A PRELIMINARY EVALUATION OF THE ABILITY OF FROM-REACTOR CASKS TO GEOMETRICALLY ACCOMMODATE COMMERCIAL LWR SPENT NUCLEAR FUEL

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CONF-910435--17

DE91 005481

ABSTRACT

The Department of Energy has sponsored a number of cask design efforts to define several transportation casks to accommodate the various assemblies expected to be accepted by the Federal Waste Management System. At this time, three preliminary cask designs have been selected for the final design—the GA-4 and GA-9 truck casks and the BR-100 rail cask. The GA-4 cask is designed for PWR fuel only; the GA-9 cask is a longer cask with less shielding designed for BWR fuel only; and the BR-100 cask is designed to accommodate both PWR and BWR fuels. In total, this assessment indicates that the current Initiative I cask designs can be expected to dimensionally accommodate 100% of the PWR fuel assemblies (other than the extra-long South Texas Fuel) with control elements removed, and >90% of the assemblies having the control elements as an integral part of the fuel assembly. For BWR assemblies, >99% of the assemblies can be accommodated with fuel channels removed. Because of the button and spring interference, the basket openings in these casks will not accommodate assemblies in the BWR/2,3 and BWR/4-6 fuel classes with the fuel channels in place.

INTRODUCTION

The strategy for designing, developing, and acquiring From-Reactor casks was identified in the Transportation Business Plan published by the Department of Energy (DOE) in 1986.[1] In the Plan, it was recognized that a single set of cask specifications would not result in an optimal transportation fleet; in fact, it was recognized that at least two sets of specifications and related cask designs would be needed to accommodate the wide variation of physical and radiological characteristics of spent nuclear fuel (SNF) to be accepted by and transported within the Federal Waste Management System (FWMS). The two types of cask designs were identified as: Initiative I From-Reactor casks, which would be designed to accommodate the majority of SNF in a reasonably optimal fashion over the life of the FWMS (or the life of the cask, whichever is shorter), and Initiative III casks, which would be designed to accommodate SNF falling outside the capability of Initiative I casks, such as nonstandard fuel, nonfuel-bearing SNF assembly irradiated hardware, and possibly other miscellaneous high-activity wastes. The Initiative I cask system preliminary designs were completed in 1989. The Transportation Business Plan includes conducting an evaluation of the performance of these preliminary designs in the overall FWMS prior to final design completion and the submission of applications to the Nuclear Regulatory Commission for certification of the designs. This paper summarizes preliminary results of one part of that evaluation related to the ability of the From-Reactor Initiative I casks to accommodate the physical and radiological characteristics of the SNF projected to be accepted into the FWMS.

DESCRIPTION OF DOE FROM-REACTOR TRANSPORTATION CASKS

Three transportation casks are being designed as part of the DOE Cask System Development Program for transporting SNF assemblies. Dimensions of these casks are summarized in Table 1. The two legal-weight truck casks are being designed by General Atomics. The GA-4 cask will transport four PWR assemblies, and the GA-9 cask will transport nine BWR assemblies. The BR-100 cask being designed by Babcock and Wilcox (B&W) can accommodate either 21 PWR or 52 BWR fuel assemblies. Different basket designs are used for the different fuel types.

PHYSICAL ACCOMMODATION OF SNF

For the purpose of the evaluations in this paper, physical accommodation has been determined by simply comparing the overall length and cross-section dimensions of SNF, both with and without nonfuel assembly hardware (NFAH) included, with the internal length of the cask cavity and the size of the cells in the cask baskets. NFAH is considered because it has a significant impact on the overall dimensions of the Light-Water-Reactor fuel assembly and, hence, its physical accommodation by the casks. The presence of NFAH in the fuel assemblies impacts not only the weight of the cask but adds significantly to the weight of the payload, which is critical in achieving the desired Initiative I cask capacities. It is noted that Appendix E of the Standard Contract indicates NFAH will be handled as follows:

> "Non-fuel components including, but not limited to control spiders, burnable poison rod assemblies, control rod elements, thimble plugs, fission chambers, and primary and secondary neutron sources, that are contained within the fuel assembly, or BWR channels that are an integral part of the fuel assembly, which do not require special handling, may be included as part of the spent nuclear fuel delivered for disposal pursuant to this contract."

