National Spent Fuel Program Preliminary Report RCRA Characteristics of DOE-Owned Spent Nuclear Fuel DOE-SNF-REP-002

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ABSTRACT

In 1989, a question was raised regarding the applicability of the Resource Conservation and Recovery Act (RCRA) subtitle C hazardous waste regulations to Department of Energy (DOE)-owned Spent Nuclear Fuel (SNF). This question presumes that DOE-owned SNF is solid waste. If it is determined to be solid waste, would DOE-owned SNF be excluded from RCRA regulation, or would it require dual regulation under RCRA as well as the Atomic Energy Act of 1954? During 1989, most DOE-owned SNF was destined for reprocessing as a valuable product, and thus no further actions were visibly taken because RCRA applies to waste. However, the regulatory status of DOE SNF came into question again in 1992 with DOE's decision to cease reprocessing of SNF.

Through enactment of the Federal Facilities Compliance Act of 1992, how RCRA applies to DOE waste became clearer with the addition of the term "mixed waste" to the definition section (§1004) of RCRA. This new definition includes source, special nuclear, and byproduct material as defined by the Atomic Energy Act that it is mixed with hazardous waste. Intent to regulate SNF under these decisions is not apparent. SNF, which is determined to be waste that contains nonradionuclide hazardous components, appears to be subject to dual regulation under RCRA regulation and the Atomic Energy Act to the extent that the RCRA regulation is consistent with requirements under the Atomic Energy Act. Literal interpretation and application of the definitions for source, special nuclear, and byproduct materials provided in the Atomic Energy Act clearly establish exclusions that should be carefully considered for effective management of SNF.

EXECUTIVE SUMMARY

This report presents information on the preliminary process knowledge to be used in characterizing all Department of Energy (DOE)-owned Spent Nuclear Fuel (SNF) types that potentially exhibit a Resource Conservation and Recovery Act (RCRA) characteristic. This report also includes the process knowledge, analyses, and rationale used to preliminarily exclude certain SNF types from RCRA regulation under 40 CFR §261.4(a)(4), "Identification and Listing of Hazardous Waste," as special nuclear and byproduct material.

The evaluations and analyses detailed herein have been undertaken as a proactive approach. In the event that DOE-owned SNF is determined to be a RCRA solid waste, this report provides general direction for each site regarding further characterization efforts. Each site has very specific SNF management activities scheduled that would be impacted by such a determination. Therefore, each site should consider the information within this report as these activities are scheduled and coordinated in order to satisfy the site-specific SNF management requirements. The intent of this report is also to define the path forward to be taken for further evaluation of specific SNF types and a recommended position to be negotiated and established with regional and state regulators throughout the DOE Complex regarding the RCRA-related policy issues.

In order to be subject to RCRA hazardous waste regulation, SNF must be a solid waste. This has not been established by DOE. If SNF is a solid waste, it must appear as a RCRA-listed hazardous waste under 40 CFR §261.31-33, or it must be determined to be a characteristic hazardous waste as detailed under 40 CFR §261.21-24 to be regulated as RCRA hazardous waste. Characteristic waste is either ignitable, corrosive, reactive, or toxic.

A combination of process knowledge and select sampling and analysis serve as the basis for this evaluation effort. Process knowledge is accepted by EPA [40 CFR §262.11(c), "Standards Applicable to Generators of Hazardous Waste"] when characterizing nuclear materials for applicability of RCRA mixed-hazardous waste regulations to minimize the threat to human health and the environment.

For evaluation of both regulatory applicability and management technologies, the various types of DOE-owned SNF have been divided into 55 categories based on fuel type, matrix type and material, cladding type, uranium-235 enrichment, burnup, potential hazardous materials and characteristics, and actinide content. Current preliminary process knowledge and analyses indicate that 47 of the categories would not be subject to RCRA regulation if SNF is determined to be a solid waste. Only sodium-bonded and disrupted fuels, representing 8 SNF categories, require further evaluation before a more definitive position regarding RCRA applicability can be established.

Fifteen of the 55 categories were initially identified as potential RCRA concerns; fourteen categories by virtue of reactivity and one by virtue of toxicity. Preliminary data indicates that none of the 55 categories of SNF would be characteristic due to ignitability or corrosivity.

Initial process knowledge evaluations conducted in the late 1980s and early 1990s identified some known or suspected characteristics of DOE-owned SNF that could potentially subject certain categories of SNF to regulation as RCRA hazardous waste. As a result, eight concerns, which will serve as the focus of this preliminary report, were identified as follows:

1. SNF containing beryllium as a listed RCRA hazardous waste
2. Reactivity of uranium metal SNF

3. Reactivity of uranium hydrides generated by SNF
4. Reactivity of metallic carbide SNF
5. Toxicity of stable fission and activation products^a
6. Toxicity of materials of construction^a
7. Toxicity of disrupted SNF
8. Reactivity of sodium bonded SNF.

Each of the eight concerns listed above, and their current status, is summarized and categorized below as either resolved, preliminarily resolved but requiring confirmatory data or policy clarification, or requiring further evaluation.^b

Resolved Concerns

SNF Containing Beryllium—Initial evaluations have resolved the concern regarding the presence of beryllium, a RCRA-listed waste, in certain types of SNF. RCRA regulates beryllium as a listed hazardous waste when it is discarded as an unused commercial chemical product or in powder form (40 CFR §261.33). Beryllium, used in nuclear fuel, would not be considered an unused product because it is used as a component in a manufactured item, and therefore, could no longer be considered a discarded commercial product. Furthermore, commercial chemical products, once combined with other ingredients, would not be considered a listed waste upon disposal provided they are not considered the sole active ingredient.

Reactivity of Uranium Metal SNF—Initial evaluations also resolved the concern regarding the potential reactivity of uranium metal fuels. Uranium metal fuels are present in 5 SNF categories representing approximately 80% of DOE-owned SNF by mass in Metric Tons of Heavy Metal (MTHM) and 19.0% by volume. Uranium metal is specifically excluded from RCRA solid waste regulation as a special nuclear material (SNM) under 40 CFR §261.4(a)4.

Preliminarily Resolved Concerns

Reactivity of Uranium Hydrides—The SNF categories that are involved in the uranium-hydride concern are the same as the uranium metal SNF since uranium hydrides are generated directly from uranium metal, a material excluded from RCRA. Discussion with regulatory agencies, concerning the application of the SNM exclusion to uranium hydrides, as well as further evaluation of the actual reactivity of uranium hydrides is required. Uranium-zirconium hydrides that occur in manufactured form in certain fuels have been studied and shown to be stable.

a. Broad concerns potentially impacting a substantial number of SNF types.

b. Some of the fuels contained in this document have been defined in the acronym list when a definition was available. However, not all definitions for fuel names were available at the time of publication. Therefore, the acronym list is not all inclusive.

Reactivity of Metallic Carbide SNF—Another concern considered resolved by preliminary data is the potential reactivity of uranium and thorium dicarbides. The uranium and thorium dicarbides are present in two categories and represent approximately 1% of DOE-owned SNF by mass in MTHM and 21.6% by volume. This concern is considered preliminarily resolved due to exclusion of uranium compounds as SNM. A position paper addressing uranium compounds as encompassed by the SNM exclusion has been issued and is awaiting DOE and NRC concurrence.

Two additional concerns considered resolved by preliminary data are (1) the potential toxicity of stable fission and activation products present in SNF and (2) the potential toxicity of leachate from materials of construction. Both of these concerns have broad sweeping impact to all categories of SNF.

Toxicity of Stable Fission and Activation Products—The concern regarding the potential toxicity of stable fission and activation products is preliminarily resolved through exclusion. Stable fission and activation products are byproduct material, which is excluded under 40 CFR §261.4(a)4. A position paper has been drafted to specifically address this exclusion.

Toxicity of Materials of Construction—Preliminary resolution of the materials of construction concern is through extensive process knowledge and sampling of unirradiated materials. This indicates that the solubility of these materials is not sufficient to cause the leach rates to exceed the RCRA limits. The only remaining issue is the effect of irradiation on the solubility of these materials. Irradiation is not expected to significantly change the solubility.

Requiring Further Evaluation

Toxicity of Disrupted SNF—Disrupted fuels contain toxic metals as alloyed in control rods that cannot be removed due to meltdown conditions. These fuels are present in one category representing 3% of DOE-owned SNF by mass in MTHM and 9.5% by volume. Analyses conducted on unirradiated control rod material were below the RCRA allowed TCLP limits. Analysis of actual TMI core debris is currently underway.

Reactivity of Sodium-Bonded SNF—Extensive evaluation of the sodium-bonded SNF concern is required. Evaluation will involve determination of the extent of reactivity of the metallic sodium bonding. The sodium-bonded SNF is present in six categories representing approximately 3% of DOE-owned SNF by mass in MTHM or 13% by volume. The metallic sodium bonded fuels appear to be the most likely to exhibit a RCRA characteristic.

Efforts to further evaluate and analyze these concerns, as well as the confirmatory efforts required to finalize those concerns reported as preliminarily resolved, are ongoing; definitive paths forward for their resolution have been provided within this report.

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ACRONYMS

ACRR	Annular Core Research Reactor
ANL-E	Argonne National Laboratory-East
ANL-W	Argonne National Laboratory-West
ATR	Advanced Test Reactor
BWR	Boiling Water Reactor
CFR	Code of Federal Regulations
DOE	U.S. Department of Energy
DOE EM	DOE/Office of Environmental Management (Headquarters), Germantown, Maryland
DOE-HQ	Department of Energy Headquarters
EBR	Experimental Breeder Reactor
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
FFTF	Fast Flux Test Facility
FSVR	Fort St. Vrain Reactor, Platteville, Colorado
GCRE	Gas-Cooled Reactor Experiment
HEDL	Hanford Engineering Development Laboratory
HFIR	High-Flux Isotope Reactor
HTGR	High-Temperature Gas Cooled Reactor
HTRE	High-Temperature Reactor Experiment
HWCTR	heavy-water components test reactor
ICPP	Idaho Chemical Processing Plant
IFR	Integral Fast Reactor
INEL	Idaho National Engineering Laboratory
LANL	Los Alamos National Laboratory

LOFT	Loss-of-Fluid Test
LWR	Light Water Reactor
MSRE	Molten Salt Reactor Experiment
MTHM	metric tons of heavy metals
MTR	Materials Test Reactor
NRC	Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
PBF	Power Burst Facility
PWR	Pressurized Water Reactor
RBOF	Receiving Basin for Off-Site Fuel
RCRA	Resource Conservation and Recovery Act
SFD	Severe Fuel Damage
SNAP	Space Nuclear Auxiliary Power
SNF	Spent Nuclear Fuel
SNL	Sandia National Laboratory
SNM	special nuclear material
SRE	Sodium Reactor Experiment
SRF	Safety Research Fuel
SRS	Savannah River Site
SS	stainless steel
TCLP	Toxicity Characteristic Leaching Procedure
TMI-2	Three Mile Island-2
TRIGA	Training Reactor, Isotopes, General Atomic
WAPD	Westinghouse Atomic Power Division
Y-12	Oak Ridge Y-12 Plant, Oak Ridge, Tennessee

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DOE/SNF/REP-002

1. INTRODUCTION

The Resource Conservation and Recovery Act (RCRA) Subtitle C regulatory program covers solid waste categorized as hazardous. Subtitle C is designed to provide cradle-to-grave control of hazardous waste. In order for the U.S. Department of Energy (DOE)-owned Spent Nuclear Fuel (SNF) to be subject to Subtitle C regulation, it must first be a solid waste as defined under 40 Code of Federal Regulations (CFR) 261.2, "Identification and Listing of Hazardous Waste," (Figure 1-1). A major consideration, which is clearly a regulatory applicability issue, is whether SNF is excluded from the RCRA definition of solid waste. This determination has not been officially made by DOE to date. It is clear, however, that source, byproduct, and special nuclear materials (SNM), which are components of SNF, are specifically excluded from RCRA [40 CFR §261.4(a)(4)].

