE-manufactured fuel did transition from an older utility scheme to what could be called a "quasi-ANSI" system. This latter system, like the ANSI Standard, uses two alphabetic prefix characters (LJ or LY are commonly used) followed by four additional characters. Unlike the ANSI Standard, the third character is alphanumeric and the last three characters are strictly numeric rather than the ANSI-specified base-34 numbering system. Fortunately, the result is similar in that no duplication is believed to exist in this quasi-ANSI system used by GE.

Utility scheme serial numbers, which are difficult to describe generically, can consist of from two to eight characters. Typical formats include some type of prefix code that may identify the reactor site (e.g., AKA106 where AK identifies Arkansas 2), the fuel batch (e.g., A028 where A designates fuel batch for St. Lucie 1), or both (e.g., LAB002 where LA is for Waterford 3 and B is a batch identifier). Some prefix codes are simple alphabetic sequences (A, B, C, etc.) that usually vary with the fuel batch. The remainder of the serial number is frequently just an ascending numeric sequence. Obviously such simple codes will result in many serial number duplications between reactor sites. For example, 17 fuel assemblies from domestic reactors have a reported serial number of A01. Duplication among such utility schemes is quite common.

2.3 ASSEMBLY CLASSIFICATION SCHEME FOR LWR FUEL ASSEMBLIES

The CDB Program has developed an assembly classification scheme to characterize LWR fuels in a well-defined and systematic manner.[5] A two-stage scheme was developed that consists of 24 broad categories known as assembly classes that are further divided into 124 assembly types. That scheme is used in this report and, therefore, a brief review follows.

The assembly classes are determined by the configuration of the reactor cores in which the assemblies are used. 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 11 generic or multiple-reactor classes (2 BWR and 9 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). Table 2 lists the 24 assembly classes and their deployment.

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. 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.[5]

Table 2. Assembly classes for LWR reactors

BWR Assembly Classes	Reactors Using	Assembly Types
Multi-Reactor Classes:		
GE BWR/2,3	9	18
GE BWR/4,5,6	27	19
Single-Reactor Classes:		
Big Rock Point	1	8
Dresden 1	1[b]	9
Elk River	1[b,c]	1
Humboldt Bay	1[b]	4
Lacrosse	1[b]	2
Pathfinder	1[b]	1

PWR Assembly Classes	Reactors Using	Model Types
Multi-Reactor Classes:		
B&W 15x15	8	12
B&W 17x17	(3)[a]	1
CE 14x14	5	3
CE 16x16	4	2
CE System 80	3	1
WE 14x14	6	7
WE 15x15	10	7
WE 17x17	32	7
South Texas	2	1
Single-Reactor Classes:		
Fort Calhoun	1	3
Haddam Neck	1	7
Indian Point 1	1[b]	2
Palisades	1	2
St. Lucie 2	1	1
San Onofre 1	1	2
Yankee Rowe	1	4

[a]Not yet in operation.
[b]Shut down.
[c]All reprocessed

3. SERIAL NUMBER DUPLICATION

3.1 DETERMINING DUPLICATION

There are a number of ways to approach the problem of determining serial number duplication. No one technique is more correct than another, but the perception of correctness depends on the viewer's perspective. For example, individual utilities may only be concerned with serial number duplication within their own fuel management system, fuel manufacturers will likely be concerned only with fuel they produce, whereas facilities that will be physically handling fuel assemblies from multiple reactors (e.g., consolidation at a central facility) may only be concerned about serial number duplication within an assembly class since fuels within a particular class are physically similar. Finally, a regulatory agency handling records on all domestic fuel assemblies may well require serial number uniqueness within the entire domestic fuel inventory. For these reasons, a number of approaches were considered in this study that included determining duplication for the entire inventory, by reactor type, by assembly class, and at individual reactor sites. All of the data handling and analysis was performed using Ashton-Tate's® Developer's Edition of dBASE® IV version 1.1.

There are three terms used in this report that require explanation. The term "number of duplicates" refers to the number of serial numbers that must be removed from a particular group in order to be left with a unique set of numbers free from duplication. A second term, "instances of duplication," refers to the number of serial numbers in a group that appear more than once. An example will illustrate these terms. Consider the group to consist of the following six serial numbers; A1, A1, A2, A2, A2, and A3. Using the previous terms, the number of duplicates is three since removing one of the A1 and two of the A2 serial numbers results in the following unique set; A1, A2, and A3. However, there are five instances of duplication: two instances of serial number A1 and three instances of serial number A2. The number of times a given serial number is repeated is the "order of replication" for that particular number (i.e., two for twins, three for triplicates, etc.).