This section of the contract may be interpreted in different ways. Under one interpretation, DOE may be obligated to transport SNF, with nonfuel components including BWR channels in place, as standard fuel.

The dimensional data for the various fuels and casks and the accommodation judgments presented in this paper are based on nominal cold unirradiated fuel assembly and cask dimensions. Reload fuels produced by other vendors have not been specifically examined. However, there is no reason to believe that reload fuel designs will be significantly different dimensionally from the fuel originally supplied. Additional "as-discharged" dimensional fuel data are needed from utilities so that adequate clearance can be provided in cask designs for reload fuel variations, as well as irradiation growth, differential thermal expansion, and manufacturing tolerances.

ACCOMMODATION OF PWR FUEL

The assessment of the accommodation of the various types of PWR fuel assemblies in the GA-4 and BR-100 casks is summarized in Table 2. The GA-4 cask, with an internal cavity length of 4.248 m will accommodate all bare PWR fuel assemblies except the CE 16x16 and the WE South Texas fuel assemblies. The South Texas fuel exceeds the maximum nominal physical dimensions (4.52 m) defined in the DOE Standard Contract and is classified as nonstandard fuel. However, the two classes of CE 16x16 fuel are considered standard fuel. It should be noted that the reactors that use these fuel assemblies currently have rail service, and service by the GA-4 cask may not be required. Alternatively, it may be possible to adapt the longer GA-9 cask to accommodate the CE 16x16 fuel assemblies, and that possibility is being investigated.

TABLE 1 DIMENSIONS OF INITIATIVE I TRANSPORTATION CASKS

	BR-100	GA-4	GA-9
Mode	Rail	Truck	Truck
Capacity, assemblies			
BWR	52	--	9
PWR	21	4	--
Cavity length (m)	4.597	4.428	4.521
Basket cell (m)			
BWR	0.145	--	0.148
PWR	0.221	0.223	--

DOE may be obligated to transport SNF with non-fuel components inserted as standard fuel. In that case, the GA-4 cask will not accommodate 28% of the PWR assemblies. The increased quantities of SNF not accommodated include the WE 17x17, CE 14x14, and B&W 15x15 fuels. The WE 17x17 fuel falls into the not-accommodated category because the 0.076 cm clearance between the length of the WE 17x17 assembly with control rod inserted and the length of the cask cavity is considered to be inadequate.

With an internal cavity useful length of 4.572 m, the BR-100 rail cask can accommodate all PWR fuel assemblies except the extra-long South Texas Plant fuel and a the small fraction of the CE 16x16 fuel that may contain NFAH.

QUANTITY OF PWR FUEL ACCOMMODATED

The quantities of fuel that can be dimensionally accommodated by the GA-4 truck and the BR-100 rail From-Reactor casks are evaluated for the period from FWMS startup through the year 2025. Dimensional data for PWR fuel assemblies are summarized in Table 2. Fuel acceptance plans and rates were calculated with the Waste Stream Analysis Model.[2]

A commonly used DOE transportation scenario assumes that GA-4 truck casks are required to serve only those reactors not accessible by rail or those that cannot physically handle rail casks in their facilities. All other reactors are assumed to be served by the BR-100 rail casks. These assumptions significantly reduce the variety and quantity of fuels that must be accommodated in truck casks. Under these assumptions, ~40% of the PWR fuel assemblies are predicted to be transported by truck. The remaining 60% of the PWR fuel assemblies will be transported in the BR-100 rail cask.

As shown in Table 3, the GA-4 truck cask can accommodate all SNF scheduled to be transported by truck when the control elements are removed. However, if the control elements are inserted, the increased overall length of the B&W, CE, and WE fuel configurations reduces the number of fuel assemblies that can be accommodated, see Table 3. In particular, the large reductions in the amount of B&W 15x15 fuel that can be transported in the GA-4 cask results from the current indication that nearly all of that fuel may have a control element (control cluster, burnable poison rod, power shaping rod, instrument tube, or neutron source) inserted. The overall length of these configurations exceeds the GA-4 cask cavity length.

