CHARACTERIZATION OF NON-FUEL HARDWARE

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ABSTRACT

This paper presents the results of an investigation into the disposal requirements for non-fuel pin hardware and non-fuel-assembly components that will be generated during consolidation of spent fuel that the Department of Energy (DOE) has contracted to accept for disposal. Radionuclide and material characteristics and estimates of anticipated quantities are presented. Disposal options, applicable regulations, and cost estimates are also discussed. Activation products in the hardware components are likely to necessitate disposal in geologic repositories because of current 10 CFR 61 requirements for most of these disassembly wastes; disposal in geologic repositories does have some cost advantage if the volume of the hardware is reduced.

INTRODUCTION

Pursuant to the Nuclear Waste Policy Act of 1982, the Department of Energy has contracted with utilities that operate nuclear power plants to accept spent nuclear fuel for disposal. Current thinking is that the spent fuel will be more efficiently and economically disposed of if it is consolidated. This will entail removing the fuel rods from the fuel assembly and packaging them separately. However, the consolidation process will generate a waste stream consisting of the disassembly hardware (i.e., end fittings, grid spacers, etc.). Additionally, the contract specifies certain nonfuel components that will also be accepted for disposal. These are noted in Appendix E of the contract:

> "Non-fuel components including, but not limited to, control spiders, burnable rod assemblies, control rod elements, thimble plugs, fission chambers, and primary and secondary neutron sources, that are contained within the fuel assembly, or BWR fuel channels that are 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 paper defines and characterizes these nonfuel components in terms of projected quantities, material compositions, and radionuclide inventory. We also address the regulations affecting disposal, several disposal options, and their cost impact.

FUEL DISASSEMBLY HARDWARE

Fuel assemblies consist of fuel rods and the associated hardware to hold the fuel rods in a fixed orientation in the reactor core. Studies done to date indicate an advantage for removing the fuel rods from the fuel assembly and consolidating them in specially designed containers for emplacement in a repository. As a result of this operation, the hardware that held the fuel rods together must be disposed of separately.

The fuel assembly hardware consists of different components, depending on fuel type and manufacturer. However, there are two basic types of fuel assemblies, those for boiling water reactors (BWR), Fig. 1, and those for pressurized water reactors (PWR), Fig. 2. BWRs have upper and lower end fittings, grid spacers, and one or two water rods. PWRs have upper and lower end fittings, grid spacers, and as many as 24 thimble tubes. Table I details the material composition of these components and their estimated masses for Westinghouse 17 x 17

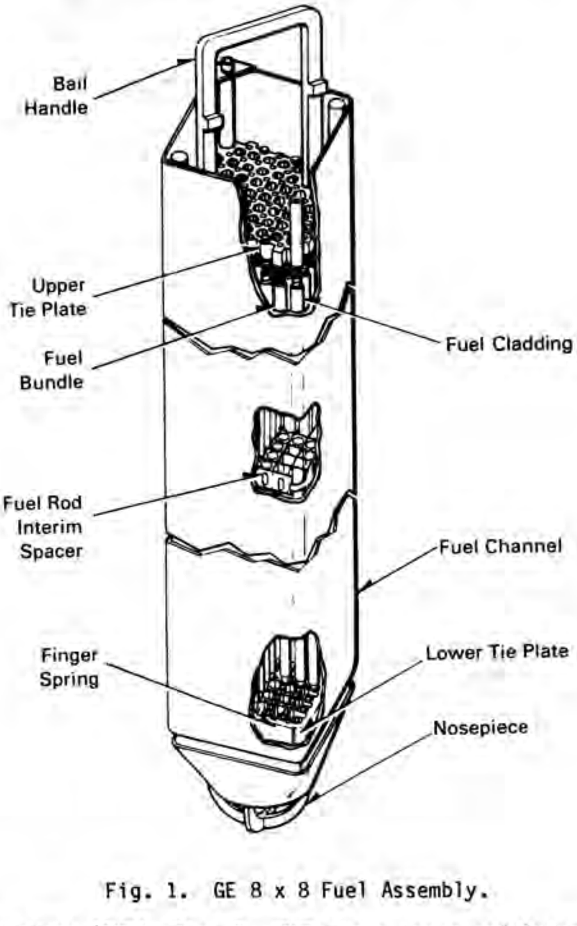

Fig. 1. GE 8 x 8 Fuel Assembly.