These distinctions are important because the instances of duplication indicate how many individual fuel assembly serial numbers could potentially be confused with other serial numbers, while the number of duplicates is a measure of the degree of replication. For instance, if three fuel assemblies from different reactor sites had identical serial numbers, and

these numbers, along with some associated data in a record keeping system, were suddenly confused, then three assemblies and three reactor sites would be affected by this blunder even though the alteration of only two of these numbers would result in a unique set. This would be a third-order replication since one number was used three times.

By calculating the ratio of instances of duplication to the number of duplicates, the average number of times that a duplicate serial number is repeated can be determined. This value is referred to as the replication ratio, D_I/D_N. Expressed mathematically, the replication ratio is as follows:

$$\frac{D_I}{D_N} = \frac{\sum_{x=2}^{i} N_x\, x}{\sum_{x=2}^{i} N_x\, (x-1)},$$

where subscript x is the order of replication and N_x is the number of duplicate sets of order x. For example, for four sets of triplicate serial numbers, x would be 3 and N_3 would be 4. If all duplicates in a group occur in pairs, then the replication ratio is 2, if all are triplicates the ratio is 1.5, if all are quadruplicates the ratio is 1.33. Table 3 lists the replication ratio for a serial number group where the order of replication is the same for the entire group (i.e., all duplicates are twins, triplicates, or quadruplicates, etc.). This table, along with a calculated replication ratio, can be used to determine the average order of replication.

Table 3. Replication ratio for various orders of replication

Order of replication	Replication ratio
2	2.00
3	1.50
4	1.33
5	1.25
6	1.20
7	1.16

3.2 RESULTS OF DUPLICATION STUDY

The serial number data from the EIA dated October, 1990, contains 72,344 fuel assembly serial numbers for domestic LWR reactor fuel. Of this, 1,009 assemblies are listed as multiple-reactor irradiations, meaning that this fuel has been previously irradiated and was transferred to another reactor for continued use. Another 364 assemblies are listed as temporarily discharged, meaning that the fuel has been irradiated and that it is intended to be used again in the future. The remaining 70,971 assemblies are listed as permanently discharged and were the only group used for this study.

Considering the entire discharged fuel inventory of 70,971 assemblies, it was found that 59,023 serial numbers were unique. The remaining 11,948 serial numbers represent the number of duplicates and therefore would have to be changed in order to have a completely unique set of identifiers for all LWR fuel, regardless of vendor, utility, or reactor. The instances of duplication are 14,660. The difference between these two numbers, 2,712, represents the number of different serial numbers that are replicated.

The number of fuel assembly serial numbers and instances of duplication at each reactor site are shown in Table 4. The reactor sites are grouped and the results are subtotaled by CDB assembly class. Of the 24 CDB assembly classes, 21 classes have discharged assemblies represented in Table 4. The three classes not included are Elk River (all reprocessed), Pathfinder (not in EIA serial number records), and B&W 17 x 17 (these reactors are not yet in operation).

Some degree of duplication is found in 16 of the 21 assembly classes. Only 5% of the duplication occurs at BWR reactors. The four BWR reactors that show some duplication are Oyster Creek, Big Rock Point, Dresden 1, and Humbolt Bay. This represents less than 2% of all BWR fuel assemblies. Duplication is also found in 11 of the 15 PWR classes, representing just under half of all PWR fuel assemblies.

The fuel at four of the BWR reactors duplicate because a simple serial numbering scheme was used on some of this fuel (e.g., serial numbers such as A015 appear at both Dresden 1 and Humbolt Bay). All of the duplication at PWR reactors also occurred because of the simple numbering schemes employed at these sites (similar to the example above).

