CHARACTERISTICS OF DOE SPENT NUCLEAR FUEL AFFECTING PRETREATMENT AND FINAL DISPOSITION

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I. ABSTRACT

The Department of Energy (DOE) has more than 200,000 units of Spent Nuclear Fuel (SNF) in storage at 13 different DOE facilities, and several universities and non-DOE institutions. This SNF is part of the DOE National Spent Nuclear Fuel program that will determine how the fuel will be stored, conditioned and dispositioned. It is necessary to know the characteristics of the fuel to manage the SNF, determine interim storage, pretreatment, and dispositioning of the SNF.

Several key characteristics have been determined that will allow the preliminary evaluation of the SNF. These characteristics include: Fuel type and compound, Fuel matrix type and compound, Cladding material, Uranium 235 enrichment, Uranium 235 burnup, Hazardous material content, Fuel unit dimensions and Actinide content. Each of these characteristics will impose special considerations on handling, treatment, and dispositioning requirements for the SNF. Total characterization of the SNF will require the evaluation of many more characteristics and properties than presented here.

This paper presents the key characteristics that can be used to evaluate the DOE management options. The rational for the selection of each of the characteristics are presented. The DOE inventory is examined using the identified key characteristics. Several figures are used to show the distribution of the SNF by characteristic. The characteristics of the largest quantities of DOE SNF are presented and discussed.

II. INTRODUCTION

The Department of Energy (DOE) has more than 150 different types of Spent Nuclear Fuel (SNF), comprising more than 200,000 units, in storage at DOE, private non-DOE, university facilities across the United States and foreign countries. The present DOE SNF management plan does not include reprocessing the fuel for the recovery of uranium, but involves interim storage until DOE is prepared to disposition the fuel in a national repository. Prior to any long term actions the SNF will need to be characterized sufficiently to support the proposed actions. The determination of which characteristics will be important will depend on the proposed action. Some characteristics will be universally important. There is a need to understand the characteristics of the SNF and to put the fuel in categories of SNF with similar characteristics. This will allow the evaluation of the SNF and the proposed dispositioning options by categories rather than individually.

III. BACKGROUND

The DOE and its contractors have built and operated many different types of nuclear reactors for a variety of purposes over the past forty years. In addition, the DOE has taken ownership of some commercial and other fuels generated by private groups. The types of reactors that produced the SNF can be divided into four main categories: production of special materials, research, training, and power generation. Because of the nature of the DOE research and development program many of the fuels are "one of a kind."

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VI. DESCRIPTION OF WORK

Characterization of the SNF requires a determination of the important characteristics. Some dispositioning options will need information that others do not. Some information appears to be universally important. Characteristics data was obtained from a variety of sources. The SNF inventory was divided into categories based on the characteristics of each of the SNFs.

A. Important Characteristics

From evaluation of the final dispositioning requirements and of the proposed processes for dispositioning SNF, several characteristics were judged most important. These characteristics included: fuel type and compound, matrix type and material, cladding type, uranium enrichment, fuel burn-up, hazardous material content, and actinide content. The justifications for these criteria are listed below.

Fuel type and compound Possible fuel types and compounds include: metallic, non-aluminum uranium alloy, oxide, hydride, carbide, aluminum alloy. These characteristics are important because of two considerations. First, chemical reactions, such as the rapid oxidation of metallic uranium in air, or the reaction of carbide fuels with water to produce an explosive gas must be included in long term storage and final repository safety analysis. Second, the release of fission products and actinides depend on the material in which they are contained and the leaching rate of the fission products and actinides from the material.

Matrix type and material The matrix refers to the material that the uranium metal or compound may be mixed with that are also enclosed by the fuel cladding. For example uranium aluminide particles could be immersed in powdered aluminum metal and pressed into plates such as is done in ATR fuel. Possible categories of matrix types and materials include: aluminum, zirconium, thorium, ternary oxide, ceramic, metallic carbides, graphite, etc. Each of these types is important because they will affect the corrosion rate of the fuel and the release rate of the fission products and actinides.