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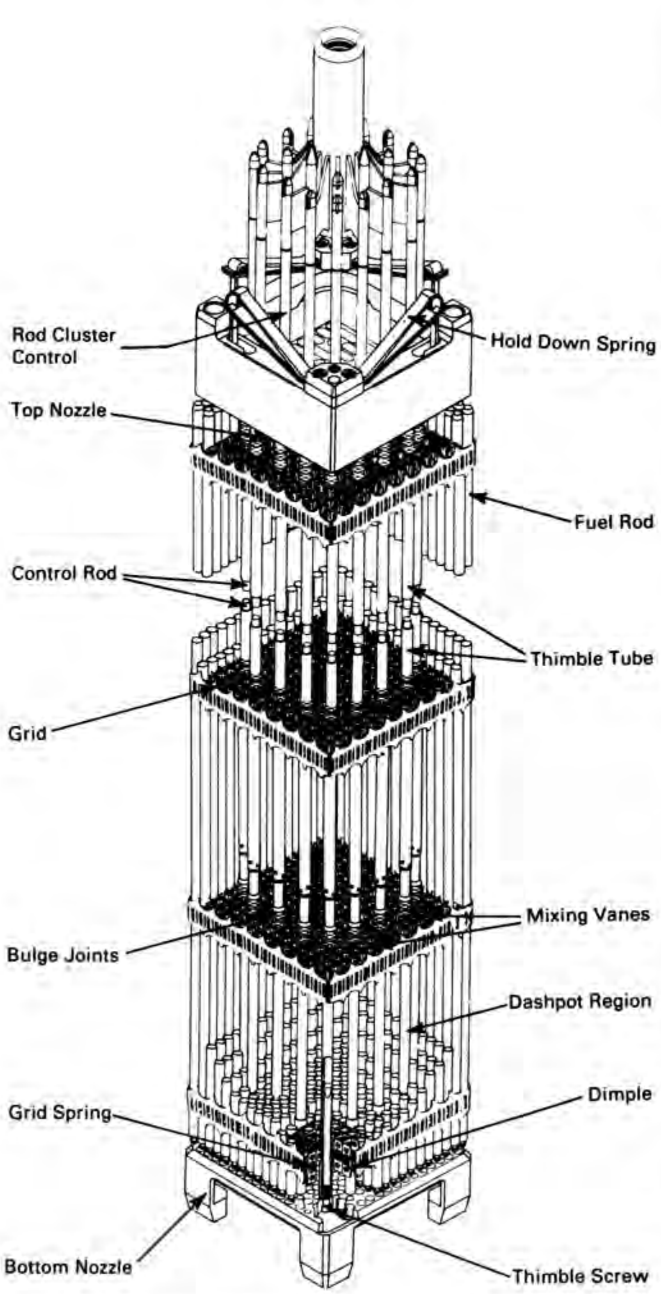


Fig 2. Westinghouse 17 x 17 Fuel Assembly.

(PWR) and General Electric 8 x 8 (BWR) fuel assemblies. Other fuel assembly types may have different compositions for similar components. In addition, current and future design changes may affect these components.

In addition to the disassembly hardware, there are a number of other components that may routinely require handling. In the case of a BWR fuel assembly, a fuel channel may be attached to the assembly. The fuel channel weighs approximately 45 kg, which is considerably more than the fuel assembly hardware, which weighs only about 12 kg. Since the present lifetime of a fuel channel is no more than twice that of a fuel assembly, this will result in a significant quantity of material requiring disposal. While a PWR fuel assembly does not have anything as massive as a fuel channel, it does have a variety of other components such as control rod clusters, burnable poison rods, neutron sources, and thimble plugs. Table II lists a number of these items, their material compositions, and their masses.