In order to evaluate DOE-owned SNF types that may potentially exhibit characteristics similar to those of a hazardous waste under RCRA, this report summarizes the status of preliminary process knowledge characterization efforts being conducted at the Idaho National Engineering Laboratory (INEL). The efforts at the INEL are to evaluate such characteristics should SNF be determined a solid waste subject to RCRA regulations. This SNF process knowledge characterization effort is being conducted under the RCRA Applicability to SNF Program Outline under the INEL portion of the National Spent Fuel Program (EM-37/INEL).

1.1 Background to Evaluations of Potentially Hazardous Spent Nuclear Fuel

Process knowledge evaluations concerning potential RCRA characteristics of DOE-owned SNF have been undertaken with various levels of effort since 1988. Initial documented work conducted in 1989 and 1990 to evaluate potential RCRA characteristics of SNF focused on eight concerns, which represented those most significant from a RCRA standpoint: (1) reactivity of sodium bonding, (2) reactivity of uranium-carbide, (3) reactivity of uranium metal, (4) reactivity of hydrides, (5) toxicity of leachate from materials of construction (e.g., cladding, end pieces, spacers, springs, etc.), (6) leachability of cadmium and silver from melted control rods in disrupted SNF [e.g., Three Mile Island (TMI)-2], (7) toxicity of stable fission and activation products, and (8) whether SNF containing beryllium could be considered a RCRA-listed hazardous waste. Initial evaluations focused primarily on the identification of effected SNF types and interpretation of RCRA regulations. In addition, general mixed waste compliance issues were disclosed to U.S. Department of Energy Headquarters (DOE-HQ) personnel. Appendix A addresses these widespread mixed waste compliance issues as identified.

Focused efforts were again placed on this initiative in 1992 after the cessation of all reprocessing of DOE SNF. Foremost, existing data concerning the issues were reviewed to assess their validity and to qualitatively determine which concerns were most significant. Thereafter, information

Figure 1-1. Applicability of RCRA solid waste definition to DOE-owned spent nuclear fuel.

concerning the type, quantities, and location of SNF types having the greatest potential to exhibit a RCRA characteristic was gathered, and efforts were undertaken to evaluate potential characteristics in greater detail.

A comprehensive list of all DOE-owned SNF types, quantities, and locations was prepared based on data presented in the Draft SNF-Programmatic Environmental Impact Statement (EIS). These data were reorganized into 53 categories of similar SNF types. Further evaluation of these categories and ongoing efforts to verify the data reported resulted in both elimination of some categories as SNF and addition of others recently determined to be classified as SNF. The categories now total 55. These categories are being evaluated individually to document DOE process knowledge concerning the potential RCRA characteristics of each SNF category.

Efforts conducted since 1992 have also included a comprehensive evaluation of the applicability of SNF to RCRA. A brief summary of the evaluation is provided in Appendix B.

For the basis of this report, it is assumed that all nonfuel-bearing components will be removed from all nondisrupted SNF prior to final disposition. Nonfuel-bearing components are considered the extraneous hardware such as burnable poisons, end plates, control rods, reflectors, safety rods, etc. This is a very sound assumption due to DOE policy of waste minimization.

1.2 Process Knowledge

Initial process knowledge evaluations conducted in the late 1980s and early 1990s consisted of identifying known characteristics of DOE-owned SNF and major materials of construction that could potentially exhibit RCRA characteristics or be considered RCRA-listed (40 CFR §261.31-§261.33) if SNF were determined to be waste. These initial efforts focused on the obvious concerns for the major fuel types encountered within the DOE complex. In-depth evaluations of materials of construction were not undertaken at that time to quantify potential RCRA materials of concern.

Recent efforts undertaken since 1992 have included literature reviews, mass balance calculations, and analysis of unirradiated surrogate materials to develop process knowledge of the characteristics of DOE-owned SNF. Efforts have included:

- Reevaluation and documentation of the broad concerns
- Reevaluation of SNF types previously suspected to exhibit a RCRA characteristic
- Categorization of RCRA characteristics potentially exhibited by excluded SNM and byproduct material versus nonexcluded materials
- Identification of other DOE-owned SNF types that may exhibit these characteristics
- Categorization of DOE-owned SNF types by similar characteristics and materials of construction
- Documentation of SNF storage locations and quantity
- Preliminary investigation and documentation of individual SNF type materials of construction.

Information available about DOE-owned SNF is varied. Fuel received in the recent past is well characterized and documented. Older fuels, especially older research fuels, do not have the same level of information available. DOE traditionally evaluated SNF for reprocessing and recovery of uranium. Major considerations to ensure recovery included knowledge of uranium enrichment and cladding type. Considerations such as potential reactivity were also evaluated to ensure safe interim storage. Other materials of construction (e.g., burnable poisons, end piece construction, control rod makeup, etc.) were not always identified in detail. These now require evaluation to form information similar to U.S. Environmental Protection Agency (EPA) concepts of process knowledge.

Current DOE process knowledge is based on available information concerning:

- Type, quantity, and quality of materials of construction from manufacturer specifications, records, etc.
- Knowledge of material characteristics used in construction
- Location and history of use
- Material damage during use
- Post use or damage studies, if any
- Mass balance calculations
- Analysis of unirradiated surrogate samples
- Published information
- Post use storage.

Evaluations provided in this report use various combinations of this information to formulate conclusions. Additional evaluations are required to complete efforts for several fuel types.

DOE SNF consists of SNM and byproduct material considered excluded under RCRA [40 CFR §261.4(a)(4)] and various nonfuel-bearing components (e.g., cladding, bonding, assembly, etc.). Each of the RCRA characteristics (40 CFR §261.21 through §261.24) were considered in the process knowledge evaluations (see Appendix C). No DOE SNF is believed to exhibit the characteristic of corrosivity or ignitability.

1.3 Report Format

The process knowledge information developed for this report is presented in four sections for clarity. Section 2 presents a comprehensive list of all DOE-owned SNF types, quantities, and locations that was prepared from data used in the DRAFT SNF-Programmatic EIS. The basis for this list and the categorization of fuel types is discussed. Section 3 presents information on those categories of SNF with no identified RCRA concerns. It also addresses those issues initially identified as RCRA concerns, which have been resolved. Section 4 presents information on those initially identified concerns that have been resolved by preliminary data. Section 5 presents information on those initially identified concerns that require further evaluation.

A cross reference, listing DOE-owned SNF alphabetically with the appropriate category, and a listing of the DOE-owned SNF types in each category is provided in Appendix D.

2. CATEGORIZATION OF DOE-OWNED SNF

DOE owns in excess of 150 different types of SNF. These fuels were developed for and operated in many diverse types of reactors over the past 40 years. In addition, DOE has assumed ownership of certain commercial SNF. Reactor types used to generate this material can be divided into three main categories: reactors for SNM production, research and training, and power generation. Because of the nature of DOE research and development, many DOE fuels are unique, one-of-a-kind fuels.¹

Production fuels were used at the Savannah River Site (SRS) and at Hanford to produce nuclear materials for the Nation's defense programs. These include single pass and N Reactor fuels at Hanford, and K, L, and P Reactor fuels at SRS. Research and training fuels include both low and high enriched fuels from DOE and commercial reactors. Prominent fuels within this category include Light Water Reactor (LWR) fuels, Advanced Test Reactor (ATR) fuels, and High Temperature Gas-cooled Reactor (HTGR) fuels. The ATR was designed as an experimental test reactor that allowed the insertion of numerous experiments into the core. ATR fuel is contained in plates with aluminum cladding, and unlike Pressurized Water Reactors (PWR), the assemblies contain no control rods or other components. HTGR fuels were used for research as well as for concurrent power generation. These reactors used graphite as a moderator. LWR fuels comprise the majority of commercial fuels used for power generation. LWR fuels are used in PWR and Boiling Water Reactors (BWR), and are composed generically of fuel in an assembly. Schematics representing several DOE fuel types are provided in Appendix E. Navy fuel includes training and power generation fuels. Design information for Navy fuel is classified.

DOE historically categorized SNF into broad categories based on the fuel type, type of cladding, and fuel enrichment. Because of the cessation of reprocessing and the change in mission to condition SNF for disposal in a repository, efforts have been undertaken to recategorize DOE SNF into categories meaningful to the new mission. These categories form the basis to evaluate similar SNF types.

Initially, 38 categories of SNF were developed based on seven characteristics. As better information was received from the sites that were managing the various fuels, more refined evaluations were conducted. Additional evaluations conducted in 1994 resulted in 53 categories of SNF that served as the basis for earlier revisions of this report. A more recent refinement of this information resulted in 55 categories (Appendix F). The increase from 53 categories to 55 is due to some materials being reclassified as non-SNF, with others that had not been considered SNF in the past being classified as SNF. Characteristics used to develop categories include: fuel type, matrix type and material, cladding type, uranium-235 enrichment, burnup, potential hazardous materials and characteristics, and actinide content. Many of these categories include small volumes of research reactor SNF. SNF categories are summarized in Table 2-1. Fuel types, quantities, and locations of SNF within each category are provided in Appendix G.

Table 2-1. Categories of DOE-owned spent nuclear fuel.