Table 4. Instances of duplication tabulated by assembly class and reactor

Reactor name	Number of assemblies	Instances of duplication
BWR multi-reactor classes:		
Assembly class: GE BWR/2,3		
Dresden 2	2437	0
Dresden 3	1648	0
Millstone 1	1928	0
Monticello	1504	0
Nine Mile Point 1	1620	0
Oyster Creek	1564	160
Pilgrim	1320	0
Quad Cities 1	1757	0
Quad Cities 2	1623	0
Subtotal for assembly class:	**15401**	**160**
Assembly class: GE BWR/4,5,6		
Browns Ferry 1	1352	0
Browns Ferry 2	1192	0
Browns Ferry 3	1004	0
Brunswick 1	1056	0
Brunswick 2	1252	0
Clinton	168	0
Cooper Station	1344	0
Duane Arnold	944	0
Enrico Fermi 2	220	0
Fitzpatrick	1384	0
Grand Gulf 1	828	0
Hatch 1	1526	0
Hatch 2	1154	0
Hope Creek	496	0
LaSalle 1	628	0
LaSalle 2	464	0
Limerick 1	788	0
Peach Bottom 2	1736	0
Peach Bottom 3	1688	0
Perry 1	268	0
River Bend 1	388	0
Shoreham	560	0
Susquehanna 1	956	0
Susquehanna 2	764	0
Vermont Yankee	1594	0
Washington Nuclear 2	564	0
Subtotal for assembly class:	**24318**	**0**

Table 4. (continued)

Reactor name	Number of assemblies	Instances of duplication
BWR single-reactor classes:		
Assembly class: Big Rock Point		
Big Rock Point	339	183
Subtotal for assembly class:	**339**	**183**
Assembly class: Dresden 1		
Dresden 1	1583	66
Subtotal for assembly class:	**1583**	**66**
Assembly class: Humboldt Bay		
Humboldt Bay	660	299
Subtotal for assembly class:	**660**	**299**
Assembly class: Lacrosse		
LaCrosse	334	0
Subtotal for assembly class:	**334**	**0**
PWR multi-reactor classes:		
Assembly class: B&W 15x15		
Arkansas 1	508	177
Crystal River 3	395	169
Davis-Besse	262	0
Oconee 1	666	153
Oconee 2	632	12
Oconee 3	640	153
Rancho Seco	493	158
Three Mile Island 1	345	177
Subtotal for assembly class:	**3941**	**999**
Assembly class: CE 14x14		
Calvert Cliffs 1	716	0
Calvert Cliffs 2	612	0
Maine Yankee	922	188
Millstone 2	626	468
St. Lucie 1	611	472
Subtotal for assembly class:	**3487**	**1128**
Assembly class: CE 16x16		
Arkansas 2	421	0
San Onofre 2	365	322
San Onofre 3	255	253
Waterford 3	260	0
Subtotal for assembly class:	**1301**	**575**

Table 4. (continued)

Reactor name	Number of assemblies	Instances of duplication
Assembly class: CE System 80		
Palo Verde 1	188	0
Palo Verde 2	108	0
Palo Verde 3	104	0
Subtotal for assembly class:	**400**	**0**
Assembly class: South Texas		
South Texas 1	36	36
Subtotal for assembly class:	**36**	**36**
Assembly class: WE 14x14		
Ginna	613	597
Kewaunee	490	481
Point Beach 1	551	175
Point Beach 2	482	108
Prairie Island 1	477	361
Prairie Island 2	508	353
Subtotal for assembly class:	**3121**	**2075**
Assembly class: WE 15x15		
Cook 1	706	11
Indian Point 2	604	85
Indian Point 3	432	219
Robinson 2	671	0
Surry 1	551	373
Surry 2	522	309
Turkey Point 3	497	453
Turkey Point 4	499	362
Zion 1	724	318
Zion 2	648	239
Subtotal for assembly class:	**5854**	**2369**
Assembly class: WE 17x17		
Beaver Valley 1	426	424
Beaver Valley 2	56	56
Braidwood 1	88	0
Byron 1	164	164
Byron 2	88	0
Callaway	268	245
Catawba 1	196	0
Catawba 2	136	0
Cook 2	504	0
Diablo Canyon 1	200	0
Diablo Canyon 2	144	142
Farley 1	539	531
Farley 2	385	382
Harris	104	40

Table 4. (continued)