CHARACTERIZATION

As can be seen from Tables I and II, most of these components are made of various alloys of stainless steel, Inconel, and Zircaloy. There will be some other materials such as fissile material in power range monitors, primary and secondary neutron sources, and neutron-absorbing material in the control rods. When these components are irradiated in the reactor core, certain isotopes become sufficiently activated to pose handling and disposal concerns. Table III presents elemental compositions for these metals. Some of these elements are found only in trace quantities and are difficult to characterize accurately because their concentration can vary considerably. For example, cobalt can vary from 200 to 2600 ppm; niobium can vary from essentially zero to almost 300 ppm. These are normal metallurgical variations but have a marked impact on the radionuclide characteristics of the hardware and subsequent handling.

TABLE I

Fuel-Assembly Structural Materials

	PWR Westinghouse 17 x 17		BWR General Electric 8 x 8	
	Material	kg/MTU	Material	kg/MTU
Fuel Zone				
Guide Tubes	Zircaloy-4	21.3	--	--
Water Rods	--	--	Zircaloy-2	9.3
Grid Spacers	Inconel-718	12.8	Zircaloy-4	10.6
Grid-Spacer Springs	Inconel-718		Inconel X-750	1.8
Grid-Brazing Material	Nicro-braze 50	2.6	--	--
Miscellaneous	SS-304[a]	9.9	--	--
End Fitting Zone				
Top End Fitting	SS-304	14.8	SS-304	10.9
Bottom End Fitting	SS-304	12.4	SS-304	26.1
Expansion Springs	--	--	Inconel X-750	2.1
Total		73.8[b]		60.8[c]

(a) Distributed throughout the PWR core in sleeves and so forth.
(b) Non-fuel pin (w/sleeves).
(c) Non-fuel pin (2 water rods).

Currently, an analysis may be performed to determine that an element is below an acceptable level. How much below may not be determined and, in fact, the results may only indicate the impurity is not detectable by that test. This is often misinterpreted as zero, instead of less than the minimum detectable level of the test. However, the

TABLE II

Non-Fuel-Assembly Components

Component(a)	Material	Estimated Mass (kg)
BWR Channel	Zircaloy-4	45
BWR Cruciform Bearings	Stellite-3 Haynes-25	0.043(b)
PWR Control Rod Cluster	SS-304(d)	5 (c)
PWR Thimble Plugs	SS-304	2.5

(a) There are also power range monitors (fission chambers) and neutron sources.
(b) Set of 4 pins and rollers.
(c) Varies with design.
(d) Neutron absorber material can be B_4C, HfO_4, or Ag-In-Cd.

maximum concentrations prescribed in the recent 10 CFR 61 (12/83) regulations may be below the minimum detectable limit for the test method employed. For example, niobium is limited to 120 ppm in Zircaloy-2. The typical concentration runs in the <50 ppm range. This is sufficient to cause the ^{94}Nb concentration to be above the disposal limits after several years in a reactor environment. However, some testing methods will not detect levels of <50 ppm and are erroneously reported as zero.

DISPOSAL OPTIONS

A primary consideration in evaluating disposal options is the applicable regulations. The regulation that has the most impact is 10 CFR 61, which governs the shallow land (near-surface as opposed to deep geologic) disposal of radioactive waste. In particular, section 61.55 classifies radioactive waste into several categories. The most radioactive category is referred to as Class C. The limits for Class C are given in Tables IV and V. These are listed separately in two categories, long-lived and short-lived radionuclides. Within each category,