Category	Description
1	High uranium-235 enrichment, zirconium cladding, high burnup, classified
2	High uranium-235 enrichment, uranium-zirconium-hydride fuel, stainless steel cladding, graphite plugs, low burnup, minor plutonium and molybdenum
3	High uranium-235 enrichment, uranium-zirconium-hydride fuel, zirconium cladding, graphite plugs, low burnup, minor molybdenum
4	High uranium-235 enrichment, uranium-zirconium-hydride fuel, declad, in aluminum cans, low burnup, minor molybdenum
5	High uranium-235 enrichment, uranium-oxide fuel, aluminum matrix, aluminum cladding, high burnup
6	High uranium-235 enrichment, uranium-oxide fuel, stainless steel matrix, stainless steel cladding, some titanium dioxide, range of burnup
7	High uranium-235 enrichment, mixed uranium- and plutonium-oxide fuel, stainless steel clad, metallic sodium bonded
8	High uranium-235 enrichment, uranium-oxide fuel, thorium-oxide in matrix, stainless steel cladding, uranium-233
9	High uranium-235 enrichment, uranium-oxide fuel, beryllium-magnesium-titanium-zirconium-yttrium ceramic, ternary fuel, ferrous cladding
10	High uranium-235 enrichment, uranium-oxide fuel, zirconium-oxide matrix, zirconium cladding, calcium, boron, minor molybdenum
11	High uranium-235 enrichment, uranium-oxide fuel, zirconium cladding
12	High uranium-235 enrichment, uranium-oxide powder or pellets, ceramic matrix of beryllium and calcium, declad
13	High uranium-235 enrichment, uranium and thorium-oxide fuel, microspheres in stainless steel pipe
14	High uranium-235 enrichment, uranium-aluminum fuel, aluminum matrix, aluminum cladding, low burnup
15	High uranium-235 enrichment, uranium-aluminum or uranium-alloy fuel, aluminum matrix, aluminum cladding, high burnup
16	High uranium-235 enrichment, uranium-molybdenum alloy fuel, zirconium, 1.9 kg (4.1 lb) plutonium, possible MoH, sodium bonded
17	High uranium-235 enrichment, uranium metal fuel, zirconium matrix, zirconium clad
18	High uranium-235 enrichment, uranium metal fuel, stainless steel clad, metallic sodium bonded, over 50 kg (110 lb) plutonium
19	High uranium-235 enrichment, uranium-carbide fuel, thorium carbide, coated particles, graphite matrix and clad, uranium-233
20	High uranium-235 enrichment, uranium-carbide fuel, possible graphite, zirconium clad

Table 2-1. (continued).

Category	Description
21	High uranium-235 enrichment, mixed uranium- and plutonium-carbide, stainless steel clad, metallic sodium bonded
22	High uranium-235 enrichment, uranium-oxide fuel, graphite matrix, zirconium cladding, low burnup
23	Low uranium-235 enrichment, uranium zirconium-hydride-fuel, aluminum cladding, graphite plugs, low burnup, minor plutonium and molybdenum
24	Low uranium-235 enrichment, uranium-zirconium-hydride fuel, stainless steel cladding, graphite plugs, low burnup, minor plutonium and molybdenum
25	Low uranium-235 enrichment, uranium-zirconium-hydride fuel, Incoloy® 800 cladding, graphite plugs, possible molybdenum
26	Low uranium-235 enrichment, uranium-oxide fuel, stainless steel cladding, high burnup
27	High uranium-235 enrichment, uranium-oxide fuel, aluminum cermet, aluminum cladding
28	Low uranium-235 enrichment, uranium-oxide fuel, zirconium-dioxide calcium-oxide ceramic matrix, ternary fuel, stainless steel cladding, low burnup
29	Low uranium-235 enrichment, uranium-oxide fuel, thorium-oxide matrix, stainless steel cladding, 1.54 kg (3.4 lb) uranium-233, low burnup
30	Low and natural uranium-235 enrichment, uranium-oxide fuel, zirconium matrix, zirconium cladding
31	Low uranium-235 enrichment, mixed uranium-plutonium-oxide fuel, zirconium cladding
32	Low uranium-235 enrichment, mixed uranium-plutonium-oxide fuel, stainless steel cladding, 300 kg (661 lb) plutonium, high burnup
33	Low uranium-235 enrichment, uranium-zirconium metal fuel, uranium-plutonium-zirconium matrix, with uranium dioxide, thorium dioxide, and uranium nitrate
34	Plutonium-oxide fuel, stainless steel cladding
35	Low uranium-235 enrichment, uranium-oxide fuel, zirconium cladding, lower burnup
36	Low uranium-235 enrichment, uranium-oxide fuel, ceramic matrix, zirconium cladding, high burnup, gadolinium oxide
37	Low uranium-235 enrichment, uranium-oxide fuel, thorium oxide, zirconium dioxide, calcium oxide ceramic matrix, zirconium cladding, contains U-233, 6.6 kg (14.5 lb) plutonium
38	Low uranium-235 enrichment, uranium-oxide fuel particles, carbon coated particles, zirconium cladding, stainless steel brackets, high burnup, 120 kg (264 lb) plutonium
39	Low uranium-235 enrichment, uranium-aluminum fuel, aluminum matrix, aluminum cladding
40	Low uranium-235 enrichment, uranium-molybdenum alloy fuel, stainless steel clad, metallic sodium bonded

Table 2-1. (continued).

Category	Description
41	Low or depleted uranium-235 enrichment, uranium metal fuel, zirconium matrix, zirconium clad
42	Low uranium-235 enrichment, uranium-thorium fuel, zirconium clad, low burnup
43	Low uranium-235 enrichment, uranium metal fuel, beryllium zirconium clad, cladding breaches, medium burnup, plutonium
44	Low uranium-235 enrichment, uranium metal fuel, molybdenum zirconium clad
45	Low uranium-235 enrichment, uranium metal fuel, stainless steel clad, metallic sodium bonded, plutonium
46	Low uranium-235 enrichment, uranium-carbide fuel, stainless steel clad, medium burnup, metallic sodium bonded
47	Low uranium-235 enrichment, uranium-silicon fuel, aluminum cermet, aluminum cladding
48	Low uranium-235 enrichment, molten salt matrix, lithium-beryllium-zirconium-uranium fluoride salts
49	Natural uranium-235 enrichment, uranium-oxide fuel, zirconium cladding, high burnup, plutonium
50	Natural uranium enrichment, uranium-oxide fuel, some zirconium cladding—some declad, in stainless steel tubes, high burnup
51	Low uranium-235 enrichment, uranium-oxide fuel, zirconium cladding, damaged fuel not intact, melted cadmium control rods
52	Natural uranium-235 enrichment, uranium-oxide fuel particles, carbon coated particles, zirconium cladding, stainless steel brackets, high burnup, 120 kg (265 lb) plutonium
53	Depleted uranium, uranium metal fuel, aluminum clad, low burnup, plutonium
54	Low uranium-235 enrichment, uranium nitride fuel, niobium cladding
55	Natural uranium, uranium metal block in stainless steel container

3. SPENT NUCLEAR FUEL WITH NO IDENTIFIED RCRA CHARACTERISTICS

Preliminary evaluations indicate that 40 of the 55 categories of DOE-owned SNF do not exhibit a RCRA characteristic. These 40 categories have also been dismissed from posing RCRA concerns due to fuel-bearing component related issues based on initial evaluation of those materials present. This equates to approximately 378.3 metric tons of heavy metal (MTHM) (14.3% by total mass of heavy metal or 24.5% by volume) of DOE-owned SNF inventory. From an interim storage or disposal standpoint, the number, which primarily affects size and cost, is the volumetric total.

The methods detailed by this report for evaluation of RCRA applicability to DOE-owned SNF are consistent with those that, as mentioned later in Section 4.1.2, have been used previously for resolution of RCRA applicability to both Naval and commercial fuels.

Navy fuel was designed as a very durable material to withstand the rigors of use on ocean-going vessels. A representative sample of this fuel was subjected to Toxicity Characteristic Leaching Procedure (TCLP) analysis by the Navy and found not to leach regulated levels of RCRA heavy metals (Appendix H). Evaluation of the cladding and fuel matrix composition indicates that there is no potential for the other RCRA characteristics (ignitability, corrosivity, and reactivity) being exhibited by Naval SNF.

Also, as discussed in Section 4.1.2, S. Cohen and Associates performed an evaluation of RCRA applicability to commercial SNF for the EPA.² They addressed in this evaluation the RCRA concerns pertaining to commercial SNF regarding leachability of stable fission products and the effects of irradiation on the bulk solubility of the materials of construction in commercial fuels.

To clarify the major points used in process knowledge evaluations of DOE-owned SNF, the SNF categories with no identified RCRA characteristics will be discussed below by fuel and matrix characteristics. For details regarding cladding and other materials of construction characteristics, see Section 5.3.

3.1 Fuel and Matrix Characteristics

The fuel and matrix materials (fuel meat) found within DOE-owned SNF that are not expected to exhibit a RCRA characteristic occur as nine major fuel types (Table 3-1). For the purposes of this discussion, fuel meat is considered the SNM (i.e., uranium or plutonium as oxides, hydrides, etc.) and the SNM matrix (e.g., ceramic, etc.). Enrichment is not a vital consideration in this discussion. Uranium and plutonium, their alloys and compounds (i.e., SNM), as well as their byproducts generated during the irradiation process are currently considered excluded under RCRA 40 CFR 261.4(a)4.

3.1.1 Uranium-Zirconium-Hydride Fuel

Uranium-zirconium-hydride (UZrH) fuels are typified by Training Reactor, Isotopes, General Atomic (TRIGA) fuels. Concern over the reactivity of UZrH fuels originated from the initial concern raised over the reactivity of uranium hydrides. A major difference between the uranium-zirconium-hydride concern and the uranium hydride concern is that UZrH exists as manufactured fuel meat. This fuel matrix material is a chemical compound existing only because of the zirconium and

Table 3-1. DOE fuel meat not expected to exhibit a RCRA characteristic.

Fuel type	Category
Navy (classified)	1
Uranium-zirconium-hydride	2, 3, 4, 23, 24, 25
Uranium-aluminum alloy	14, 15, 39
Uranium-molybdenum	16
Lithium-beryllium-zirconium-uranium salt	48
Mixed uranium-plutonium-oxide	31, 32
Mixed uranium-thorium oxide	42
Uranium-oxide	5, 6, 8, 9, 10, 11, 12, 13, 22, 26, 27, 28, 29, 30, 35, 36, 37, 38, 49, 50, 52
Plutonium-oxide	34
Uranium-zirconium metal	33
Uranium silicon	47

uranium. Uranium compounds are currently considered SNM.^a A position paper, establishing the DOE position that uranium compounds are excluded as SNM, has been developed by the National Spent Fuel Program [DOE/Office of Environmental Management (EM)-37] for consideration by the Nuclear Regulatory Commission (NRC) and the EPA.³ This paper established the position for exclusion of other uranium compounds such as uranium and thorium dicarbide (metallic carbide) and uranium hydrides. Details on the uranium hydrides concern and discussion on whether these fuels are excluded are covered in Section 4.1

In addition to the position that these fuels are excluded as SNM, the concern over the potential for UZrH SNF to form reactive products from possible corrosion or thermal disassociation during storage has been evaluated through process knowledge. Details of this evaluation are discussed below. Specifically, this concern pertains to the production of materials from aging UZrH fuel by the following potential mechanisms:

- Extensive corrosion of the UZrH by the basin water, forming significant amounts of potentially pyrophoric (reactive) UH_3 within the spent fuel matrix
- Release of highly reactive particulate UZr_x intermetallics due to corrosion of the fuel matrix

a. 42 USCS §2014—the term "*special nuclear material*" means (1) plutonium, uranium enriched in the isotope 233 or in the isotope 235, and any other material which the commission, pursuant to the provisions of Section 51 [42 USCS §2071], determines to be special nuclear material, but does not include source material; or (2) any material artificially enriched by any of the foregoing, but does not contain source material.

