MOV.19990312.0001

WBS: 9.2.1

QA: N/A

MOV.19990312.0001

**Civilian Radioactive Waste Management System
Management & Operating Contractor**

Cost Impact of Rod Consolidation on the Viability Assessment Design

A00000000-01717-5708-00004 REV 00

Revision 00

March 29, 1999

Prepared for:

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Under Contract Number
DE-AC08-91RW00134

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ABSTRACT

The cost impact to the Civilian Radioactive Waste Management System of using rod consolidation is evaluated. Previous work has demonstrated that the fuel rods of two assemblies can be packed into a canister that can fit into the same size space as that used to store a single assembly. The remaining fuel assembly hardware can be compacted into the same size canisters with a ratio of 1 hardware canister per each 6 to 12 assemblies. Transportation casks of the same size as currently available can load twice the number of assemblies by placing the compacted assemblies in the slots currently designed for a single assembly. Waste packages similarly could contain twice the number of assemblies; however, thermal constraints would require considering either a low burnup or cooling.

The analysis evaluates the impact of rod consolidation on CRWMS costs for consolidation at prior to transportation and for consolidation at the Monitored Geological Repository surface facility. For this study, no design changes were made to either the transport casks or waste packages. Waste package designs used for the Viability Assessment design were employed but derated to make the thermal limits. A logistics analysis of the waste was performed to determine the number of each waste package with each loading.

A review of past rod consolidation experience found cost estimates which range from \$10/kgU to \$32/kgU. \$30/kgU was assumed for rod consolidation costs prior to transportation. Transportation cost savings are about \$17/kgU and waste package cost savings are about \$21/kgU. The net saving to the system is approximately \$500 million if the consolidation is performed prior to transportation. If consolidation were performed at the repository surface facilities, it would cost approximately \$15/kgU. No transportation savings would be realized. The net savings for consolidation at the repository site would be about \$400 million dollars.

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CONTENTS

	Page
ABSTRACT	V
1. INTRODUCTION.....	1
2. ROD CONSOLIDATION EXPERIENCE AND COST PROJECTION	3
2.1 PAST EXPERIENCE IN AT-REACTOR CONSOLIDATION	3
2.1.1 The Oconee Demonstration.....	3
2.1.2 The Maine Yankee Demonstration	4
2.1.3 Ginna Fuel Demonstration at West Valley	4
2.1.4 Ginna Fuel Demonstration at Battelle Columbus Laboratories	5
2.1.5 The Millstone-2 Demonstration	5
2.1.6 The Prairie Island Demonstration	6
2.1.7 Other Experience Relevant to Rod Consolidation	6
2.2 SECOND GENERATION ROD CONSOLIDATION DEVICES	6
2.3 SUMMARY OF EXPERIENCE IN ROD CONSOLIDATION	11
2.4 COST PROJECTIONS FOR SPENT FUEL CONSOLIDATION IN A SPENT FUEL POOL	11
3. TOTAL SYSTEM COST IMPACTS OF ROD CONSOLIDATION	13
3.1 CONSOLIDATION EFFECT ON TRANSPORTATION COSTS.....	13
3.2 CONSOLIDATION EFFECT ON WASTE PACKAGE COSTS.....	15
3.3 THE NET COST SAVINGS DUE TO CONSOLIDATION.....	18
3.4 SUMMARY OF THE COST IMPACT OF ROD CONSOLIDATION.....	18
4. SUMMARY	19
5. REFERENCES.....	21
APPENDIX A – ACRONYMS.....	A-1

FIGURES

	Page
1. B&W's Fuel Master Consolidation System.....	8
2. The Fuel Master's Rod Positioning Method.....	9
3. NAC's Fuel-Pac Consolidation and Compaction Equipment.....	10

TABLES

	Page
1. Rod Consolidation Demonstrations at in Spent Fuel Pools	11
2. Cost Projections For Spent Fuel Consolidation	12
3. Number of Shipments.....	14
4. Transportation Cost Savings (Millions of 1998\$).....	15
5. Number of Waste Packages Required.....	16
6. Waste Package Savings Due to Rod Consolidation	17
7. Total System Life Cycle Cost Savings Due to Consolidation (Millions of 1998\$).....	18

1. INTRODUCTION

This report reviews the cost impact on the Civilian Radioactive Waste Management System (CRWMS) of rod consolidation. This report is in support of the License Application Design Selection (LADS) process. Much of the results in this report are incorporated in the License Application Selection Feature Report: Rod Consolidation. (CRWMS, 1999a) Rod consolidation is a design feature that could be incorporated into a number of design alternatives for the Monitored Geological Repository (MGR). Rod Consolidation can be performed in the spent fuel pools prior to transportation or at the MGR. This study analyzes the cost savings of each option.