Reactor name	Number of assemblies	Instances of duplication
Assembly class: WE 17x17 (cont.)		
McGuire 1	332	0
McGuire 2	324	0
Millstone 3	160	160
North Anna 1	399	399
North Anna 2	359	338
Salem 1	504	502
Salem 2	253	241
Sequoyah 1	212	212
Sequoyah 2	216	215
Summer	232	232
Trojan	475	475
Vogtle 1	84	0
Wolf Creek	176	176
Subtotal for assembly class:	**7024**	**4934**
PWR single-reactor classes:		
Assembly class: Fort Calhoun		
Fort Calhoun	426	283
Subtotal for assembly class:	**426**	**283**
Assembly class: Haddam Neck		
Haddam Neck	784	772
Subtotal for assembly class:	**784**	**772**
Assembly class: Indian Point 1		
Indian Point 1	160	0
Subtotal for assembly class:	**160**	**0**
Assembly class: Palisades		
Palisades	597	380
Subtotal for assembly class:	**597**	**380**
Assembly class: San Onofre 1		
San Onofre 1	468	401
Subtotal for assembly class:	**468**	**401**
Assembly class: St. Lucie 2		
St. Lucie 2	320	0
Subtotal for assembly class:	**320**	**0**
Assembly class: Yankee Rowe		
Yankee-Rowe	417	0
Subtotal for assembly class:	**417**	**0**
GRAND TOTAL FOR ALL ASSEMBLIES:	**70971**	**14660**

Newer PWR fuel that followed the ANSI Standard showed no duplication. Some newer fuel has ANSI serial numbers but still shows duplicates in Table 4 because non-ANSI numbers were reported to the EIA (such is the case with many of the WE 17 x 17 reactors).

The virtual lack of duplication at BWR reactors is due to the use of a less simplistic, though non-ANSI, serial numbering scheme by General Electric (GE). This system was quite effective in reducing duplication for BWR fuel. Some of the GE serial numbers, specifically those 6 digit numbers starting with LJ, could actually be ANSI serial numbers, except they have been assigned out of the sequence as specified in the ANSI Standard.

In either case, the point is clear. If utilities receive their fuel with ANSI serial numbers and then use those numbers for all record keeping and reporting systems then serial number uniqueness is guaranteed in the entire domestic LWR fuel inventory.

The analysis then focused on duplication within the individual fuel inventory at each reactor site. Only three serial number duplicates where found, two at the Fitzpatrick reactor (serial no. ea0558 and ly4857) and one at San Onofre 2 (serial no. A050), but discussions with Howard Chou at EIA[9] indicated that these are most likely reporting anomalies and not representative of true serial number duplication. These anomalies will be corrected by the EIA. Therefore, the result is that no duplication occurred at any one reactor site when the comparison was limited to fuel at that site.

This result has interesting implications, namely, that the combination of a site identifier (such as the INIS site code reported in EIA data files) and the fuel assembly serial number results in a unique identification code for the entire LWR fuel inventory. This is a useful observation since existing data base files could easily be modified to consider both the site identifier and serial number as the means to identify fuel assemblies. As long as individual utilities continue to use serial numbers unique to each site, this method of combining two existing codes will produce unique identifiers for existing record keeping systems. This method has obvious shortcomings though, since movement of fuel assemblies to other sites could cause loss of site identity because this information is not directly obtainable by inspection of the assemblies.

The replication ratio, previously defined in Sect. 4.1, was calculated for the entire fuel inventory. Analysis of the 70,971 permanently-discharged fuel assemblies showed that there were 59,023 unique serial numbers and therefore 11,948 duplicates. By comparing each serial

number to every other serial number, it was determined that there are 14,660 instances of duplication. The replication ratio is then found to be 14,660/11,948 or about 1.227. Referring back to Table 3, this replication ratio is between the values for serial number groups of five and six. This means that on average, when a given serial number is duplicated, it is replicated between five and six times. This same conclusion can also be reached by dividing the instances of duplication by the number of different serial numbers that are replicated [14,660/(14,660-11,948) or about 5.4].

The following example will demonstrate how simple utility numbering schemes can create many duplications at multiple reactor sites. Note from Table 4, that the BWR reactor Oyster Creek has 160 instances of duplication. By comparing each one of the 1,564 Oyster Creek serial numbers to all serial numbers at other reactors (note that this operation requires over 108 million comparisons), it can be determined how many other reactor sites are affected by these 160 duplicates and how many duplications occur at each of these other sites. The results of this comparison are given in Table 5 and clearly demonstrates how the use of simple numbering schemes can create duplications at many reactor sites and across different reactor classes and even fuel vendors. Tabulations similar to Table 5 could be generated for all reactor sites.