- Release of reactive quantities of hydrogen, either by extensive thermal disassociation of the metal hydride or by extensive corrosion of the fuel matrix.

A report summarizing the available literature in response to concern of RCRA reactivity of UZrH was prepared (Appendix I). Process knowledge evaluations concluded that UZrH is a very stable hydride, highly unlikely to have experienced extensive corrosion as a consequence of underwater storage. Because of the negligible extent of corrosion of the hydride matrix, the inventory of excess elemental zirconium has not been effected, and the amount of hydrogen produced by corrosion has been insignificant. Therefore, UZrH fuels would not be considered reactive according to RCRA (40 CFR §261.23) due to concerns of hazardous materials from corrosion of uranium-zirconium-hydride.

3.1.2 Uranium-Aluminum Alloy

UAl_x and UAl alloy SNF are typified by Materials Test Reactor (MTR) and ATR fuels. Aluminum fuels are also represented by targets at SRS. Significant concerns have not been raised over the potential for uranium-aluminum alloy fuel meat to exhibit a RCRA characteristic. Aluminum is not a RCRA-listed or characteristic hazardous waste. Therefore, additional investigations have not been pursued.

3.1.3 Lithium-Beryllium-Zirconium-Uranium Salt

Lithium-beryllium-zirconium-uranium molten salt fuel is represented by Molten Salt Reactor Experiment (MSRE) SNF located at the Oak Ridge National Laboratory (ORNL). It is composed of a uranium-fluoride salt fuel in a matrix of lithium, beryllium, and zirconium. Lithium occurs in this fuel as a nonmetallic form and would not be reactive. As previously discussed, there are neither apparent RCRA concerns over leachate products from zirconium, nor are there concerns over beryllium being present in this fuel in the form regulated as listed waste (40 CFR §261.33). Resolution of beryllium as listed waste is detailed in Section 3.2.1. Extensive assessments of the RCRA applicability to this fuel were conducted in the late 1980s through the early 1990s and resulted in an ORNL determination that the RCRA hazardous waste regulation does not apply to this fuel. The assessment details supporting this resolution are included in Appendix J.

3.1.4 Other Fuel Forms

The DOE fuel also occurs in several other very stable and nontoxic forms that would not be expected to exhibit a RCRA characteristic. These include mixed uranium-plutonium oxide, uranium oxide, plutonium oxide, uranium-zirconium metal, uranium thorium, and uranium silicon fuel meat. Oxide forms of uranium or plutonium are not expected to be reactive under RCRA. In addition, neither uranium-zirconium metal nor uranium silicon would be considered reactive. As previously discussed, there are no RCRA concerns over leachate products from zirconium. Likewise, silicon, a nonmetallic element, would not be expected to exhibit a RCRA characteristic in an alloy.

The DOE fuels also occur with other materials in the fuel matrix including zirconium oxide, molybdenum, polyethylene, graphite, graphite and silicone coatings (i.e., similar to paraffin hydrocarbons),⁴ ceramic beryllium and calcium, and other ceramic forms. None of these materials would be expected to exhibit a RCRA characteristic.

3.2 Resolved Concerns

As previously discussed, initial RCRA evaluations have focused on eight initially identified concerns affecting DOE-owned SNF. Of the eight initially identified RCRA concerns, two have been fully evaluated and resolved. These concerns and the details of their resolution are discussed below.

3.2.1 SNF Containing Beryllium As RCRA Listed Hazardous Waste

Beryllium occurs in the form of beryllium oxide within the fuel matrix of certain DOE-owned SNF types [e.g., Gas-Cooled Reactor Experiment (GCRE)—Category 9]. It is also seen in a ceramic Be and calcium fuel matrix (e.g., ACRR, GCRE—Category 12), as beryllium in MSRE (Category 48) and N-Reactor fuel (Category 43), in hardware (e.g., end caps—Category 43), as well as other uses.

RCRA regulates beryllium as a listed hazardous waste when it is discarded in an unused state as a commercial chemical product (40 CFR §261.33). Beryllium used in nuclear fuel would not be considered an unused product because it was used as a component in a manufactured item and, therefore, could no longer be considered a discarded commercial product. Furthermore, commercial chemical products, once combined with other ingredients, would not be considered a listed waste upon disposal provided they are not considered the sole active ingredient.

3.2.2 Potential Reactivity of Uranium Metal SNF

Reactivity of uranium metal SNF was initially identified as a concern because uranium metal can react pyrophorically when subjected to very specific conditioning involving very high surface exposure and temperatures. Reactivity, however, is not believed to be a concern with the uranium metal as is found in SNF. Even if uranium metal in the form found in SNF exhibited the potential of reacting pyrophorically, that characteristic would not force RCRA regulations of these fuel categories due to the exclusion provided as SNM under 40 CFR §261.4.(a)4.

4. CONCERNS RESOLVED BY PRELIMINARY DATA

Of the remaining six initially identified RCRA concerns regarding DOE-owned SNF, four are considered to be resolved based on preliminary data, as documented in this section. These resolutions are being addressed as resolved by preliminary data because that final resolution will be provided through very limited remaining analysis or through official regulatory or policy determinations. The positions on which the regulatory or policy determinations are based are detailed in separate position papers that have been developed by the National Spent Nuclear Fuel Program (DOE EM-37) for consideration by the NRC and EPA. The analytical data collection efforts required are currently underway and are expected to definitively resolve those concerns.

The two remaining initially identified RCRA concerns require further evaluation and are addressed in detail in Section 5.

4.1 Reactivity of Uranium Hydrides

Recent attention has been centered around the stability of uranium metal SNF and the potential for these fuels to form reactive uranium hydrides during extended underwater storage, followed by drying. Initial process knowledge evaluations considered uranium metal SNF reactive only due to potential pyrophoricity, not due to the potential for hydride formation.

Concern of uranium hydrides involves the same categories of SNF as the reactivity of uranium metal concern which are excluded as SNM. Therefore, dialogue with regulators is required to determine whether uranium hydrides resulting from a reaction of uranium metal (a material excluded as SNM) can also be excluded. Further evaluations of these fuels and the reactivity characteristic is ongoing in parallel with these discussions. Status of the determination of applicability of the SNM exclusion as well as results of ongoing evaluations of the reactivity of uranium hydrides will be included in future versions of this report.

Seven of the 55 categories of SNF represent uranium metal fuels. However, two categories of uranium metal fuels (18 and 45) are sodium-bonded fuels and have the potential of exhibiting the characteristic of reactivity due to the metallic sodium-bonding agent. These sodium-bonded fuels are discussed later in Section 5.3. Specific information concerning the uranium metal fuels, which present the concern regarding formation of reactive uranium hydrides is summarized below.

Category 17. High uranium-235 enrichment, uranium metal fuel, zirconium matrix, zirconium clad

There are two SNF types represented in this category; heavy water components test reactor (HWCTR) high-enriched uranium and ORNL (S1W). Both fuels are located in the Receiving Basin for Off-Site Fuel (RBOF) Facility at SRS.

Category 41. Low or depleted uranium-235 enrichment, uranium metal fuel, zirconium matrix, zirconium clad

Only one fuel type exists in Category 41 (HWCTR low-enriched uranium). This fuel (1.8 MTHM) is stored at RBOF at SRS.

Category 43. Low uranium-235 enrichment, uranium metal fuel, beryllium zirconium clad, cladding breaches, medium burnup, plutonium

N Reactor fuel represents the only fuel in Category 43. This fuel type makes up the single largest fuel type within DOE (2100.06 MTHM). N Reactor fuel is stored at Hanford in the K East and K West Basins as well as in plutonium uranium extraction (PUREX).

Category 44. Low uranium-235 enrichment, uranium metal fuel, molybdenum zirconium clad

Only one fuel type exists in Category 44 (SPEC Orme). This fuel (0.002 MTHM) is stored in CPP-603 at the INEL.

Category 53. Depleted uranium, uranium metal fuel, aluminum clad, low burnup, plutonium

SPR fuel represents the only fuel in Category 53 (3.37 MTHM). SPR fuel is stored at Hanford in the K East and K West Basins as well as in PUREX. SPR is an aluminum clad fuel.

4.2 Reactivity of Metallic Carbide SNF

Uranium and thorium-dicarbide (UC_2 and ThC_2 respectively), and mixed uranium-plutonium-carbide compounds are currently considered to be SNM excluded under 40 CFR §261.4(a)(4). The official exclusion of these materials from regulation as RCRA hazardous waste is pending the outcome of a definitive determination by the joint DOE/EPA Mixed Waste and Materials Management Workgroup, regarding the applicability of the exclusion to radioactive compounds. The position paper regarding the regulatory determination has been submitted to DOE HQ (EM-37) for consideration by the NRC and EPA for final resolution of this concern.³ This position is further substantiated by a recent NRC Staff Response regarding exclusion of a uranium compound as source material.⁵

Uranium and thorium dicarbide occur as stoichiometric molecules (compounds) made up of uranium and thorium covalently bonded with carbon. Unlike common mixed waste (i.e., waste that contains both hazardous waste and source, special nuclear material or byproduct material subject to the Atomic Energy Act of 1954), these compounds exist solely due to the bonding of carbon and the uranium or thorium (i.e., SNM).

Although additional regulatory discussions will be required, carbide SNF, which may be reactive due to the SNM, is considered excluded from RCRA regulation. Carbide fuels that contain other nonspecial nuclear material, such as sodium (Categories 21 and 46), would require dual management under the Atomic Energy Act and current RCRA regulations if determined to be a solid waste. Detailed discussion concerning fuels containing sodium is found in Section 5.2.

In parallel with the aforementioned discussion, characteristics of SNF that may be similar to the RCRA characteristics of reactivity exhibited by uranium, thorium, and mixed carbide fuel meat are discussed separately in the following sections.