Rod consolidation produces lower transportation and waste management costs due to a reduced volume of waste. It has been shown that the fuel rods from two assemblies can be placed into a new canister with the same cross sectional area as a slot in a spent fuel pool rack, transportation basket, or waste package basket. By use of these two assembly canisters, savings in transportation and wastes package costs can be realized with little change in current designs. This report determines the cost impact of at consolidation prior to transportation and MGR consolidation while minimizing changes in the current Viability Assessment design of the MGR. (DOE 1998a)

Section 2 of this report reviews the rod consolidation experience to date. It provides brief technical descriptions in order to lead to an understanding of the cost estimates made in the literature. These cost estimates are compiled so a cost of consolidation prior to transportation can be made in units of cost per kgU.

Section 3 provides a logistics analysis of the number of shipments and waste packages needed if consolidation were performed. This section presents the assumptions necessary for the analysis and a brief discussion on these assumptions. Once the number of shipments and waste packages is known the cost analysis is presented.

Section 4 summarizes the findings of this report.

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2. ROD CONSOLIDATION EXPERIENCE AND COST PROJECTION

This section describes the past experience with at-reactor spent nuclear fuel (SNF) assembly consolidation. It also provides a description of second generation consolidation technology. The final portion of this section makes a cost projection for rod consolidation based on previous work in the open literature.

2.1 PAST EXPERIENCE IN AT-REACTOR CONSOLIDATION

In the late 1970s and early 1980s, many utilities increased the SNF storage capacity of their pools by re-racking with high density racks, sometimes two or three times. At that time, it was generally anticipated that after maximum re-racking, the next major increment of SNF storage capability would come from the in-pool consolidation of assemblies. This was to be done by removal of the rods from two fuel assemblies and inserting them into open baskets, commonly called canisters, that would occupy only one rack location. On the surface, this consolidation could potentially double the storage capacity of the pool. However, storage of the empty assembly structural components (bottom and top end fittings, guide and instrumentation tubes, and spacer grids for Pressurized Water Reactors (PWRs) and Boiling Water Reactors (BWRs), plus BWR fuel channels) posed a problem. Designs to cut up the structural material and compact it were envisioned. It was believed that 10 of these structures could be consolidated into 1 basket or canister fitting in 1 rack position. For example, if 10 assemblies were consolidated into 5 canisters, 5 storage locations would be made available. However, the 10 empty assembly structures would be compacted into the volume of 1 additional canister, occupying 1 additional rack location. Only 4 new locations would be made available from the consolidation of 10 assemblies. This implies that the fuel pool capacity was not doubled but increased by 67 percent (each 6 slots now support 10 fuel assemblies rather than 6). If only a 5 to 1 compaction of the structural material were possible, the capacity would only increase by 43 percent. Clearly, the compaction of the structural material was an important issue.

With this brief introduction, a quick review of the six actual experiences with in-pool fuel rod consolidation will be presented along with some information regarding fuel assembly reconstitution.

2.1.1 The Oconee Demonstration

In 1982, Westinghouse and Duke Power Company participated in an at-reactor fuel consolidation demonstration at Oconee. (Gerstberger 1987) Four irradiated fuel assemblies were consolidated into two canisters of fuel. The structural material was cut up and compacted "achieving at least a 6 to 1 volume reduction." The structural material was placed in three short (52 inch) containers for shipment to Barnwell. The first two containers each stored 1.5 assemblies worth of structural material. No serious problems occurred during the demonstration. The technique used involved pulling all the fuel rods out of the assembly at one time. This was followed by pushing them into a transition canister that converted the square array to a close packed triangular array. Finally, the fuel rods were pushed from the transition canister into the

storage canister. This process achieved a 2 to 1 compaction ratio. The fuel storage canister had a thin wall to separate the two assemblies.

In a follow up analysis of the project done by Duke Power and Westinghouse (Personal correspondence documented in a letter from D. Lancaster to the CRWMS Record Processing Center (RPC), February 25, 1999), it was concluded that consolidation in late 1983 would cost approximately \$10,000 per assembly (\$22/kgU 1984\$). Using a 10 to 1 compaction ratio for the structure, this equates to \$25,000 per space created ($\$10k * 10 / (4 \text{ spaces created})$). Since dry storage costs were estimated at about \$20,000 per space, consolidation did not appear attractive. The decision appears to have been based on economics. There was no indication of dissatisfaction with the non-economic aspects of consolidation.