Cladding type Cladding materials include primarily aluminum, stainless steel, and zirconium. Some fuels do not have cladding either because they have been declad or were constructed without cladding. This characteristic is important because some cladding material is much more susceptible to corrosion, which will affect long term storage. In addition, some conditioning technologies may only work for certain types of cladding. It is presently uncertain if cladding integrity and material will be considered for repository placement.

Uranium 235 enrichment The current DOE method of classifying SNF by uranium enrichment is high (>20% U-235) low (<20% U-235), natural (0.711% U-235), and depleted (<0.711% U-235). Uranium 235 enrichment is a major criterion for evaluating criticality concerns. Some fuels may have other fissile materials, such as uranium 233 or plutonium 239, which will be evaluated on an individual basis as more information is available.

Burn-up The fuel burn-up ranges from low to very high. This characteristic coupled with the fuel design parameters and the age of the fuel will determine the source term for fission products and actinides in the SNF and also the heat generation rate.

Hazardous material content This category specifically identifies SNF that may contain Resource Conservation and Recovery Act (RCRA) defined hazardous constituents but can also include any other materials that are deemed to be hazardous. This characteristic is important because it could affect the design of interim storage facilities and the licensing of the repository.

Actinide content Plutonium and thorium are considered to be the most important actinides. Actinide content is important because of their long half lives and release rate from the repository after closure. In addition plutonium is a concern because of proliferation issues. Because all irradiated fuels may have some plutonium, a judgement was made on each fuel where the information was available, as to whether the quantity of plutonium was significant.

Size Intact pressurized water reactor commercial fuel assembly generally is 8.5" X 8.5" X 161" and weights 1500 pounds. Intact boiling water commercial fuel assembly is generally 5.5" X 5.5" X

176" and weights 600 pounds. Test and research reactor fuel assemblies varies significantly and can be as large as 22" in diameter and as small as 3" in diameter. Their length varies between 20" and 40" and weights between 7 and 25 pounds.

B. SNF Inventory

The SNF inventory was taken from the inventory documents used in the SNF & INEL Environmental Impact Statement (EIS) preparation. That inventory was prepared using the Directory of Nuclear Research Reactors, and the DOE Integrated Spent Nuclear Fuel Database System.

Two times were used in the analysis, 1995 and 2035. These time were selected because they represented the record of decision date for the EIS and the ending period of the EIS. DOE presently has only four operating reactors generating spent fuel; ATR, HFIR, BMRR, and HFBR. In addition, the navy, universities, and returns for foreign fuel combine to increase the DOE SNF inventory between 1995 and 2035. Estimates of SNF generation were supplied by the generators.

Information was gathered from all available sources concerning the specific characteristics of interest for each fuel. The spreadsheet containing the EIS inventory was then divided into categories based on the characteristics of the SNF. This created 55 categories of fuel, each with distinct characteristics. Table 1 (next page) summarize the categories.

Depending on the needs of the user, some categories could be combined to form a smaller number. For example, if burnup were not a concern then the high and low burnup categories of a particular fuel could be combined.

V. RESULTS

A. Distribution

Twenty of the 55 categories contain 95% of the total mass and 99% of the Metric Tons of Heavy Metal (MTHM). There is not a direct correlation between total mass and MTHM. Some SNF like the naval fuel is constructed with much more structural material for ruggedness and these will have more total mass.

The increases in the DOE SNF inventory between 1995 and 2035 are relatively small. Naval fuel has the largest increase, followed by aluminum clad. The increases from all other sources are spread among six other small categories. The rest of the analysis in this paper of the data will be based on the 1995 inventory because the projected changes are so small.

Twenty-five of the 55 categories (45%) contain only one SNF type. This is indicative of the reactor and fuel development missions of the DOE, where there were many one of a kind fuels manufactured.

Thirty-two of the 55 categories (58%) are located at only one DOE site. This is an outgrowth of the reactor fuel development program as well as in many cases DOE segregating fuel by type at the various DOE sites. This was done because of specific capabilities located at particular sites.