Carbide fuel meat (i.e., uranium and thorium dicarbide) that may exhibit the RCRA characteristic of reactivity includes: Peach Bottom 1, Peach Bottom 2, SRE-UC, ACN-1, FC-1, AC-3, EBR-2, CX, and Fort St. Vrain. These fuels are represented in four categories (19, 20, 21, and 46). Peach Bottom 1, Peach Bottom 2, and Fort St. Vrain are primarily stored at the Idaho Chemical Processing Plant (ICPP) at the INEL, although significant amounts of Fort St. Vrain SNF

still reside at the reactor site. A small amount of Peach Bottom fuel is still located at ORNL. SRE-UC fuel is stored in the RBOF at SRS, CX is located at Sandia National Laboratory (SNL), EBR-2 is located at Los Alamos National Laboratory (LANL), while the remaining carbide fuels are located in the Fast Flux Test Facility (FFTF) at the Hanford site.

Specific information concerning the effected storage facilities and quantities of carbide fuels (i.e., MTHM) is summarized in Table 4-1.

4.3 Toxicity of Stable Fission and Activation Products

Initial issues raised in the late 1980s concerning RCRA and SNF included the potential leachability of fission and activation products in DOE SNF. Although these products are currently considered excluded from the definition of a solid waste under RCRA as byproduct material [40 CFR §261.4(a)(4)], concern over fission and activation products that appear in the EPA list of toxicity characteristic waste (40 CFR §261.24) raised questions.

Fission products (i.e., byproduct material) that result from the burnup of uranium (or other SNM), and activation products that result from irradiation of cladding, etc., (i.e., also byproduct material) decay over time resulting in many stable, nonradioactive elements. Although many fission products may take hundreds of years to decay to stable elements, other fission products may decay to stable elements within months or years of irradiation. DOE indicated in their Byproduct Material Rule (10 CFR §962, "Byproduct Material") that only the actual radionuclide is considered byproduct material excluded from RCRA. Therefore, questions focused on whether these stable elements would be considered excluded and at what concentration they may occur in SNF.

Common stable fission products in SNF listed in 40 CFR §261.24 include arsenic, barium, cadmium, lead, selenium, and silver. The previously mentioned evaluation by S. Cohen & Associates projected potential concentrations of stable fission and activation products in commercial SNF using ORIGEN® Codes, a computer simulation of fission and activation product generation and decay. The Cohen report indicated that commercial SNF would not be expected to fail the EPA TCLP due to regulated RCRA metals in the fuel meat. Similarly, the U.S. Navy has performed process knowledge calculations of its SNF and concluded that it would also be considered nonhazardous if evaluated under RCRA (Appendix H).

Certain DOE-owned SNF is similar to fuels reported by Cohen & Associates and the Navy in that the fuels do not have sufficient concentrations of regulated metals to be of concern. Preliminary process knowledge based on these evaluations indicates that stable fission and activation products in DOE-owned SNF are not expected to occur at leachable levels sufficient to fail TCLP.

Results of the calculated TCLP concentrations of metals listed in 40 CFR §261.24 are provided for ATR fuel. These calculations are based on fission products from the uranium aluminide fuel (SNM) ($TCLP_{UAI}$), as well as for an ATR fuel element ($TCLP_{ATR}$). Assuming that 100% of available metals were leached from the uranium fission products ($TCLP_{UAI}$), concentrations of silver, barium, cadmium, and selenium appear at levels greater than those listed in 40 CFR §261.24. Although it is not known to what extent the fuel meat alone would leach, it is unrealistic to assume that 100% of available metals would leach from a sample of fuel meat (see Table 4-2).

Because the leachability of a representative sample of spent fuel would be evaluated based on the "universe, or whole" (i.e., including the cladding, etc.), not just on the fuel meat, the mass of the other ATR element components must be considered. In the ATR example, the mass of ATR element

Table 4-1. Metallic carbide spent nuclear fuel.

Fuel type	Location		Metric tons of heavy metal
	Site	Facility	
Fort St. Vrain Reactor (FSVR)	INEL	CPP-IFS	8.6
FSVR	Public Service of Colorado		16
Peach Bottom 1	INEL	CPP-IFS	0.046
		CPP-749	1.564
Peach Bottom 2	INEL	CPP-IFS	1.3
Peach Bottom	ORNL	Building 7829	0.003
SRE-UC	SRS	RBOF	0.044
EBR-2	LANL		— ^a
ACN-1	Hanford	FFTF	— ^a
FC-1	Hanford	FFTF	— ^a
AC-3	Hanford	FFTF	0.1
CX	Sandia		0.02
Total metallic carbide SNF			27.677+ ^a

a. Unknown small quantity.

Table 4-2. Summary of ppm and the maximum TCLP concentration of each element for an ATR fuel element.^a

Element	PPM _{UAI} (μg/g)	PPM _{ATR} (μg/g)	TCLP _{UAI} (mg/L)	TCLP _{ATR} (mg/L)	Regulated level §261.24 (mg/L)
Silver	105.1	8.8	5.3	0.4	5
Arsenic	2.5	0.2	0.1	0.01	5
Barium	25,596.5	2,140.8	1,279.8	107.0	100
Cadmium	282.3	23.6	14.1	1.2	1
Selenium	945.0	79.0	47.2	4.0	1

a. The calculated TCLP concentrations provided are based on the assumption that 100% of the element is leached out of the sample.

components minus the mass of the end boxes was used since the end boxes are removed prior to storage. Because there are likely only traces of regulated metals in aluminum cladding of an ATR fuel element, the additional mass of material in a representative sample would cause the actual results to decrease (see Table 4-2). Although calculated results ($TCLP_{ATR}$) exceed the levels listed in 40 CFR §261.24 for barium, cadmium, and selenium, this result again assumes 100% leachability of the elements. Based on TCLP tests conducted on unirradiated stainless steel and other metals, leaching rates do not approach this figure.

For example, Type 304L stainless steel (18.5% chromium) was found to leach only 0.647 mg/L (0.35%) of available chromium when reduced in size to 0.6 cm ($\approx 1/4$ in.) pieces [a particle size reduction below than the required 0.95 cm (0.37 in.)]. Similarly, silver-indium-cadmium alloy control rod material (80-15-5%) was found to leach 0.049% and 0.5%, respectively, of the available silver and cadmium (see Sections 5.3 and 5.4). Neither of these examples directly apply to the leachability of metals from fuel meat since different metals and alloys have different solubilities. They do provide indirect, qualitative evidence that 100% leachability of available elements is unrealistic. The leach rate of stable fission products from an ATR element would have to be fifty times greater than the maximum observed leach rate (0.5%) mentioned above in order to fail. Therefore, it does not seem likely that stable fission and activation products result in SNF being RCRA characteristically hazardous.

4.4 Toxicity of Leachate from Materials of Construction

As early evaluations of the types and categories of SNF within the inventory of DOE-owned SNF were initiated, concern was raised over the possibility that the material from which the various components and hardware within a fuel assembly were constructed may contain constituents that could potentially exhibit the RCRA characteristic of toxicity. The scope of potential impact of this concern becomes less extensive when the field of materials of construction is narrowed to primarily cladding. In most instances, the current storage configuration of SNF is as fuel meat with cladding intact. Removal of the extraneous hardware and components (nonfuel bearing components) prior to storage of the SNF is common practice. There are some cases, however, where hardware and components other than cladding have been left intact due to either storage or transportation safety concerns or damage to the assembly due to disruption while in the reactor. If materials, such as control rods, are not removed due to damage or disruption, this does not implicate that particular SNF as being a RCRA hazardous waste unless later discovered to be so due to a characteristic material.

Ongoing activities in support of final resolution of this concern include further review of the byproduct exclusion provided under 40 CFR §261.4(A)(4). The exclusion is for byproduct material as defined in the Atomic Energy Act. A position paper, establishing the DOE position regarding the exclusion of materials of construction and nonfuel bearing components as byproduct material will be developed and submitted to DOE in support of the final resolution of this issue.

Further evaluation of this concern includes closer examination through process knowledge, and if required, analysis of carefully selected materials. Preliminary evaluations and the need for future evaluations are detailed in Section 4.4.1.2. Results of these evaluations and analyses will be included in future versions of this report.

Data regarding the nonfuel bearing components has been included herein for information only. It is yet to be determined whether these materials and components will be included as materials to be managed and characterized as SNF.

4.4.1 Cladding Properties

Identified cladding types for DOE-owned SNF and the associated fuel categories are summarized in Table 4-3. Most DOE-owned SNF is clad with aluminum, Hastelloy,[®] stainless steel, or zircaloy. Only a small fraction of SNF is represented by Incoloy,[®] Nichrome,[®] nickel plated, or other cladding types. Similarly, certain fuels are declad, or there is insufficient information to determine the cladding type. Therefore, summary information in Table 4-4 should be interpreted carefully.

Various unirradiated steels and alloys have been analyzed at the INEL using the TCLP test. Analytical results summarizing the data and findings is included in a preliminary report (Appendix K). Analysis was performed on Types 304L, 308L, 304, 316, and 347 stainless steel; Hastelloy G-30, C-22, C-4, and C-276; Inconel[®] 625; Nitronic 33, and 50; Incoloy 825, Carpenter 20 CB-3 and 20; and Monel 400. Two of the samples (T-304 and Carpenter 20) were found to leach chromium above RCRA TCLP limits when the sample was prepared into fine shavings. Samples of these same metals prepared into 0.6-cm (1/4-in.) squares [still below the maximum particle size of 0.95 cm (0.37 in.) per TCLP protocol], did not fail TCLP. Therefore, SNF clad with these materials would not be expected to exhibit the RCRA toxicity characteristic due to leaching of RCRA metals from the cladding. Likewise, any compounds made of these materials would not fail TCLP.

Table 4-3. Spent nuclear fuel cladding types.

Cladding type	Category
Unspecified aluminum	2, 5, 15, 13, 14, 22, 23, 24, 27, 39, 47
1100 aluminum	15, 14, 23
6061 aluminum	5, 15, 14, 39
8001 aluminum	13, 53
Ferrous	9
Incoloy [®] 800	25
Nichrome [®]	9
Nickel plated	6
Type 304 and 304L stainless steel	6, 8, 9, 13, 22, 24, 28, 35
Type 316L stainless steel	6
Type 347 stainless steel	6
Unspecified stainless steel	2, 3, 6, 24, 26, 29, 32, 34, 35, 44, 49,
Hastelloy [®]	2, 4
Hastelloy [®] X	9
Zirconium alloy (zircaloy)	3, 10, 11, 16, 22, 26, 31, 32, 35, 36, 37, 38, 41, 42, 43, 49, 50, 51, 52

Table 4-4. Other identified materials.