At a conference in 1986 (DOE 1986, p. S-345), B. Rasmussen, a senior engineer at Duke Power, was asked: "What perspectives can you provide on how Duke Power will choose the technology to be employed to provide future storage at the Oconee station? Will cost, regulatory aspects, operational uncertainties, or technology be the deciding factor in this choice?" His response was, "No technical concerns with respect to equipment exist in Duke Power's perspective. The main concerns are economic with respect to disposal/storage solutions for the generated scrap hardware."

2.1.2 The Maine Yankee Demonstration

Maine Yankee worked with Proto-Power Corporation to produce an automated method of removing fuel rods and placing them in another container. Cold demonstrations were performed in October and November 1981. (Zacha 1988). In May 1984, two assemblies with damaged structures were disassembled and the rods placed in two new assembly structures. One report (Bailey 1985) suggested an attempt to consolidate an assembly in August 1983 with a consolidation ratio of 1.6 to 1. This has not been confirmed, and in fact the later references, although not commenting on such a test, lead to the opinion that such a test did not occur. (Wagner 1987) In a conference paper in 1986, Proto-Power discusses its system and points out that it is being made in phases. At the time the paper was presented, only the rod pulling system was completed and the former for consolidation had thus far not been made. (Hallahan 1986). There is no information on the disposal of the damaged fuel assembly structures.

2.1.3 Ginna Fuel Demonstration at West Valley

From December 1985 to February 1986, a team lead by Nuclear Assurance Corporation (NAC) consolidated six fuel assemblies from Rochester Gas and Electric's Ginna Nuclear Power Plant. (Bailey 1986) The fuel assemblies used came from a batch of fuel that had experienced fuel densification. This problem with early PWR fuel resulted in a design change to increase the density of the pellets. With fuel densification the fuel column shrinks, and at positions high in the core a tilted pellet can hold up the column, resulting in a voided region in the clad. Since there is less thermal absorption around these voids, the power locally increases. With the local increase in power and the pressure at operating temperatures, the clad flattens and often fails. While pulling one of these flattened fuel pins, it got caught in the grids. The pulling pressure was increased, and as the rod was released a baseball-to-grapefruit size bubble of fission gas was released. No increased dose or increased pool radioactivity was recorded. With this fuel there

was a concern over complete fuel breakage; however, no fuel broke in a way to become a mechanical handling problem.

After pulling the rods, the rods were placed in a slightly tilted consolidation canister. No former was used. It was found that an essentially vertical placement into a close packed array without a former was very difficult. On the last assembly, a compaction ratio for the fuel of 1.8 was achieved and it was stated that a few more pins could have been placed in the canister to raise the packing fraction to 1.9. The demonstration concluded that in order to reach a packing factor of 2, a former or horizontal operation was needed, but that greater than 1.8 was possible with little effort.

The structural material was sheared but no information was given on the compaction ratio or method of storage.

2.1.4 Ginna Fuel Demonstration at Battelle Columbus Laboratories

From August to October 1986, a team using the US Tool and Die device consolidated five assemblies from Ginna that were in a pool at Battelle Columbus Laboratories. (Bailey 1987) These assemblies had over fifty rods that had collapsed clad due to fuel densification. During removal of the fuel rods, one or two of the rods appeared to release small gas bubbles. None of the bubbles were sufficient to set off radiation detection alarms at the pool surface. Crud release from the fuel increased the beta-gamma activity of the small research pool by a factor of 10.

The device used pulled the pins down from the bottom into a funnel. Due to flattened pins that would not pass through the funnel, compaction ratios of 1.88, 1.89, 1.90, and 1.90 were all that was achieved for the first four assemblies. On the fifth assembly, the failed fuel pins were replaced with dummy rods so the 2 for 1 compaction could be demonstrated. No information on the handling of the structural material was given. Note: two fuel rods were broken in the handling of the fuel for this demonstration. Neither fuel rod was broken as part of the disassembly or compaction of the fuel into consolidation canisters. This fuel was at Battelle because of the large amount of damage due to densification and is not typical of most spent fuel rods.

2.1.5 The Millstone-2 Demonstration

The Electric Power Research Institute (EPRI), Northeast Utilities, Baltimore Gas and Electric, U.S. Department of Energy (DOE), and Combustion Engineering performed a demonstration of rod consolidation at the Millstone-2 pool in August to September 1987. (EPRI 1990) The equipment was designed by Combustion Engineering. For the demonstration, six fuel assemblies were consolidated into three canisters achieving a 2 for 1 volume reduction. The non-fuel structure compaction system failed. The final disposition of the structural material was not given in the main reference for this section. The compaction device was cold tested to yield a 14 to 1 compaction for the guide tubes and grids. (EPRI 1990, p. 2-37) If the end fittings are not compacted, this yields a total compaction of only 7 to 1.