Table 5. Reactor sites where Oyster Creek serial numbers are duplicated

Reactor site	CDB assembly class	No. of serial numbers also found at Oyster Creek	Serial numbers at this reactor and at Oyster Creek
Callaway	WE 17x17	65	A001-A065
Dresden 1	Dresden 1	66	A001-A066
Fort Calhoun	Fort Calhoun	45	A001-A045
Humboldt Bay	Humboldt Bay	156	A001-A156
Maine Yankee	CE 14x14	69	A001-A002, A004-A070
Millstone 2	CE 14x14	69	A001-A069
Palisades	Palisades	68	A001-A068
San Onofre 1	San Onofre 1	52	A001-A052
San Onofre 2	CE 16x16	60	A001, A004-A043 A045-A059, A062-A065
San Onofre 3	CE 16x16	55	A009-A020, A022-A028, A030-A036, A038-A044, A046, A048-A053, A056-A059, A061, A063, A065-A073
St. Lucie 1	CE 14x14	69	A001-A069
Zion 2	WE 15x15	4	U01A, U02A, U03A, U04A

3.3 DATA ANOMALIES

The following is a description of data anomalies and inconsistencies discovered during the preparation of this report. One of the more important inconsistencies relates to how serial number information is reported to and stored by the EIA. EIA serial number information for each fuel assembly is placed in a single, 14-character data field. Only one data field is available for serial number information for each fuel assembly. It is known that some reactor sites have reported two serial numbers on some of their assemblies since two serial numbers separated by a space have been found in the EIA serial number data field (i.e., Diablo Canyon 1 reported both an ANSI and a utility serial number for 200 fuel assemblies). In addition, some fuel is known to have two serial numbers associated with it (refer to the Callaway example given in Sect. 2.2), yet only one of the numbers is reported to the EIA. It is quite possible that other fuel also contains two or more serial numbers but only one set of numbers is reported to the EIA. This creates obvious complications when trying to determine the amount of duplication.

There are 1,210 fuel assemblies from Hatch 1 (603), Hatch 2 (407), and Diablo Canyon 1 (200) that are reported as having two serial numbers. Both sets of serial numbers from the Hatch reactors follow the ANSI Standard, and, therefore, it is unlikely that both numbers appear on the fuel. Furthermore, the modification code field indicates that the Hatch fuel has been reconstituted (some fuel rods have been removed from the original assembly and reused in another assembly). It is probable that one of the serial number sets represents the "source assembly" and the second set represents the "target assembly" for the reconstitution process. The 200 Diablo Canyon assemblies are reported as having both an ANSI and utility serial number. It is assumed that this is the case and that two numbers have actually been placed on the assemblies.

It is recommended that future revisions of the EIA RW-859 report form make specific request for all serial numbers known to be on the fuel assemblies. The type of serial number being reported (ANSI, utility, or others) should also be specified. The EIA data base files should accommodate the results by the addition of data fields for two or more serial numbers and for the type identifiers.

A number of minor inconsistencies in reporting syntax were noted such as the use of spaces, dashes, or case-sensitive alphabetic characters within serial numbers. Whether these

are reporting errors or actually occur on the assemblies is unknown. The large number of these syntactical inconsistencies creates concern. Also note that computer systems are often very rigid regarding the use of dashes and spaces—far more so than the human eye. The majority of the fuel assemblies at 16 reactors are affected by these inconsistencies. The following examples serve to illustrate.

All the serial numbers for fuel at Indian Point 1 & 2, Lacrosse, Robinson 2, and Susquehanna 1 & 2 contain one or more dashes. The obvious question is whether or not these dashes actually appear on the assemblies. The dashes can create real confusion. For example, at Indian Point 1 there is a serial number 502-1-37 and a serial number 502-137. Are these the same assembly? From the batch, burnup, and enrichment data it appears that they are different assemblies, but the ease with which these two numbers could be confused is obvious. In addition, some of the serial numbers at Big Rock Point, St. Lucie 1, and Turkey Point 4 contain dashes.