TABLE III

Elemental Compositions of LWR Fuel-Assembly Structural Materials

Element	Atomic Number	Structural Material Composition, Grams Per Tonne of Metal(a)								
		Zircaloy-2	Zircaloy-4	Inconel -718	Inconel X-750	Haynes -25	Stellite -3	SS-302	SS-304	Nicrobraze 50
H	1	13	13	0	0	0	0	0	0	0
B	5	0.33	0.33	0	0	0	0	0	0	50
C	6	120	120	400	400	1,500	27,000	1,500	800	100
N	**7**	**80**	**80**	**1,300**	**1,300**	**0**	**0**	**1,300**	**1,300**	**66**
O	8	950	950	0	0	0	0	0	0	43
Al	13	24	24	6,000	8,000	0	0	0	0	100
Si	14	0	0	2,000	3,000	10,000	10,000	10,000	10,000	511
P	15	0	0	0	0	300	0	450	450	103,244
S	16	35	35	70	70	300	0	300	300	100
Ti	22	20	20	8,000	24,900	0	0	0	0	100
V	23	20	20	0	0	0	0	0	0	0
Cr	24	1,000	1,250	190,000	150,000	210,000	330,000	180,000	190,000	149,709
Mn	25	20	20	2,000	70,000	20,000	10,000	20,000	20,000	100
Fe	26	1,500	2,250	180,000	67,800	30,000	30,000	697,740	688,440	471
Co	27	10	10	4,700	6,490	457,900(b)	423,000(c)	800	800	381
Ni	**28**	**500**	**20**	**520,000**	**722,000**	**110,000**	**30,000**	**89,200**	**89,200**	**744,438**
Cu	29	20	20	1,000	500	0	0	0	0	0
Zr	40	980,000	980,000	0	0	0	0	0	0	100
Nb(d)	**41**	**120**	**120**	**55,500**	**9,000**	**0**(e)	**0**(e)	**100**	**100**	**0**
Mo	42	0	0	30,000	0	0	0	0	0	0
Cd	48	0.25	0.25	0	0	0	0	0	0	0
Sn	50	16,000	16,000	0	0	0	0	0	0	0
Hf	72	78	78	0	0	0	0	0	0	0
W	74	20	20	0	0	160,000	140,000	0	0	100
U	92	0.2	0.2	0	0	0	0	0	0	0
Density, grams/cm^3	--	6.56	6.56	8.19	8.30	--	--	8.02	8.02	--

(a) All numbers rounded.
(b) Can be as high as 528,900.
(c) Can be as high as 500,000.
(d) Also known as Columbium (Cb).
(e) Maximum limit is 1000.

TABLE IV

Class C Limits for Long-Lived Radionuclides

Radionuclide	Half-Life (years)	Limit Ci/m^3
^{14}C	5,730	8
^{14}C in activated metal	5,730	80
^{59}Ni in activated metal	80,000	220
^{94}Nb in activated metal	20,000	0.2
^{99}Tc	213,000	3
^{129}I	16,000,000	0.08
Alpha-emitting transuranic nuclides with half-life greater than five years	>5	100(a)
^{241}Pu	14.7	3,500(a)
^{242}Cm	0.4	20,000(a)

(a) Nanocuries per gram.

TABLE V

Class C Limits for Short-Lived Radionuclides

Radionuclide	Half-Life (years)	Limit Ci/m^3
Total of all nuclides with less than 5 year half-life	<5	No limit
^{3}H	12.3	No limit
^{60}Co	5.3	No limit
^{63}Ni	100	700
^{63}Ni in activated metal	100	7,000
^{90}Sr	29	7,000
^{137}Cs	30	4,600

the sum of the fractions (actual concentration divided by the allowable concentration) of the radionuclides determines whether the mixture of radionuclides is in excess of allowable limits (i.e., sum of the fraction <1). This is done separately for each category. Waste with a concentration in excess of the Class C limits "is not generally acceptable for near-surface disposal" (10 CFR 61.55.a.3.iii). The code does allow for waste in excess of Class C to be disposed of by different and, in general, more stringent disposal methods (10 CFR 61.55.a.2.iv) on a case-by-case consideration. However, requirements are not specified and there has been no exercise of this option to date. Table VI shows the relation of the principal isotopes of concern to the Class C limits. As can be seen, most of the hardware is significantly over the limit. In particular, those items made of Inconel are well over the limit because niobium is a major constituent of the alloy (1-5%) Other components made of stainless steel and Zircaloy are for the most part over the limit but not to as great an extent. The end fittings from a PWR fuel assembly and the lower end fitting of a BWR fuel assembly are the only components that are under the Class C limits. This is because of the neutron flux drop-off in those regions.