For the different WE fuels, only the WE 17x17 with control cluster inserted cannot be accommodated in the GA-4 cask. Likewise, the presence of the control cluster in the St. Lucie 2 fuel results in an overall length that slightly exceeds (2 to 5 cm) the cask cavity length. For the non-B&W fuels, the quantities of control elements are based on the fuel supplier expectation that control clusters will only have to be replaced once or twice during reactor lifetime. If and when such replacement occurs, essentially all fuel assemblies discharged in that period would contain a control rod cluster. For this paper, sufficient data were not available on each reactor to estimate the timing of control element replacement. Therefore, a uniform control element shipping rate of 10% was assumed for WE and CE fuels.

In summary, the GA-4 truck cask can accommodate all of the fuel assemblies scheduled to be transported by truck if the control elements are removed. However, if the control elements are left in place, the GA-4 truck cask will only accommodate 82% of the assemblies scheduled to be transported by truck. The remaining 18% will have to be transported either in Initiative III casks or the control elements will have to be removed from the assemblies and handled separately.

The accommodation of the balance of the PWR fuels in the BR-100 cask is shown in Table 4. With the exception of the South Texas and a small fraction of the CE 16x16 fuel with control clusters inserted, all fuels scheduled to be transported by rail are accommodated, with or without the control clusters. The fuels that cannot be accommodated in the BR-100 cask fall outside the Standard Contract envelope, and since the projected quantities are small (~7% of the total PWR assemblies to be shipped by rail) it appears logical to allocate this shipping requirement to Initiative III casks.

ACCOMMODATION OF BWR FUELS

BWR fuel assemblies are manufactured in a wide range of sizes, from the short (2.134 m) Big Rock Point assembly to the long (4.468 m) BWR/4-6 assembly. There is also a wide range of assembly cross sections, having side dimensions ranging from 0.109 m to 0.166 m. The dimensions of the various types of BWR assemblies are summarized in Table 5.

The cavity lengths of both the GA-9 and the BR-100 casks are adequate to accommodate all BWR fuels. However, each BWR assembly is enclosed in a fuel channel with wall thicknesses that may vary from 0.15 to 0.30 cm. Spacer springs and buttons on two sides of the channel near the upper end position the assembly in the reactor and attach the channel to the assembly. The buttons add between 0.51 and 0.785 cm to the overall cross-sectional dimension of the fuel channel. The springs also add to the cross section but may be deflected to conform with the basket cell or may be removed altogether.

TABLE 2 ACCOMMODATION OF PWR FUEL ASSEMBLIES IN GA-4 AND BR-100 FROM-REACTOR CASKS

	Overall Length-meters (a)		Accommodation of Fuels By Casks: GA-4 Truck Cask (b)		Accommodation of Fuels By Casks: BR-100 Rail Cask (c)	
PWR Fuel Assembly Identification	w/o Control Element	w/Control Element	w/o Control Element	w/Control Element	w/o Control Element	w/Control Element
Indian Point 1	3.485	na	yes	yes	yes	yes
B&W 15x15	4.209	4.366 (d)	yes	no	yes	yes
CE 14x14	3.993	4.267	yes	no	yes	yes
Fort Calhoun	3.716	3.988	yes	yes	yes	yes
Palisades	3.787	na	yes	yes	yes	yes
St. Lucie 2	4.026	4.293	yes	no	yes	yes
CE 16x16	4.491	4.75-4.80	no (e)	no (e,f)	yes	no (f)
CE 16x16, SYS. 80	4.529	4.902	no (e)	no (e,f)	yes	no (f)
San Onofre 1	3.482	3.518	yes	yes	yes	yes
WE 14x14	4.059	4.183	yes	yes	yes	yes
Haddam Neck	3.482	3.520	yes	yes	yes	yes
WE 15x15	4.059	4.166	yes	yes	yes	yes
Yankee Rowe	2.845	na	yes	yes	yes	yes
WE 17x17	4.059	4.247 (g)	yes	no (h)	yes	yes
South Texas	5.055 (f)	(i)	no	no	no	no

Notes:

na Not applicable, these assemblies use cruciform blades to control reactivity.