The use of spaces within the serial number occurs on all fuel reported from Cook 2 and Pilgrim, and on some assemblies from Cook 1 and Prairie Island 1 & 2. The serial numbers from Pilgrim contain from one to four embedded spaces (i.e., LJ2 _ 926, BE _ _ 206, BE _ _ _ 37, and BE _ _ _ _ 1). Again, the obvious question is whether or not these spaces actually occur within the serial numbers attached to these assemblies.

A less common ambiguity is the use of lowercase letters in the serial numbers. All the fuel reported from Fitzpatrick and some of the fuel from Indian Point 3 list lowercase prefix codes in the serial numbers.

Finally, some of the serial numbers reported to the EIA are not the same as serial numbers reported in other documentation. For example, according to a Combustion Engineering (CE) vendor document,[8] there were three test assemblies shipped to Calvert Cliffs 1 during the first half of 1974 with serial numbers of 1BT01, 1BT02, & 1BT03. The data reported to EIA shows three test assemblies with serial numbers of 1BT04, 1BT06, & 1BT07. One of these assemblies has been chosen by the Materials Characterization Center at Pacific Northwest Laboratories for evaluation as an Approved Testing Material (ATM). The report on this characterization[10] states that the serial number of the test assembly is BT03 (without the prefix digit 1). It therefore appears that three different serial numbers are being reported for this one assembly.

Every anomaly described in this section could cause potential confusion in a record keeping system. This is especially true of computer data bases, since computers are more rigorous in their treatment of character case and the use of spaces and dashes than their human counterparts.

4. CONCLUSIONS

This study analyzed assembly serial number usage in domestic LWRs to determine what serial numbering schemes are used, the effectiveness of these schemes, and to quantify the amount of duplication. The conclusions are as follows:

- The serial numbering scheme adopted by ANSI ensures uniqueness of fuel assembly serial numbers. The ANSI scheme is being used by PWR fuel fabricators on most newer-manufactured fuel (after 1974).

- GE-manufactured BWR fuel is not following the ANSI Standard but has adopted a similar numbering scheme that has ensured serial number uniqueness on all newer BWR fuel.

- Based on this study, it is recommended that fuel fabricators and utilities adhere to the ANSI Standard (or the GE equivalent) for fuel assembly identification. This includes the placement of ANSI serial numbers on all new fuel assemblies, and the use of ANSI serial numbers by the utilities and the EIA when performing record keeping and meeting reporting requirements.

- Some degree of duplication is found in 16 of the 24 CDB assembly classes. Four BWR assembly classes contained some duplication but such assemblies represented less than 2% of all BWR fuel assemblies. Duplication was also found in 11 of the 15 PWR classes, which represented about half of all PWR fuel assemblies.

- Analysis of 70,971 fuel assembly serial numbers from permanently-discharged fuel identified 11,948 serial number duplicates. The remaining 59,023 serial numbers were unique. Serial numbers at 50 PWRs accounted for 95% of the duplication with the remaining 5% occurring at 4 BWRs.

- All of the identified serial number duplication was due to the use of utility numbering schemes that are frequently too simplistic to ensure uniqueness. The utility schemes used serial numbers that varied in length from two to eight characters. Typical formats include some type of prefix code that may identify the reactor site, fuel batch, or both. The remainder of the serial number is usually just an ascending numeric sequence.

- On average, when a given serial number is duplicated, it is replicated between five and six times. This value is an overall average for all duplicated serial numbers.

- No serial number duplication occurred at any particular reactor site when the comparison was limited to fuel at that site. The three exceptions were traced back to data entry errors that will be corrected by the EIA. Thus, the combination of fuel assembly serial number and reactor site identifier is currently unique within the entire domestic spent fuel inventory. It is therefore recommended that DOE accept such LWR fuel only after the site identification has been clearly determined.

- If utilities want to place additional identifiers on the fuel, which is allowed under the ANSI Standard, then either the ANSI or both identifiers should be used for reporting purposes. In no case should only the utility identifiers be used except when this is the only identifier that has been previously placed on the fuel.

- Organizations responsible for collecting and tabulating serial number information, such as EIA, should request that all known serial numbers (ANSI, utility, and other numbering schemes) attached to each assembly be reported and identified by numbering scheme. Data base files should accommodate all of this by the addition of data fields for two or more serial numbers and for the type identifiers.

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