TABLE VI

Ratio of Calculated Specific Activity to Maximum Allowable Specific Activity for Shallow Land Burial(a)

	m^3/MTU(b)	^{14}C	^{59}Ni	^{94}Nb	^{63}Ni
Half-Life		5730 yrs	8×10^4 yrs	2×10^4 yrs	100 yrs
10 CFR 61 limit		80 Ci/m^3	220 Ci/m^3	0.2 Ci/m^3	7000 Ci/m^3
PWR Fuel Assembly (33,000 MWD/MTU)					
Total Fuel Assembly Hardware	0.00651	1.1	3.6	990	15
Grids/Springs/etc. (SS-304 & Inconel-718)	0.00312	2.4	7.4	2100	32
End Fitting (SS-304)	0.00339	0.03	0.02	0.08	0.08
BWR Assembly (28,000 MWD/MTU)					
Total Fuel Assembly Hardware w/Channel	0.04526	0.15	0.09	9.8	0.43
Grids/Springs/etc. (Zircaloy-4 & Inconel X-750)	0.00209	0.41	1.5	86	7.3
End Fittings (SS-304)	0.00461	0.33	0.20	0.94	0.95
Channel (Zircaloy-4)	0.03856	0.12	<0.01	6.8	<0.01
BWR Cruciform					
Cruciform w/out Pins & Rollers (SS-304 & B_4C)	0.01330	0.53	0.32	1.5	1.5
Pins & Rollers (Stellite-3 & Haynes-25)	4.7×10^{-6}	<0.01	0.69	>>1	3.3

(a) Based on ORIGEN2 calculations; all ratios rounded to two significant figures.

(b) Full density.

Notwithstanding the preceding constraints, we did consider near-surface disposal as one alternative. The other alternative for disposal was a geologic repository. Several other parameters were also considered. They were transport mode (train versus truck), volume reduction (uncompacted versus compacted), and the location of the consolidation facility (reactor site versus MRS versus repository) as it affects transportation cost. Table VII illustrates the combinations considered. Our objective was to determine if there were any obvious advantages to any combination of the above parameters. This was by no means an exhaustive study, but it does help in narrowing down some of the many options available. The scenarios evaluated and the transportation distance assumptions are illustrated in Fig. 3. These scenarios would each affect the cost of the consolidation process differently. However, this aspect was not evaluated since we were not concerned with a determination of the best location for fuel consolidation. Rather, our concern was with the treatment and disposal of the non-fuel wastes remaining after spent fuel consolidation and with the impact that the consolidation location would have on the disposal costs for these wastes.

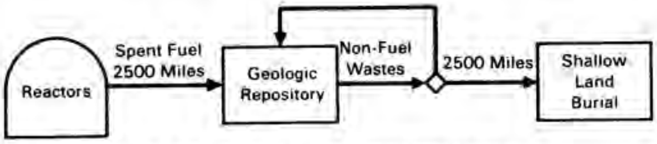
TABLE VII

Matrix of Cases Evaluated for Each Disposal Option

Waste Form	Transport Mode	Type of Container[a]
Uncompacted	Rail	Drum Canister
	Truck	Drum Canister
Compacted	Rail	Drum Canister
	Truck	Drum Canister

(a) 55-gal drums or canisters 2 ft in diameter and 10 ft long.

Scenario I Spent Fuel Consolidation at the Repository



Scenario II Spent Fuel Consolidation at an Intermediate Facility

Scenario III Spent Fuel Consolidation at Each Reactor

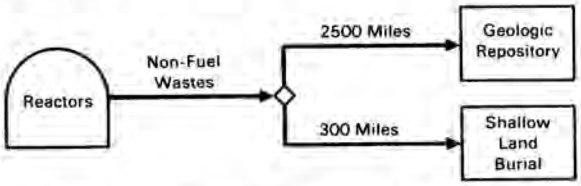


Fig. 3. Three Scenarios for Disposal of Non-Fuel Wastes.

COST ANALYSIS

The cost comparisons developed for the three scenarios and the eight alternatives are presented in Table VIII. These cost comparisons account for the cost of the overpack required, which depended on the disposal alternative; transportation of the waste to the disposal site from the consolidation facility; and the cost of the disposal service, i.e., shallow land or repository. The costs do not include the cost of volume reduction (compaction). However, it is apparent from the magnitude of cost savings for the compacted wastes that this treatment is easily justified.

The transportation costs are the sum of the capital costs and shipping charges. For the transportation cost estimates we assumed that the federal government will purchase the required shipping casks. The reference shipping casks used to determine the transportation costs were the high-level defense waste (HLDW) truck and rail casks that are currently being developed by GA Technologies Inc. The reference rail shipping cask was modified to provide two levels of gamma shielding. The uncompacted wastes require the equivalent of approximately 6 in. of steel shielding and the compacted wastes require 9 in. of steel shielding, which reduces the cargo capacity of the cask. The truck cask is the same design for both compacted and uncompacted waste.