During the test, two of the fuel rods were temporarily stuck, but both rods were removed on the second try. The pool water lost clarity but did not increase in radioactivity. The loss of clarity was most likely due to some loss of the hydraulic fluid from the fuel consolidation system.

The experience at Millstone lead to the following statement (EPRI 1990, p. 4-14):

"The technology has been shown to be a safe and cost effective option for nuclear utilities. Positive encouragement may now be offered to others in the nuclear industry with respect to the viability of the option for both near-term and long-term fuel storage requirements."

2.1.6 The Prairie Island Demonstration

Westinghouse was contracted to perform a rod consolidation demonstration between October and November 1987 of 36 fuel assemblies in the Prairie Island spent fuel pool. (Kapitz 1989) A 2 to 1 compaction of the fuel rods was demonstrated. One fuel rod (out of over 6 thousand) was damaged (but not broken) in the process and was not put in the consolidation canisters. WasteChem was hired for the compaction of the structural material. It was determined that only the inconel material would prevent shipping the material out as low level waste. Unfortunately, the WasteChem system could not separate the inconel grids from the zircaloy. Prairie Island only observed a 5 to 1 reduction of the structural material.

2.1.7 Other Experience Relevant to Rod Consolidation

The largest rod consolidation demonstration was done dry at the Idaho National Engineering and Environmental Laboratory (INEEL) Test Area North (TAN) facility. Forty-eight assemblies were consolidated between May and September 1987. A 2 to 1 compaction of the fuel rods was achieved. (Fisher 1988)

In 1984, Westinghouse repaired 17 fuel assemblies at the Kori #1 Nuclear Power Plant in Korea. Six of these were "reassembled." This meant that all the fuel pins were removed and placed in a new fuel structure of grids and guide tubes. In 1986, three assemblies from the Salem #2 plant were reassembled. (Gerstberger 1987)

In France, "repair and reconstitution of 900 MWe assemblies are now routine operations." "Present global status (1993): 32 repairs and 29 reconstitutions (reassembly). They were performed by our three fuel suppliers, since 1986, without major problem." (IAEA 1993, p. 97) Although reassembly is not rod consolidation, the concerns on debris generated in disassembly are identical. Clearly, the debris concern has now been fixed.

In the early 1980's, Allied General Nuclear Services (AGNS) was actively involved in a cold demonstration of rod consolidation at their Barnwell South Carolina plant. (Bailey 1985) Using simulated fuel assemblies, AGNS demonstrated 2 for 1 compaction of fuel rods. A demonstration with simulated BWR fuel was also performed. Equipment was built for BWR fuel consolidation and delivered to the Browns Ferry Station in June 1983. (Bailey 1985, p. 7).

2.2 SECOND GENERATION ROD CONSOLIDATION DEVICES

Two second generation rod consolidation devices have been designed, the Babcock and Wilcox Fuel Master and the NAC Fuel Pac. (Forsberg, 1991) Both systems claim fuel consolidation ratios of 2 to 1 and hardware consolidation ratios of 10 to 1. Figure 4-1 shows the Fuel Master system and Figure 4-2 shows the fuel positioning scheme used in the Fuel Master system. Figure

4-3 illustrates the NAC Fuel Pac design. Neither company is still actively marketing their system since dry storage appears more economical for creating fuel pool storage space.

Compaction of the structural material still seems to be an issue. The bottom end fitting of a PWR is low level waste. The top end fitting generally has inconel springs. If these springs are removed, the top end fitting is low level waste. The guide and instrumentation tubes are low level waste. The grids are inconel and are greater than class C waste. They also contain a significant amount of Co-60 activation product. If the grids were cut out of the structure and just stacked without compaction, a 12 to 1 compaction ratio would be gained if the rest of the components were shipped off as low level waste. The low-level waste costs for the non-inconel components are insignificant. Unfortunately, no design exists which cuts out the grids and hold-down spring and separates it from the rest of the waste. Current techniques mix the crushed grids with the rest of the structure producing a mixture of greater than class C waste.