(a) No allowance made for differential thermal expansion, irradiation growth and distortion; additional detailed data needed for final design of casks.

(b) GA-4 cask preliminary design internal cavity length 4.248 m x 0.223 m basket cell openings.

(c) BR-100 cask preliminary design internal cavity length 4.597 m x 0.221 m basket cell openings.

(d) Overall length of this B&W fuel approximately equal regardless of which control element (control rod, burnable poison, power shaping, orifice rod) is installed.

(e) Existing reactors using this fuel currently have rail service.

(f) Outside standard contract envelope.

(g) Overall length with control cluster only; length with burnable poison, thimble plug and source assemblies and early control clusters ~0.06 m to 0.152 m shorter.

(h) Clearance of 0.076 cm between cask and control cluster is judged to be inadequate.

(i) Specific overall length dimension not available but known to be beyond accommodation in both casks and outside standard contract. envelope.

TABLE 3 QUANTITIES OF FUEL ASSEMBLIES ACCOMMODATED IN GA-4 TRUCK CASKS

PWR Fuel Assembly Identification	Shipping Requirement		Accommodated w/o Control Elements		Accommodated With Control Elements	
	Assy's	MTU	Assy's	MTU	Assy's	MTU
Indian Point 1	160	31	160	31	160	31
B&W 15x15	5652	2618	5652	2618	0	0 (a)
CE 14x14	4818	1835	4818	1835	4336	1652 (b)
Fort Calhoun	1094	392	1094	392	1094	392
Palisades	1285	514	1285	514	1285	514
St. Lucie 2	1273	493	1273	493	1146	444 (b)
WE 14x14	5128	1818	5128	1918	5128	1918
Haddam Neck	1407	549	1407	549	1407	549
WE 15x15	8795	3986	8795	3986	8795	3986
Yankee Rowe	678	161	678	161	678	161
WE 17x17	8382	3631	8382	3631	7544	3268 (b)
TOTALS	38,672	16,128	38,672	16,128	31,573	12,914
Fraction Accommodated - %			100	100	82	80

Notes:

(a) Assumes all this type of B&W fuel has a control element inserted.
(b) Assumes 10% of these types of CE and WE fuel have a control cluster inserted.

Table 4 QUANTITIES OF PWR FUEL ASSEMBLIES ACCOMMODATED IN BR-100 RAIL CASKS

PWR Fuel Assembly Identification	Shipping Requirement		Accommodated w/o Control Elements		Accommodated with Control Elements	
	Assy's	MTU	Assy's	MTU	Assy's	MTU
B&W 15x15	3176	1474	3176	1474	3176	1474
CE 14x14	3370	1264	3370	1264	3370	1264
CE 16x16	5319	2178	5319	2178	4787	1960 (a)
CE 16x16, Sys. 80	4085	1705	4085	1705	3677	1535 (a)
San Onofre 1	964	354	964	354	964	354
WE 14x14	2543	929	2543	929	2543	929
WE 15x15	4788	2177	4788	2177	4788	2177
WE 17x17	29727	13291	29727	13291	29727	13291
South Texas	2331	1261	0	0	0	0
TOTALS	56,303	24,633	53,972	23,372	53,032	22,984
Fraction Accommodated - %			96	95	94	93

Notes:

(a) Assumes 10% of these types of CE fuel have a control cluster inserted.

TABLE 5 BWR ASSEMBLY CLASS NOMINAL DIMENSIONS EXCLUDING CHANNEL BUTTONS AND SPRINGS

Assembly Class	Length (m)	Cross section (m)	Quantity (assemblies)	Percent of total (assemblies)
La Crosse	2.598	0.148	333	0.3
Dresden-1	3.414	0.109	892	0.7
Humboldt Bay	2.413	0.118	390	0.3
BWR/2,3	4.348	0.138	30,783	24.8
BWR/4-6	4.468	0.138	91,208	73.4
Big Rock Point	2.134	0.166	604	0.5
TOTALS			124,210	100.0

The BR-100 cask has a square basket cell opening of 0.145 m and is able to accommodate all of the bare BWR fuel assemblies (with fuel channels removed) except the small amount of La Crosse and Big Rock Point fuels, which comprise <1% of the total amount of BWR fuel expected to be accepted by the FWMS. However, because of the button and spring interference, the BR-100 cask cannot accommodate fuels in the BWR/2,3 and BWR/4-6 fuel classes with a fuel channel in place.