The capital costs (in mid-1984 dollars) for the transportation casks were \$2.25 million for the rail cask and \$1.4 million for the truck cask (including railcar or semitrailer). We assumed that shipping casks have 15-year operational lifetimes, which requires these casks to be replaced once during the lifetime of the repository. Truck shipments were assumed to travel at an average speed of 25 mph and rail shipments to travel at an average speed of 12 mph. Turnaround times were assumed to be five days for rail shipments and three days for truck shipments. These turnaround times are the combined times for loading at the origin facility and unloading the destination facility. Shipping casks were assumed to be available 300 days per year.

Freight charges include distance and weight costs, detention or demurrage costs, and a surcharge for highway route controlled quantities of radioactive materials. The sum of these charges ranges from \$1.5/kg to \$2.1/kg for truck and from \$2.3/kg to \$3.3/kg for rail for 1,500- and 2,500-mile shipments, respectively.

Disposal costs for both shallow land burial and geologic repository disposal were estimated for the non-fuel components of the fuel assemblies. For shallow land burial, published charges (4/84) for the Barnwell, North Carolina, disposal site were used to determine disposal costs. Although Barnwell does not now accept rail shipments, this method of shipment was included as a parameter for comparison purposes. The cost estimates for shallow land disposal include a high-integrity container (HIC) cost for Class C wastes, which is actually incurred at the treatment and packaging site. We used HIC costs of $300 for 55-gal drums and $5,000 for the canister compared to $50 and $2,000, respectively, for these size containers going to geologic disposal. Other cost categories include 1) the basic burial charge combined with cask handling charges, weight surcharges when applicable, and taxes, 2) radiation surcharges, and 3) curie surcharges. The radiation and curie surcharges are very significant cost components for this type of waste. The curie surcharges are based on 10-year-old wastes. The rate per curie declines as the number of curies in a shipment increases even though the surcharge per shipment increases.

The estimates for disposal costs in a repository were based on waste disposal in a salt repository. No capital costs were allocated to this additional waste; only the additional incremental costs of handling and disposal of these wastes were included. The cost estimates for repository disposal accounted for four cost categories. These included receiving, packaging, emplacement, and the initial container cost. It was assumed that if 55-gal drums were sent to a repository, they would be overpacked into a more efficient four-drums-per-overpack configuration since the facility would already be geared to handling large remote-handled packages. Emplacement is the cost of emplacing those canisters into boreholes in the repository. These repository disposal costs were estimated at $4,300/55-gal drum or $11,400/canister if received by rail or $4,900/55-gal drum and $13,500/canister if received by truck.

Our principal conclusions can be summed up as follows:

1. The concentration of activation products in the spent fuel hardware components will likely necessitate geologic repository disposal for a large fraction of these disassembly wastes.
2. A more detailed quantitative analysis of material is required to further characterize the waste form for disposal purposes.
3. There is a strong economic incentive to perform volume reduction on these disassembly wastes.
4. Waste packaging for geologic disposal appears to be more cost-effective in a large canister than in a 55-gal drum.
5. Assuming volume reduction, geologic disposal has a cost advantage over shallow land disposal even though some of the components might qualify for near-surface burial.
6. Assuming volume reduction, the transport mode does not appear to have a significant impact on the cost.

TABLE VIII

Total Cost Estimate for Three Scenarios ($ millions)

Waste Form	Transport Mode	Type of Container	Scenario I		Scenario II		Scenario III	
			Repository	Shallow Land	Repository	Shallow Land	Repository	Shallow Land
Uncompacted	Rail	Drum	1566	651	1667	651	1667	651
		Canister	1077	1408	1393	1291	1510	1151
	Truck	Drum	1566	2090	2308	1985	2413	1859
		Canister	1077	2156	1673	2048	1781	1918
Compacted	Rail	Drum	197	392	281	367	306	337
		Canister	135	449	219	423	245	392
	Truck	Drum	197	395	308	372	331	344
		Canister	135	439	233	420	252	397