Fuel Master Fuel-Consolidation System

Figure 1. B&W's Fuel Master Consolidation System

CONSOLIDATION CANISTER

FUEL ROD POSITIONING MECHANISM

Figure 2. The Fuel Master's Rod Positioning Method

Figure 3. NAC's Fuel-Pac Consolidation and Compaction Equipment

2.3 SUMMARY OF EXPERIENCE IN ROD CONSOLIDATION

There were six hot demonstrations of reactor pool equipment in the 1982 to 1987 period (see Table 1). All of these demonstrations were on PWR fuel. The demonstrations show a learning process that resulted in dependable 2 to 1 compaction of the fuel rods. They also show that the compaction of the non-fuel components was not demonstrated to the satisfaction of the utilities. Compaction of the structural material ranges from 5 to 1 to claims of 10 to 1. Although there were some problems in the operation of the demonstrations, both Prairie Island and Oconee would now consider rod consolidation. (Kapitz 1989, and Personal correspondence documented in a letter from D. Lancaster to the CRWMS RPC, February 25, 1999) In the rate regulated utility environment, strong incentives exist to favor low risk over low cost. The dry storage option was perceived to be lower risk and approximately the same cost as rod consolidation, and neither utility elected to continue to pursue rod consolidation to avoid dry storage. Neither utility was offered any incentive from DOE equivalent to the offset system costs, but rather the utilities faced the disincentive that the consolidated fuel could be classified as non-standard fuel under 10CFR961 and hence would be picked up much later in the queue.

Table 1. Rod Consolidation Demonstrations in Spent Fuel Pools

Utility and Vendor	Dates	Pool	Number of Assemblies
Duke Power, Westinghouse	10,11/82	Oconee 1/2	4
Maine Yankee	8/83	Maine Yankee	1
Rochester G&E, NAC	12/85-2/86	West Valley	6
Rochester G&E, US Tool & Die	8-10/86	Battelle, Columbus	5
Northeast/Baltimore G&E, CE	8,9/87	Millstone 2	6
Northern States Power, Westinghouse	10,11/87	Prairie Island 1/2	36

After the above demonstrations had been performed, two second generation rod consolidation devices were manufactured and cold tested. Babcock and Wilcox developed the "Fuel Master" and the "Fuel Pac" was developed by NAC. Both products use automation to reduce the amount of labor necessary and hence reduce dose when compared to the previous generation of rod consolidation. Both systems claim 10 to 1 compaction of the structural components. Both systems also claim that above 10 to 1 compaction is possible if some of the low level waste portion of the fuel assembly is separated and disposed as low level waste.

2.4 COST PROJECTIONS FOR SPENT FUEL CONSOLIDATION IN A SPENT FUEL POOL

Numerous cost projections for consolidation have been made. These cost projections have been adjusted for inflation since the estimate was made and put in a consistent format (i.e.: fixed costs were amortized in the same manner). (CRWMS 1999b) All of the costs include a canister for holding the fuel pins. This canister cost ranges from \$2,000 to \$5,500 with the best estimate cost of \$3,300 (costs in 1998\$). (McLeod 1986) Table 2 shows the published projections. In summary, the cost of consolidation at a spent fuel pool can be estimated as \$10 to \$32/kgU in 1998\$.

Table 2. Cost Projections For Spent Fuel Consolidation

Author/Reference	Year	Cost Estimate (1998\$/kgU)
Duke Power (Personal Correspondence from D. Lancaster to the CRWMS RPC, 2/25/99)	1983	\$32
McLeod (McLeod, 1986)	1986	\$19
Northern States Power(Zacha, 1988)	1988	\$20 to \$29
Northeast Utilities (Zacha, 1988)	1988	\$20
US Tool and Die (Zacha, 1988)	1988	\$12
NAC (Zacha, 1988)	1988	\$13 to \$20
Proto-Power Corp. (Zacha, 1988)	1988	\$20 to \$26
DOE/RW-0220 (DOE, 1989)	1989	\$10 to \$19
Johnson (Johnson, 1989)	1989	\$13 to \$23
EPRI NP-6892 (EPRI NP-6892, 1990)	1990	\$22

3. TOTAL SYSTEM COST IMPACTS OF ROD CONSOLIDATION

This section will estimate the cost impact to the total system due to rod consolidation. The key savings will be in the number of waste packages of each type, and in the transportation cask fleet size and the number of shipments from the power plants. If the consolidation were performed at the repository, no transportation fleet or shipment savings would result. The cost will be the cost of consolidation. The savings will be tallied and divided by the metric tons of fuel, to yield a \$/kgU consolidated. Consolidation cost estimates can then be compared to the savings. A net saving is estimated and reported. Since there are large uncertainties in the costs and savings, smaller impacts will be ignored. For example, there will be less handling operations on the surface and subsurface. In addition, the average package size and weight is less so the handling operation cost per package may be less.

This section will review the transportation cost assumptions followed by a summary of the changes anticipated by consolidation and the cost impact. The process will then be repeated for waste packages. Finally, the savings in transport and waste packages will be compared to the cost of consolidation.