There are a few SNF categories that are located at many DOE sites. This is an indication of a common type of fuel that was used in several different reactors, or in the case of EBR-II fuel that was built and tested at several different sites for the same development program.

B. Characteristics

The distribution of the fuel meat material is contained in table 2.

TABLE 2
Distribution of DOE
SNF by Fuel Meat Material

Fuel Meat Material	Total Mass (kg)	% of Total Mass
Oxide	812,470	17.5%
Al-Alloy	445,310	9.6%
Metal or Alloy	2,443,170	53%
Carbide	351,600	7.6%
Hydride	9,347	0.2%
Naval	559,000	12%

TABLE 1
DOE SPENT NUCLEAR FUEL
CATEGORIZED BY SEVEN CHARACTERISTICS

Category	enrichment	fuel type	matrix material	clad	actinides	other	burn-up	Example
1.	High	class.	class.	Zr	class.	class.	high	Naval
2.	High	hydride	Zr	SST	minor	Graphite	low	TRIGA
3.	High	hydride	Zr	Zr	minor	graphite	low	TRIGA
4.	High	hydride	Zr	declad	minor		low	SNAP
5.	High	oxide	Al	Al			high	HFIR
6.	High	oxide	SST	SST	minor	TiO_2		APPR
7.	High	U-Pu oxide		SST	Pu		Na	FFTF Test
8.	High	oxide	ThO_2	SST	minor	Th, U-233		ERR
9.	High	oxide	ceramic	Ferrous		Ti,Y,Be,Mg		GCRE
10.	High	oxide	ZrO_2	Zr	minor	Ca, B,	high	Shippingport PWR
11.	High	oxide		Zr				PCM
12.	High	oxide	ceramic	none	minor	Be, Mg, Zr	low	TORY II
13	High	oxide	powder	none	minor	ThO_2	low	KEMA
14	High	U-Al	Al	Al			low	MTR Type
15.	High	U-Al	Al	Al			high	SRS Driver
16.	High	U-Mo alloy		Zr	Pu		med.	FERMI-II
17.	High	metallic	Zr	Zr	minor		low	HWCT
18.	High	metallic	fissium	SST	Pu	Na	med.	EBR-II
19.	High	carbide	ThC, SiC	C	minor	Th, Si	med.	FSVR
20	High	carbide		Zr		graphite		FFTF test
21	High	carbide		SST	Pu	graphite, Na		FFTF test
22	High	oxide	graphite	Zr			low	TREAT
23.	Low	hydride	Zr	Al	minor	graphite	low	TRIGA
24.	Low	hydride	Zr	SST	minor	graphite	low	TRIGA
25.	Low	hydride	Zr	incoloy		graphite		PRR-1
26.	Low	oxide		SST			high	JASPER
27.	Low	oxide	Al	Al				RRR
28	Low	oxide	ceramic	SST		ZrO_2, CaO	low	PBF
29.	Low	oxide	ThO_2	SST	minor	Th, U-233	med.	Dresden
30.	Low	oxide	Zr	Zr			low	EBWR oxide
31.	Low	U-Pu oxide		Zr	Pu			EBWR
32.	Low	U-Pu oxide		SST	Pu		high	FFTF
33.	Low	U-Zr	Pu-Zr	Zr	Pu	Th,		FFTF test
34	Low	Pu oxide		SST	Pu			ZPPR
35.	Low	oxide		Zr			low	commercial LWR
36.	Low	oxide	ceramic	Zr	Pu	Gd	high	EBWR
37.	Low	oxide	ceramic	Zr	Pu	Th, CaO, U-3	med.	Shippingport LWBR
38.	Low	oxide		Zr	Pu	C coated	high	Shippingport
39.	Depleted	metallic	Al	Al			high	SRS target
40.	Low	U-Mo alloy		SST		Na	med.	FERMI blanket
41.	Natural	metallic	Zr	Zr			low	HWCT
42.	Low	oxide		Zr	Th		low	HWCT
43.	Low	metallic		Zr	Pu	Be	med.	N reactor
44.	Low	metallic		SST		Mo		SPEC
45.	Low	metallic		SST	Pu	Na		EBR-II
46.	Low	carbide		SST		Na	med	SRE
47.	Low	U-Si	Al	Al				RERTR
48.	Low	salt		none	none	Li, Be, Zr		MSRE
49.	Natural	oxide		Zr	Pu		high	Commercial
50.	Natural	oxide		Zr		disrupted	high	LOFT
51.	Low	oxide	melted	Zr	Pu	Cd	med.	TMI
52.	Low	oxide		Zr	Pu	C coated	high	Shippingport PWR
53.	Depleted	metallic		Al	Pu		low	SPR
54.	Low	nitride		Nb				FFTF-test
55.	Natural	metal		none		SST cont.	low	Core filter