Component—material	Fuel name	Category
Absorber control element—cobalt (Co)	OSIRIS	15
Blanket rods—stainless steel (SS)	Fermi Core I & II	16
Bolts etc.—SS	CANDU	35
	Commercial	35
Burnable poison—boron carbide (B_4C)	ATR	15
Burnable poison—boron	OSIRIS	15
Burnable poison—SS	Oconee-1	35
	Oconee-1(PWR)	35
Burnable poison—erbium	TRIGA FLIP-2	
Burnable poison—SS and zircaloy	HB Robinson	49
Burnable poison/safety/regulating rods, U_2O_3 in aluminum (Al), tantalum in Al	HFIR	5
Components—SS	MURR	15
Control blade (Palisades)—silver-indium-cadmium (Ag-In-Cd)	Calvert Cliffs(PWR)	49
Control rod assembly—Inconel®	Calvert Cliffs(PWR)	49
Control rods—Ag alloy	HB Robinson	35, 49
	HB Robinson(PWR)	35, 49
Control rods—Ag-In-Cd	Con Yankee	35
	IEA-R1	15
	Oconee-1	35, 49
	Oconee-1(PWR)	35
	Calvert Cliffs(PWR)	49
	TMI-2	51
Control rods—borated graphite	TRIGA AI	23
	TRIGA SST	24
Control rods—boron/SS	JRR-4	15
	KUR	15
Control rods—boron w/zirconium	ERR	8
Control rods—boron and graphite	SPR	53
Control rods—boron, SS clad, B_4C , aluminum oxide (Al_2O_3) pellets	Pathfinder	6
Control rods— B_4C	Fermi Core I & II	16
	TRIGA	24
Control rods— B_4C , Al_2O_3 , Al cladding	DOW-TRIGA	24
Control rods— B_4C with SS clad	TRIGA	24

Table 4-4. (continued).

Component—material	Fuel name	Category
Control rods—B ₄ C with SS clad on an Al follower	BORAX V	6
Control rods—Cd (also Cd cylinder)	DR-3	15
	FJR-2	15
	La Relna	15
	RA-3/RA-6	
Control rods—Cd alloy	Loss-of-Fluid Test (LOFT) FP-2	51
	LOFT UD	51
	PBF SFD 1-1	51
	PBF SFD 1-4	51
Control rods—Cd in Al tubes/Cd and Co rod material	NRU	15
Control rods—Cd clad in Al	SAFARI	15
Control rods—gadolinium oxide-aluminum oxide (Gd ₂ O ₃ -Al ₂ O ₃)	MSRE	48
Control rods—hafnium	JMTR	14
	ATRA	15
	ATR	15
	ORPHEE	15
	Scarabee	15
Control rods—haynes-25 alloy, control rods—SS	RA-3/RA-6	15
Control rods—SS/Cd	HIFAR	15
Control rods—SS clad europium oxide (Eu ₂ O ₃) in SS, zirconium boride (ZrB ₂) poison	SM-1A	6
Cd foil poison inside of outer liner	ML-1	9
Cd welded between signal arm	FJR-2	15
Control rods—Cd (also Cd cylinder)	DR-3	15
Poison—end boxes—zircaloy-2	Shippingport	38
End caps—zircaloy-2 with beryllium	N Reactor	43
Fixtures—3 magnesium oxide pellets on bottom	GCRE	9
1 beryllium oxide pellet on top	GCRE pellets	12
Frames and cover plates made of 6061 Al	SRS U-233	13
Fuel channels—zircaloy	Peach Bottom	35
	Quad City-1 (BWR)	35
Guide tubes—SS	Ginna (PWR)	35
Poison—Ag-In-Cd encased in SS	Calvert Cliffs(PWR)	49

Table 4-4. (continued).

Component—material	Fuel name	Category
Poison rods—beryllium (Be)	JMTR	14
Poison—boron steel	VBWR	6
	ERR	8
Poison rods—boro-silicate	HB Robinson	35, 49
	HB Robinson(PWR)	35
Poison-B ₄ C, uranium oxide-beryllium oxide (UO ₂ -BeO) w/niobium cups, nickel reflectors	ACRR	9
Pulse rods—Al cladding	TRIGA FLIP	2
Pulse rods—borated graphite	TRIGA	24
Pulse rods—boron carbide impregnated graphite	U.S. Geol-TRIGA	24
Pulse rods—borated graphite with Al cladding	TRIGA	24
Pulse rods—B ₄ C	PBF driver	28
Pulse rods—B ₄ C with SS cladding	TRIGA	24
Pulse rods—Cd	ARMF/CFRMF	14
Reflectors—graphite	TRIGA AI	23
	TRIGA AL OSU	23
	TRIGA	24
Regulating rods—Al with Cd clad	ARMF	15
Regulating rods—boron carbide impregnated graphite	U.S. Geol-TRIGA	24
Regulating rods—B ₄ C	PBF Driver	28
Regulating rods—B ₄ C with SS cladding	TRIGA	24
Regulating rods—B ₄ C clad with Cd and Al	FMRB	15
Regulating rods—Cd with Al clad	ARMF/CFRMF	14
	BR-2	15
	MIT	15
Regulating Rods—SS	ASTRA	15
	FRG-2	15
	GRR-1	15
	HOR	15
	IRR-1	15
	TRR-1	15
	U of Virginia	15
	TRIGA	24
	Nereide	39
	U of Michigan	39
Regulating rods—UO ₂ in polyethylene	AGN	30

Table 4-4. (continued).

Component—material	Fuel name	Category
Regulating and control rods—molybdenum	HPRR	6
Rod followed by fuel section—Cd	R2	15
Safety and regulating rods—boron in SS	BSR	14
	U of Virginia	15
	U of Michigan	39
Safety/regulating rods—borated graphite clad with SS	TRIGA FLIP	2
Safety blades—Al with boral cladding	Sterling Forest	15
	THOR	15
Safety rods—boron carbide impregnated graphite	U.S. Geol-TRIGA	24
Safety rods—borated graphite	TRIGA	24
Safety rods—boron in SS	MIT	15
Safety rods—B ₄ C	HOR	15
Safety rods—B ₄ C with SS cladding	TRIGA	24
Safety rods—B ₄ C and Al with SS cladding	SILOE	15
Safety rods—B ₄ C and Cd	ASTRA	15
Safety rods—B ₄ C and Cd with SS cladding	TRR-1	15
Safety rods—B ₄ C clad with Cd and Al	FMRB	15
	R2-0	15
Safety rods—Cd with Al clad	ARMF/CFRMF	14
	ARMF	15
Safety rods—UO ₂ in polyethylene	AGN	30
Safety sheets—boral with Al cladding	PRR-1	15
Shim safety blades—SS, boron with Al extensions	OMEGA-W	14
Shim safety rods—B ₄ C	GRR-1	15
	IRR-1	15
	ATR recycle	15
Shim safety rods—Al clad	BR-2	15
Shim safety rods—Be clad	BR-2	15
Shim safety rods—Cd	HFR	15
Shim safety rods—Cd in SS	FJR-1	15
Shroud—Cd	HFIR	5

Table 4-4. (continued).

Component—material	Fuel name	Category
Side plates—Al	BSR	14
	ORR	14
	ATR	15
	ATR recycle	15
	MURR	15
Spacers—zircaloy, Inconel, [®] SS	CANDU	35
	Commercial	35
Spacer tubes—Al	SRE	8
Springs—Inconel [®]	CANDU	35
	Commercial	35
Test assembly thermocouple w/zirconium dioxide disk	GCRE pellets	12
Tie plates—SS	Cooper (BWR)	49

4.4.1.1 Aluminum Clad Fuels. Aluminum is a common cladding material in many domestic and foreign reactor fuels, including MTR fuels. Aluminum cladding is also common in DOE research fuels, such as ATR. A schematic of an ATR element is provided in Appendix E. Concerns have not been raised over the aluminum cladding. Aluminum is not a RCRA-listed or toxic metal, therefore additional investigations have not been pursued.

4.4.1.2 Stainless Steel Clad Fuels. Issues concerning the leachability of significant amounts of chromium and potentially other regulated trace metals from stainless steel were raised in the late 1980s. Analysis of Type 304L stainless steel is used as the basis for process knowledge for materials of construction. This is because this material has been identified as the material of construction highest in content of a RCRA hazardous constituent and is a predominant material in structural components of SNF. Type 304L stainless steel has a chromium content of approximately 18.5% by weight.

Process knowledge evaluations of stainless steel clad SNF have included mass balance calculations of the amounts of chromium in the cladding and other components of SNF, as well as use of existing data from analysis of unirradiated stainless steel.

As discussed in Section 4.3, evaluations concerning the leachability of unirradiated stainless steel and other metals were conducted at the INEL in 1992–1993 and provide the most direct information. Results varied with particle size reduction techniques (i.e., milling versus cutting into pieces $\approx 1/4$ in.). As expected, higher concentrations were identified for samples with smaller particle size. Analytical results indicated that unirradiated Type 304L stainless steel that is reduced in size to $\approx 1/4$ in. (i.e., more conservative than the TCLP particle size reduction requirements) does not leach RCRA-regulated metals above the TCLP limits. Chromium and barium were the only RCRA metals detected at a quantifiable level (0.016 and 0.647 mg/L respectively).

Further process knowledge evaluations were conducted to determine the estimated concentration of chromium that might be leached from stainless steel in a complete SNF assembly. Since EPA regulations concerning sampling call for a "representative sample,"^b this procedure is valid because the entire assembly is the universe or whole. For the purposes of this evaluation, a Shippingport II assembly, which is composed of $\approx 15.5\%$ stainless steel, was used as an example of SNF with a high content.⁴ Leachability rates of chromium from unirradiated Type 304L stainless steel were used to estimate the concentration of all chromium that could be leached from the materials of construction of the entire assembly. Chromium potentially present at trace levels within the fuel matrix (i.e., material excluded under 40 CFR §261.4(a)(4)), was not considered in this evaluation. Results of this calculation estimated 0.101 mg/L of chromium would leach from a representative sample of the entire assembly. Based on the foregoing, SNF types that are clad with stainless steel would not exceed the TCLP limit for chromium (5.0 mg/L). This is true even considering the entire stainless steel assembly.

Analyses of irradiated stainless steel have not been performed, and therefore, preliminary data assumes that significant changes to the material that could increase the leachability have not occurred. As previously mentioned, Cohen and Associates, who conducted a process knowledge evaluation of commercial SNF for the EPA in 1990, indicated in their report that: "Since irradiation is unlikely to affect the bulk solubility of these materials, one would expect that the irradiated cladding and structural components would not be significantly more likely to fail the TCLP than unirradiated material." Although this statement may be based on actual tests, there are no known TCLP studies found in the applicable literature, that have been performed on irradiated stainless steel.

Because concern about the effects of irradiation on materials of construction continues to be raised, future post-irradiation analysis of carefully selected materials are planned. However, this planned analysis is contingent on continued funding.

4.4.1.3 Hastelloy® Clad Fuels. Hastelloy® was used in the cladding of only four fuel types (GCRE, ML-1, SNAP-10, SNAP). Hastelloy is a trademark name for a series of high-strength, nickel based, corrosion resistant alloys.⁴ Based on the analytical results of samples obtained from Hastelloy G-30, C-22, C-4, and C-276, the cladding alone would not leach hazardous levels of RCRA-regulated metals. Therefore, the entire assembly would not be expected to fail TCLP due to the cladding.