3.1 CONSOLIDATION EFFECT ON TRANSPORTATION COSTS

It is assumed that the consolidated fuel assemblies will be shipped in the same shipping containers as the reference Total System Life Cycle Cost (TSLCC) analysis (DOE 1998b) but with the following modifications:

1. The large PWR shipping casks (24 or 26 assemblies) will no longer need flux traps; therefore, they will contain 32 slots similar to the Holtec 32 assembly burnup credit design.
2. The casks will hold consolidated fuel assemblies and compacted structural material. The compaction ratio for the structural material was varied parametrically between 12 to 1 down to 6 to 1. The fuel is always loaded with a 2 for 1 compaction ratio, which has been demonstrated multiple times.
3. The cost basis is the same as that used in the TSLCC for the same package class. Some design modifications would be required due to the added heat, weight, and radiation source term, but these design changes are considered insignificant to the cost analysis. For example, in the case of weight increase, the consolidated fuel would add only about 10 additional tons in a 125 ton cask.
4. The logistics code only deals with whole assemblies. This prevents reaching the desired hardware compaction ratios for sites that can only accept truck casks. The logistics code does not follow slots that are used in consolidation; hence odd numbers of assemblies can be shipped. An odd number of assemblies implies a slot alternates between hardware and fuel in alternate shipments. For example, the GA/4 cask if loaded with 7 assemblies would represent a 14 to 1 compaction ratio, which is too high; however, if loaded with 6

assemblies the compaction ratio drops to 6 to 1, which is less compaction than can be achieved. (The GA/4 was loaded with six assemblies in all cases.)

Table 3 shows the shipments made under the TSLCC (for 63k Metric Tons of Uranium (MTU) of SNF) for each of the hardware compaction assumptions. Table 4 shows the cost of these shipments for each of the cases.

Table 3: Number of Shipments

Cask Class	TSLCC (63k MTU)		Consolidated (12 to 1 Hardware)		Consolidated (10 to 1 Hardware)		Consolidated (6 to 1 Hardware)	
	Assem per cask	# of casks	Assem per cask	# of casks	Assem per cask	# of casks	Assem per cask	# of casks
PWR Truck Site	4, 3 [*]	1939	6	1254	6	1254	6	1254
PWR Large Rail	26	1051	55	490	53	507	48	561
PWR Small Rail	12	1883	20	1152	20	1154	18	1284
PWR Large Rail - Canistered	24	605	55	274	53	286	48	312
PWR Medium Rail - Canistered	21	819	36	473	35	487	31	547
PWR Small Rail - Canistered	12	156	20	87	20	87	18	94
PWR South Texas	12	151	20	92	20	92	18	101
PWR Yankee Rowe	36	15	61	9	60	9	54	10
PWR MOX	9	166	15	99	15	99	13	114
PWR Sum		6785		3930		3975		4277
BWR Truck Site	9, 7 [*]	666	15	399	15	399	13	459
BWR Large Rail	61	527	104	311	102	317	92	348
BWR Small Rail	24	1704	41	1003	40	1029	36	1140
BWR Large Rail - Canistered	61	190	104	114	102	114	92	131
BWR Medium Rail - Canistered	44	389	75	228	73	234	66	258
BWR Small Rail - Canistered	24	728	41	428	40	437	36	488
BWR Big Rock Point	74	8	126	5	123	5	111	5
BWR SUM		4212		2488		2535		2829
Total		10997		6418		6510		7106

* The TSLCC truck casks were criticality limited and were derated to meet the limit. Due to the lack of moderator possible with consolidated fuel, criticality is not a problem for the consolidation cases.

Table 4. Transportation Cost Savings (Millions of 1998\$)

	TSLCC (63k MTU)	Consolidated		
		12 to 1 Hardware	10 to 1 Hardware	6 to 1 Hardware
Fleet Cost	726	548	564	574
Transportation Cost	4257	3345	3366	3493
Total	4983	3893	3930	4067
Savings	-	1090	1053	916
Savings in \$/KgU	-	17	17	14

The TSLCC transportation costs used rail shipping casks of 24 and 26 assemblies for PWR SNF. If burnup credit is approved this would increase the size of these casks to 32 assembly casks. This would eat into the transport savings credited to consolidation. Instead of consolidation increasing the number of PWR assemblies per large canistered rail shipment by 31 (55-24=31 see Table 3) consolidation after burnup credit would only increase the number of assemblies per shipment by 23 assemblies (55-32= 23). Using the ratio of 23/31 on the entire transportation savings shows a decrease in savings by about \$4/kgU. Since burnup credit only effects the PWR rail shipments the actual change in savings is about \$2/kgU.