Notes
1. Enrichment: > 20% high, < 20% low, .7% natural, <.7% depleted
2. Cladding: Zr - zirconium or zirconium alloy, SST - stainless steel, Al - Aluminum
3. Matrixes: blank means none or unknown
5. Other: other materials reported in fuel
6. Burn-up: low < 1000 MWDT, high >10,000 MWDT, blank - unknown
7. Example: representative fuel in category

The largest category of fuel meat material is metal or non-aluminum uranium alloys. These materials have the potential for adverse chemical reactions with the environment of a repository. Carbides make up the fifth largest category of fuel meat material and they also have potential chemical reactions with a storage or repository environment.

The fission product and actinide release rate from oxide fuel has been most extensively studied because it is the fuel meat used in most commercial fuel. There are in the DOE several different types of oxides forms, such as ceramics and ternary oxides that may have different release rates.

The type of cladding material is contained in table 3. Even though graphite is not a cladding it is listed to show perspective.

Table 3
Distribution of DOE SNF
by Cladding Material

Cladding Material	Total Mass (kg)	% of Total Mass
Zr	3,225,140	70%
SST	189,408	4.1%
Al	462,763	10%
Graphite	351,600	7.8%

The largest majority of the SNF is clad with Zr, which is presently considered stable in most storage environments if not previously not breached, and is also inert to most chemical that may be used for dissolution. It has not been decided if credit can be taken in the repository for the cladding serving as a barrier to fission product and actinide release.

The present condition of the fuel may influence plans to interim store or for final treatment. The fuels that have known deteriorated conditions are listed in table 4.

Table 4
Reported Condition
of DOE SNF

Condition	Total Mass (kg)	% of Total DOE SNF
Melted	325,195	7.2%
Clad Breach	1,131,500[1]	24%
Declad or no Clad	4,700	0.01%
Salt	8440	0.02%
Al clad	462,763[2]	10%
Total	1,932,598	42%

Note:
1. 30% - 50% of the N-Reactor fuel is estimated to have cladding breaches. 50% was assumed for this analysis.
2. It is estimated that all Al clad fuel is corroded or will be corroded before a repository is available.

Highly uranium 235 enriched SNF presents some possible problems for placement of the SNF into a repository. High enriched SNF (>20%) accounts for 28% of the total SNF.

DOE has considerable experience in the short term storage or processing of HEU SNF but no experience in long term storage.

VI. CONCLUSIONS

There is a wide range of SNF types and characteristics. The percent uranium in the SNF total mass varies from 1.9% to 93%. Fifty five percent of the SNF has uranium metal or uranium metal non-aluminum alloy fuel meat. Seventy five percent of the SNF is clad with zirconium. Zirconium clad SNF is considered the most resistant to corrosion. However, 38% of the fuel has known cladding defects or corrosion problems. Twenty eight percent of the fuel is made from highly uranium 235 enriched material that may present potential treatment or dispositioning problems.

DOE SNF presents a wide variety of characteristics. Much of the DOE SNF is significantly different from commercial SNF, and the present plans for commercial fuel may not apply to all DOE fuel.