The GA-9 cask has a larger basket cell, 0.148 m square. It is questionable, however, whether there is sufficient clearance to accommodate the BWR/2,3 and BWR/4-6 fuel assemblies with fuel channels in place. This conclusion is based on a dimensional review by the authors and knowledge of the redesign effort under way on the existing IF-300 rail cask to accommodate fuel assemblies with channels in place. The original IF-300 basket cell was 0.146 m, and the cell is being increased to 0.151 m to accommodate assemblies with fuel channels.

Two actions can be taken to correct the non-accommodation of BWR assemblies with attached fuel channels. The most obvious solution is to remove the fuel channels from the assemblies, thus reducing the cross section of the fuel assemblies to fit the openings in the basket. With the channels removed, there is sufficient clearance to accommodate all BWR/2,3 and BWR/4-6 assemblies. Alternatively, the basket designs could be modified, by enlarging the basket openings, to accommodate the BWR assemblies with fuel channels attached. This may result in a decrease in the capacity of the Initiative I cask when used to transport BWR fuel assemblies.

The La Crosse fuel assembly is 2.598 m long and is well within the cavity dimension of either cask. The cross section of the La Crosse assembly with a 0.2-cm-thick channel is 0.148 m. It is not possible to accommodate this class of assembly in the GA-9 cask with the channel installed. The La Crosse assemblies could possibly be accommodated if the channel is removed. Under these conditions, the assembly cross section would be ~0.144 m. Because of the limited crane capacity at the La Crosse reactor, the BR-100 cask cannot be handled and is not a transportation option for La Crosse fuel. The small number of assemblies included in the La Crosse fuel class suggests that removing and handling the channels separately should not impose a significant burden on the FWMS. An alternative solution would be to use the GA-4 truck cask, a cask designed to transport PWR fuel assemblies. The La Crosse assembly will easily fit in the GA-4 cask; however, spacers will be needed to support the assembly in the larger PWR basket cell during transportation. Because the GA-4 cask was designed to transport higher-burnup PWR assemblies, there is sufficient shielding to transport BWR assemblies safely.

The amount of Big Rock Point fuel that will be accepted by the FWMS is projected to be small (604 assemblies). These assemblies are short and have a relatively large cross section. Because of the large cross-sectional dimension, these assemblies cannot be accommodated in either of the BR-100 or the GA-9 casks. With suitable spacers, the Big Rock Point assemblies could be accommodated in the GA-4 PWR truck cask.

REMAINING ANALYSIS

The Initiative I From-Reactor cask designs provide a reasonably optimized and efficient means for transporting the majority of the SNF discharged by the commercial reactors. The objective in the designs has been to accommodate most SNF without allowing some larger-than-normal fuel assemblies to reduce the capacity of the casks and, consequently, compromise the overall performance of the system.

The NFAH inserted in discharged PWR SNF assemblies may be removed and reused with the fresh fuel assemblies. The reused elements are normally replaced only once or twice over the life of the plant. Other elements may be discharged with the assemblies. However, BWR channels will likely accompany the assemblies on a more regular basis than in the case of the control elements in PWR assemblies.

The DOE/Office of Civilian Radioactive Waste Management (OCRWM) is discussing with utilities the issues arising from implementation of the standard disposal contract. These discussions include the means for handling NFAH through the Annual Capacity Report resolutions process.[3] In the meantime, OCRWM is evaluating the available options for accepting and transporting NFAH, either installed in the SNF assembly or being shipped separately. After identification of a reasonable set of options, logistics and economic analyses will be performed to determine the feasibility of each of the options. With the results of the logistics and economic analyses and the outcome of the discussion with the utilities, prudent decisions will be made concerning the accommodation of control elements in PWR assemblies and the channels included with BWR assemblies.

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