3.2 CONSOLIDATION EFFECT ON WASTE PACKAGE COSTS

The waste package designs were identical to those used in the Viability Assessment (VA) analysis but double loaded with the restriction of the same total heat limit per package as was assumed in the VA. Each package was derated (i.e.; the number of fuel assemblies loaded into the cask was less than the number of assembly locations) until the heat load was met. This approach should meet the same temperature limits as the current VA design. The waste packages also contain the compacted structural material. It is assumed that the compacted structural material is generally placed in the center of the cask to lower the peak clad temperature of the fuel rods. Three levels of structural material compaction were calculated. Table 5 provides the number of each package design used in the reference VA analysis as well as the three cases analyzed for this study. Table 6 provides the cost savings due to the reduced number of waste packages. The unit costs were the same as used in the VA analysis. The waste package savings would result regardless of the location where consolidation is performed.

Table 5. Number of Waste Packages Required

Waste Package Type	VA Design (63k MTU)		Consolidated (12 to 1 Hardware)		Consolidated (10 to 1 Hardware)		Consolidated (6 to 1 Hardware)	
	Assem per WP	# of WPs	Assem per WP	# of WPs	Assem per WP	# of WPs	Assem per WP	# of WPs
21 PWR - No Absorber Plates	21	1369	36	1227				
			34	85	34	1386		
			32	104	32	102		
			30	166	30	163	30	1838
21 PWR - No Absorber Plates, With Absorber Rods	21	169		0		0		0
21 PWR - Absorber Plates	21	2641		0		0		0
12 PWR - No Absorber Plates	12	394	24	782	24	781		
			22	328	22	333		
			20	252	20	248	20	1546
			18	217	18	217	18	218
			16	109	16	114	16	116
			14	26	14	21	14	25
			12	14	12	15	12	11
12 PWR - No Absorber Plates, South Texas Long	12	179	24	22	24	21	24	22
			20	13	20	15	20	16
			16	63	16	62	16	58
			12	6	12	7	12	7
44 BWR - No Absorber Plates	44	773	88	727	88	729		
			80	77	80	77		
			72	107	72	108	74	1032
			64	232	64	230	64	259
			56	246	56	241	56	243
			50	268	50	268	48	349
			44	117	44	119	40	51
			32	15	32	14	32	6
44 BWR - Absorber Plates	44	2024		0		0		0
24 BWR- Thick Absorber Plates	24	93		0		0		0
Total		7642		5203		5271		5797

Table 6. Waste Package Savings Due to Rod Consolidation

	VA	Consolidation			WP Cost	VA	Consolidation					
		Hardware 12-1	Hardware 10-1	Hardware 6-1			Hardware 12-1	Hardware 12-1	Hardware 10-1	Hardware 10-1	Hardware 6-1	Hardware 6-1
Waste Package Type	# WPs	# WPs	# WPs	# WPs	\$Million	Total Cost	Total Cost	Savings	Total Cost	Savings	Total Cost	Savings
21 PWR-No Absorber Plates	1369	1582	1651	1838	0.305	417.5	482.5	-65.0	503.6	-86.0	560.6	-143.0
21 PWR-No Absorber Plates, with Absorber Rods	169	0	0	0	0.432	73.0	0.0	73.0	0.0	73.0	0.0	73.0
21 PWR - Absorber Plates	2641	0	0	0	0.381	1006.2	0.0	1006.2	0.0	1006.2	0.0	1006.2
12 PWR - No Absorber Plates	394	1728	1729	1916	0.238	93.8	411.3	-317.5	411.5	-317.7	456.0	-362.2
12 PWR - No Absorber Plates, South Texas Long	179	104	105	103	0.306	54.8	31.8	23.0	32.1	22.6	31.5	23.3
44 BWR - No Absorber Plates	773	1789	1786	1940	0.287	221.9	513.4	-291.6	512.6	-290.7	556.8	-334.9
44 BWR - Absorber Plates	2024	0	0	0	0.451	912.8	0.0	912.8	0.0	912.8	0.0	912.8
24 BWR - Thick Absorber Plates	93	0	0	0	0.333	31.0	0.0	31.0	0.0	31.0	0.0	31.0
PWR Total	4752	3414	3485	3857		1645.3	925.6	719.7	947.2	698.1	1048.1	597.2
BWR Total	2890	1789	1786	1940		1165.6	513.4	652.2	512.6	653.1	556.8	608.9
Total	7642	5203	5271	5797		2811.0	1439.0	1371.9	1459.8	1351.2	1604.9	1206.1
\$/kgU								21.8		21.4		19.1