4.4.1.4 Incoloy® Clad Fuels. Incoloy® was used in the cladding of only two fuel types (PRR-1, located in the Philippines; TRIGA fuel, located in Romania). Incoloy is a trademark name for a group of corrosion resistant alloys of nickel, iron and chromium.⁴ Based on the analytical results of a sample obtained from Incoloy 825, the cladding alone would not leach hazardous levels of RCRA regulated metals.

4.4.1.5 Nichrome® Clad SNF. Nichrome is a trademark for an alloy containing 60% nickel, 24% iron, 16% chromium and 1% carbon.⁴ Nichrome® is found in only one type of SNF (HTRE). This alloy is reported to offer good resistance and is, therefore, believed to not leach chromium in levels above RCRA limits. This presumption is based on the concentration of chromium (16%) in Nichrome® being less than that found in Type 304L stainless steel (18.5%), which did not fail TCLP.

b. "Representative sample" means a sample of a universe or whole (e.g., waste pile, lagoon, groundwater) which can be expected to exhibit the average properties of the universe or whole (40 CFR §260.10).

4.4.1.6 Ferrous Clad Fuels. Ferrous clad SNF is represented by an experimental fuel (ACRR) located at SNL. Although definitive information has not been obtained, the cladding of this SNF is suspected to be stainless steel; therefore, it has been listed as ferrous clad. There are no apparent RCRA concerns with this cladding.

4.4.1.7 Nickel Plated Cladding. Only one fuel type (HPRR) has been encountered that includes nickel plated cladding. This fuel is located at the Oak Ridge Y-12 Plant. No additional information is currently available as to whether the nickel is plated to the fuel matrix or if it is plated to another metal (such as stainless steel) that may form the actual cladding. However, there are no apparent RCRA concerns with this cladding.

4.4.2 Other Materials of Construction

Numerous other materials of construction or nonfuel bearing components have been documented, although significant amounts of data are still required to document complete process knowledge. Identified components of fuel assemblies include items such as burnable poisons, end plates, control rods, reflectors, safety rods, etc. Identified components, their materials of construction, the fuel type, and fuel category are summarized in Table 4-4. Most materials of construction would not be expected to leach RCRA-regulated metals. However, silver and cadmium are both recognized RCRA-regulated metals and are represented in a number of components. Furthermore, many of these components are removed following reactor service and prior to being placed in interim storage.

4.4.2.1 Control Rods. Control Rods (including pulse, safety, regulating, and shim rods) used to moderate nuclear reactions often contain significant amounts of cadmium and silver. Rods are believed to have been removed from SNF assemblies in all cases due to their value.

Cadmium, being a readily mobilized metal, was of specific concern. Control rods containing cadmium are reported in several configurations; although the most commonly observed is a stainless steel clad silver-indium-cadmium alloy. Based on current information, most control rods encountered are a stainless steel clad alloy consisting of 80% silver, 15% indium, and 5% cadmium. Other composite control rods containing cadmium have been identified at SRS and are composed of a cadmium-covered aluminum core encapsulated in Type 304L stainless steel (0.75-in. diameter core, 0.05-in. cadmium, 0.049-in. stainless steel). Composite control rods at SRS have been shown to leach significant amounts of cadmium (1,473 mg/L)⁴ and are, therefore, removed from the fuel prior to storage and managed as a mixed waste. Other identified control rod materials are listed in Table 4-4.

TCLP analysis was conducted on a sample of an unirradiated silver-indium-cadmium alloy control rod. The analysis results were found to not leach RCRA-regulated levels of silver or cadmium (Appendix L). It is currently not known whether irradiated control rods would leach these metals at an increased rate. A more detailed discussion of the analysis results of the sample as well as future planned analysis on irradiated samples of control rod material is provided in Section 5.1.

4.4.2.2 Poisons. Nuclear poisons may occur as integral components assembled within fuel elements or as part of the fuel matrix. Most burnable poisons reported are constructed of boron, boron carbide, boron silicate, and borated stainless steel.

As with control rods, mechanical removal of poisons that are considered hazardous under RCRA would remove potential RCRA concerns from the SNF.

4.4.2.3 Other Components. Other identified components do not generally appear to raise RCRA concerns. These components are generally constructed of stainless steel, zircaloy, aluminum, beryllium, and Inconel.[®] Exceptions to this reported in the data include a cadmium shroud (HFIR) and cadmium welded between a signal arm (FJR-2). Additional data concerning the materials of construction are required to completely assess potential RCRA characteristics of DOE-owned SNF.

5. ISSUES REQUIRING FURTHER EVALUATION

Those initially identified concerns that require further evaluation as non-RCRA concerns are detailed in this section. These two concerns include the potential toxicity of disrupted SNF and the potential reactivity of sodium-bonded SNF. Their resolution will be obtained through a combination of ongoing discussions with regulatory agencies, continued process knowledge evaluation, and future analyses. It is important to note that final resolution of these issues, where extensive analytical efforts are required, are dependent on funding availability.

The combination of select sampling and analysis and extensive process knowledge was selected as the favorable characterization method for resolution of these and other SNF concerns. This method allows for minimization of radiological exposure of personnel and minimizes generation of additional waste streams that are typical in sampling and analysis procedures.

5.1 Uranium Nitride SNF

This SNF was added to the DOE SNF categories (Category 54) within days of completion of this revision of this report. Therefore, adequate information has yet to be gathered for evaluation of whether there is a RCRA concern regarding this fuel. Thorough evaluation of this fuel will be conducted and reported in the next revision of this report.

5.2 Toxicity of Disrupted SNF

Currently five types of DOE SNF have the potential of exhibiting the RCRA characteristic of toxicity (i.e., leachable metals, 40 CFR §261.24) from materials not excluded under 40 CFR §261.4(a)(4). The five types are all in Category 51. These SNF types are represented by fuels that sustained severe damage either due to accidents or as the result of reactor and fuel tests (referred to as disrupted SNF). Primary RCRA concerns with these fuel types focus on the presence of melted control rods that contain significant amounts of silver and cadmium.

Control rods containing cadmium and silver are generally known to be removed from SNF assemblies prior to shipment and storage at DOE facilities. However, they can not be readily removed from disrupted SNF. Therefore, disrupted SNF types have been initially suspected as potentially leaching cadmium and silver at levels above the RCRA TCLP limitations for a hazardous waste.

To assess the potential for disrupted SNF to exhibit RCRA characteristic, a sample of a control rod was obtained from Babcock and Wilcox for analysis. The sample control rod was made of an alloy composed of 80% silver, 15% indium, and 5% cadmium. Stainless steel cladding was not present on the sample obtained. Analysis was performed in accordance with the *EPA Test Methods For Evaluating Solid Wastes*, Third Edition. The analysis was completed April 25, 1994. The unirradiated control rod did not leach RCRA metals at concentrations that would make it hazardous. Analytical results for cadmium (0.251 mg/L) and silver (0.0393 mg/L) were below the respective RCRA limits (1.0 mg/L and 5.0 mg/L) for these metals (Appendix L).

5.2.1 Three Mile Island-2 Core Debris

TMI-2 core debris has been suspected to potentially leach cadmium and silver at levels above the RCRA TCLP limitations for a hazardous waste. Cadmium and silver are integral materials of the TMI-2 control rods that melted with the core in the meltdown incident. Extensive materials tests

were performed on the core debris in past years to evaluate the effects of the core meltdown on the materials making up the core. No TCLP analyses were conducted on the melted core material at the time, although analyses are currently underway.

In accordance with as low as reasonably achievable and waste minimization principles, EPA and the NRC have supported the use of unirradiated samples to determine if a material exhibits a RCRA characteristic. Therefore, a process knowledge evaluation using sample results from an unirradiated surrogate control rod was performed to augment process knowledge gained during the previous studies of the TMI-2 core debris.

Based on the TCLP results of the silver/indium/cadmium control rod, TMI-2 core debris is unlikely to be RCRA hazardous. An element of uncertainty exists over the leachability of cadmium and silver in an irradiated control rod, as well as the potential leachability of the melted control rods and other core debris. Because of this, a process knowledge evaluation was conducted to determine an estimated leachate concentration of a homogenous sample of the complete TMI-2 core. Leachability rates of cadmium and silver from the unirradiated control rod were used to extrapolate this information. The mass of other material in the entire core debris (e.g., uranium, iron, etc.) was considered in the estimating process because a representative sample of the core debris would include such materials. Calculated process knowledge estimates of cadmium, and silver leachate concentrations from a homogenous sample of the entire core debris would be 0.0008 mg/kg of silver and 0.005 mg/kg of cadmium, which are well below TCLP limits. These calculated results assist in evaluation of the characteristics that may be expressed by a representative sample because it includes all core materials.

Results from analyses of silver-indium-cadmium control rods, as well as the calculated TCLP results presented above, include the mass of all cadmium and silver known to exist in the core prior to the incident. Only 47% to 60% of silver, and 23% of cadmium was accounted for in post-incident examinations of the TMI-2 reactor pressure vessel,¹ although significant release of these metals from the core is not suspected. Actual results therefore, may be lower than conservatively estimated by this analysis.

5.2.2 Other Disrupted SNF

Several other disrupted SNF types occur in the inventory of DOE-owned SNF. These include SFD 1-1 and SFD 1-4 (Severe Fuel Damage) generated at the Power Burst Facility (PBF) at the INEL. The inventory also includes several Loss-of-Fluid Test (LOFT) fuels generated during tests at the INEL. Thorough review of available data has not been conducted on these SNF types to date. Although their concerns are similar to that of TMI-2 core debris, i.e., silver and cadmium leaching, post irradiation studies conducted on these fuels may have increased the leachability of the control rods by reducing their particle size.

5.2.2.1 SFD 1-1 and SFD 1-4 Drivers. SFD 1-1 and SFD 1-4 are currently stored at the INEL. These test fuels consisted of a driver containing an assembly of fuel rods, control rods, and monitoring probes encased in zirconium. The driver was inserted into the reactor and brought to critical controlled conditions while monitoring took place. On completion of the evaluations, the driver was removed, stopping further reaction. The driver casings were then filled with an epoxy resin, opened, and the fuel assembly sectioned for macroscopic inspection. Currently further information concerning the post examination condition or size of the SNF is required. Because particle size of metal is a factor in their leachability, additional evaluations are required to determine adequate process knowledge. SFD 1-4 is reported to have used silver-indium-cadmium alloy

(80-15-5%) control rods as a moderator, although such information can only be speculated about SFD 1-1. In addition, both test bundles contained numerous instrumented rods. Additional evaluations are required to fully characterize these fuels.