3.3 THE NET COST SAVINGS DUE TO CONSOLIDATION

Table 7 summarizes the net cost savings due to rod consolidation performed prior to transportation or at the repository. If consolidation is performed prior to transportation, it is assumed that it will conservatively cost \$30/kgU to perform the consolidation. This cost estimate is based on the open literature reported in Section 2.4. In this case, the CRWMS system would save from \$200 to \$600 million. Alternatively, it is assumed that the consolidation is performed at the repository site. In this case, a lower cost of consolidation is used since repository consolidation would yield higher utilization of the consolidation devices than if a utility purchased the device, or avoidance of a service vendor's profit margin if the utility purchased services. An evaluation of the cost of pool consolidation at the repository found that \$15/kgU would be a reasonable estimate. (CRWMS, 1999b) Using \$15/kgU for repository consolidation results in a net cost benefit of between \$200 to \$400 million.

Table 7. Total System Life Cycle Cost Savings Due to Consolidation (Millions of 1998\$)

	VA Design	Consolidation Savings		
		Hardware 12-1	Hardware 10-1	Hardware 6-1
Transportation Fleet	726	178	162	152
Transportation Ops	4257	912	891	764
Waste Packages	2811	1372	1351	1206
Total	7794	2462	2404	2122
\$/kgU		39.1	38.2	33.7
Net Savings if Done Prior to Transportation at a Cost of \$30/kgU		572	515	231
Net Savings if Done at Repository at a Cost of \$15/kgU		427	407	263

3.4 SUMMARY OF THE COST IMPACT OF ROD CONSOLIDATION

Rod consolidation results in net CRWMS system savings from about a quarter to a half a billion dollars in constant 1998 dollars. This savings occurs whether the consolidation is performed prior to transportation or at the repository. The cost estimate for repository consolidation showed that the cost was dominated by labor costs. (CRWMS, 1999b) Only \$2/kgU was due to capital costs. This implies that even if the repository were to commit to consolidation at its facility it is still cost effective to consolidate prior to transportation. Transportation burnup credit would reduce the transportation cost savings by about than \$2/kgU. This is about the same as the difference in savings due to consolidation at the repository versus the prior to transportation. Hence, if transportation burnup credit is granted, consolidation at the repository preferable to consolidation prior to transportation.

4. SUMMARY

Rod consolidation in the spent fuel pool has been successfully demonstrated. Two to one compaction of the fuel has been demonstrated. The successful compaction of the structural materials above 6 to 1 has not been demonstrated. Next generation devices have been built and cold tested. The cold tests were successful in achieving 10 to 1 compaction of fuel structures. Greater than 10 to 1 compaction is possible since the assembly structural material other than inconel can be low level waste. Separation of the inconel from the rest of the structure has not been demonstrated.

Based on the available information, cost of consolidation at a utility spent fuel pool is estimated to be between \$10 and \$32/kgU. For the purpose of this summary, it will be assumed that rod consolidation prior to transportation will cost \$30/kgU. Rod consolidation at a repository would cost about \$15/kgU. The savings from reduced shipments is approximately one billion dollars or about \$17/kgU. The savings in waste package cost is about \$1.3 billion or about \$21/kgU. If a cost of consolidation prior to transportation is assumed to be \$30/kgU, CRWMS would save about a half a billion dollars if all the fuel were consolidated prior to transportation. If all the fuel were consolidated at the repository at \$15/kgU, the CRWMS system would save approximately \$400 million. Since the systems with consolidation prior to transportation and repository consolidation are compatible, and since the cost of consolidation is mainly variable costs rather than fixed costs, systems with consolidation split between being performed prior to transportation or at the repository will save between \$400 and \$500 million dollars.

The analysis in this report assumed the VA design waste package. Consideration has been given to adding additional safety margin by using more expensive materials or additional material. Any increase in the cost of the waste package beyond that estimated in the VA design would increase the savings due to rod consolidation.

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APPENDIX A

ACRONYMS

ACRONYMS

A

AGNS Allied General Nuclear Services

B

BWR Boiling Water Reactor

C

CRWMS Civilian Radioactive Waste Management System

D

DOE U.S. Department of Energy

E

EPRI Electric Power Research Institute

I

INEEL Idaho National Engineering and Environmental Laboratory

K

KgU Kilograms of initial heavy metal (normally uranium)

L

LADS License Application Design Selection

M

MGR Monitored Geologic Repository

MTU Metric Tons of Uranium

N

NAC Nuclear Assurance Corporation

P

PWR Pressurized Water Reactor

R

RPC Records Processing Center

S

SNF Spent Nuclear Fuel

T

TAN Test Area North
TSLCC Total Systems Life Cycle Cost

V

VA Viability Assessment