5.2.2.2 LOFT Drivers. Currently, little is known concerning the potential RCRA characteristics of the LOFT fuels. A number of instrumented assemblies (FP-2, UD 008V, UD 008W, UD 008X, UD 0080092) have been reported to have had silver-indium-cadmium alloy (80-15-5%) control rods, although it is currently not known whether the control rods were removed from the assemblies after the loss of fluid tests. Further information concerning the post examination condition or size of the SNF. Since particle size of metal is a factor in its leachability, additional evaluations are required to determine adequate process knowledge.

5.3 Reactivity of Sodium-Bonded SNF

Seven DOE-owned SNF categories may potentially exhibit a RCRA characteristic of reactivity due to materials not excluded from RCRA as source, special nuclear, or byproduct material. These are represented by metallic sodium-bonded fuels. One fuel type has been reported to contain a sodium-potassium alloy, which may also be reactive.

Sodium metal was used in the manufacture of certain fuels to act as a thermal conductor and a pliable medium to fill voids between the cladding and fuel until the fuel expanded upon irradiation. Efforts have been initiated to investigate if metallic sodium-bonded SNF exhibits the RCRA characteristic of reactivity. Sodium metal itself is very reactive with water. Initial discussions with personnel at the Argonne National Laboratory-West (ANL-W) indicated that sufficient information was available concerning the reactivity of metallic sodium in EBR-II to satisfy RCRA requirements, and therefore, additional efforts to characterize sodium containing SNF were not undertaken at the time. Currently, there are ten individual fuel types within seven categories identified as containing sodium (two types EBR-II, EBR, Fermi Blanket, SRE-UC, ACN-1, IFR-1, SRF-3, SRF-4 and WAPD-49). SNF storage locations and their quantities are summarized in Table 5-1.

All metallic sodium-bonded or sodium containing SNF types are currently considered suspect of exhibiting the RCRA characteristic of reactivity. Additional evaluations of individual experimental SNF types may result in modification to this determination. Specific information concerning individual SNF containing metallic sodium is provided by category below. SNF characteristics that distinguish the different categories include fuel enrichment, burnup, and fuel type.

Category 7—High uranium-235 enrichment, mixed uranium and plutonium oxide fuel, stainless steel clad, metallic sodium bonded

SRF 3 and SRF 4 are safety research fuel assemblies. The fuel is composed of a highly enriched mixed uranium-plutonium oxide fuel meat with stainless steel cladding. Both assemblies are reported to contain two radial regions separated by a hollow-walled hexagonal duct enclosing a sodium layer. The assembly central section contains 91 fuel pins with upper and lower axial blankets. The outer regions of the assembly are reported to contain boron carbide filter pins. It is currently not known if the sodium referenced in this fuel occurs as sodium metal or in another form, such as an oxide. Therefore, it is currently unknown if the sodium could be a reactive or nonreactive material.

Table 5-1. Sodium bonded or sodium containing spent nuclear fuel.

Fuel type	Category	Location		Metric tons of heavy metal
		Site	Facility	
EBR-II	18	INEL ANL-W	EBR-II	22.9
			HFEF	11.89
			RSWF	11.33
		ICPP	CPP-603	1.2
			CPP-666	0.83
			200 Area	0.0936
EBR-II (ANL-6)	18	INEL	CPP-603	0.0016
EBR-II (FFTF)	18	Argonne National Laboratory-East (ANL-E)		— ^a
EBR-II	45	Hanford	Building-327	0.02
EBR (LANL)	18	Hanford	200 Area	0.2
Fermi Blanket	40	INEL ICPP	CPP-749	34.17
SRE-UC	46	SRS	RBOF	0.044
ACN-1	21	Hanford	FFTF	— ^a
IFR-1	18	Hanford	FFTF	— ^a
SRF-3 and SRF-4	7	Hanford	FFTF	— ^a
WAPD-49 (NaK)	None	INEL, ICPP	CPP-603	— ^a
Total metallic sodium SNF				82.679+ ^a

a. Unknown small amount.

Category 18—High Uranium-235 Enrichment, Uranium Metal Fuel, Stainless Steel Clad, Metallic Sodium Bonded, Over 50 kg (110 lb) Plutonium

EBR-II is the most widely distributed and abundant metallic sodium containing fuel type (≈ 48.27 MTHM). Certain EBR-II fuels listed are demarcated with suffixes indicating the reactor in which the fuel was irradiated (e.g., ANL-6, and FFTF). Primarily, EBR-II fuel is composed of a Type 304L stainless steel clad, uranium metal fuel matrix with metallic sodium bonding. Most of the EBR-II fuel was irradiated and stored at ANL-W. EBR-II fuel irradiated at Hanford Engineering Development Laboratory (HEDL) and stored at the SRS RBOF Facility is reported to be declad and, therefore, is no longer suspected to contain sodium and not included as a concern. A schematic of EBR-II fuel is provided in Appendix E.

Experimental Breeder Reactor (EBR) fuel was irradiated at LANL and is believed to be a sodium bonded fuel, although confirmation of this information has not been obtained.

The fuel is reported to be in small fragments and pellets having poor cladding condition, and thus casting doubt on the presence of sodium metal. This fuel is currently stored in the Hanford 200 Area Burial Ground in 24 EBR-II casks. It was received at Hanford during 1989-1990.

IFR-1 is an integral fast reactor test assembly used to support development of metal fuel. The test assembly contains 169 sodium-bonded pins representing three metallic fuel alloys (two uranium-plutonium-zirconium alloys and one uranium-zirconium alloy). The assembly duct, cladding, and wire-wrap are constructed of zirconium (D9). IFR-1 is stored at Hanford in FFTF.

Category 21—High uranium-235 enrichment, mixed uranium and plutonium carbide, stainless steel clad, metallic sodium bonded

ACN-1 is a mixed carbide test fuel assembly used to develop information on helium- and sodium-bonded, mixed carbide fuel pins. The assembly contains 18 sodium-bonded and 19 helium-bonded carbide fuel pins, enclosed in a Type 316 stainless steel liner.⁴ Based on available information, this fuel type is thought to be represented by only one assembly.

Category 40—Low uranium-235 enrichment, uranium-molybdenum alloy fuel, stainless steel clad, metallic sodium bonded

Fermi Blanket is a Type 304L stainless steel clad, sodium-bonded, low enrichment uranium-molybdenum alloy fuel. It is located at the INEL in the CPP-749 dry vaults. A schematic of Fermi Blanket is provided in Appendix E. Fermi Blanket is not to be confused with Fermi Core I & II which does not contain sodium.

Category 45—Low uranium-235 enrichment, uranium metal fuel, stainless steel clad, metallic sodium bonded, plutonium

EBR-II fuel, located in Building 327 at Hanford, is reported to be a low enriched fuel, which distinguishes it from other EBR-II SNF. Otherwise, its characteristics are believed to include metallic sodium bonding. Confirmation of this information is required.

Category 46—Low uranium-235 enrichment, uranium-carbide fuel, stainless steel clad, medium burnup, metallic sodium bonded

SRE-UC is reported to be a uranium-carbide fuel with sodium-bonded, stainless steel cladding. Only a small quantity of this fuel was generated (0.044 MTHM) and is stored at RBOF in one can. Another SRE fuel is stored in RBOF as well. However, it is a uranium oxide fuel that does not include metallic sodium bonding; therefore, care must be taken to avoid confusion.

WAPD-49—Information has confirmed previous reports of experimental fuel capsules irradiated in the Experimental Test Reactor that likely contain reactive materials.⁶ Westinghouse Atomic Power Division (WAPD) fuel capsules were used for a variety of tests using uranium oxide fuels with various enrichments. Information concerning WAPD-49 fuel indicates the presence of a sodium-potassium alloy occurring as two sheaths between fuel pins. Sodium-potassium is a reactive material.

Six cans containing fuel designated as WAPD-49 are currently stored in CPP-603 at the INEL. Schematics of WAPD fuel capsules and fuel pins are provided in Appendix E. This SNF type is currently assigned to Category 1 with the naval fuels due to it being a classified fuel.

6. CONCLUSIONS AND RECOMMENDATIONS

DOE owns approximately 2,700 MTHM of SNF, which is distributed primarily at the Hanford Site, the INEL, and SRS (Figure 6-1). Eight identified concerns regarding RCRA applicability to DOE-owned SNF have been extensively evaluated and analyzed with the results reported herein. Of these eight concerns two are considered resolved and require no further action (Section 3), two are considered preliminarily resolved requiring official determination by DOE (Section 4), and four require further evaluation and analysis to determine whether they are subject to RCRA regulation as mixed waste (Section 5). Of the issues requiring further evaluation, two have been identified as broad concerns potentially impacting a substantial number of SNF types, and two are fuel-specific concerns impacting specific categories of SNF only.

The preliminary conclusion drawn from the data herein indicates that approximately 3% by MTHM (or 19% by volume) may exhibit characteristics analogous to RCRA characteristics (Figures 6-2a and b). Most of this SNF is located at the INEL. Distribution and percentages of SNF believed potentially exhibiting a RCRA characteristic are summarized in Table 6-1.

Those fuel categories clearly excluded as SNM (uranium metal SNF) are not reflected in the above percentages. The fuel categories involved in the uranium hydrides concern involve the same categories as the uranium metals concern and are, therefore, omitted from the above percentages. Also absent from these percentages are the concerns involving stable fission and activation products and materials of construction. These numbers have been omitted due to the promising resolution indicated by preliminary data. DOE SNF is primarily made up of special nuclear and byproduct materials considered excluded under RCRA [40 CFR §261.4(a)(4)]. Metallic sodium-bonding metals, and silver and cadmium control rod materials are not excluded from RCRA (Table 6-2).

6.1 Conclusions & Recommendations

Conclusions to date are based on the preliminary data presented in this report. These conclusions are to be finalized through concurrence of the DOE and the appropriate regulatory agencies. Therefore, the following conclusions and recommendations are subject to change in response to such discussion and negotiation. Recommended path forward guidance for resolution of each of the RCRA concerns are illustrated in Figures 6-3 through 6-10. Implementation of these activities is contingent on funding.

6.1.1 Reactivity of Uranium Hydrides

Uranium metal fuels (categories 17,18, 41,42, 43, 44, 45, and 53) represent the largest portion (approximately 80% by MTHM and 19.0% by volume) of DOE-owned SNF. These fuels are a concern because of the formation of potentially reactive hydrides after extended wet storage followed by drying. However, SNF that exhibits a characteristic similar to RCRA characteristics of hazardous waste due solely to SNM materials is considered excluded from RCRA under 40 CFR §261.4(a)(4). Currently, it is not clear whether the SNM exclusion is applicable to a material produced through a reaction of the SNM itself. Clarification of this matter should be sought by DOE with concurrence by the regulatory agencies and the NRC. Additional process knowledge evaluations should be undertaken in parallel to evaluate the potential reactivity of uranium hydrides.

Specific recommendations and actions to resolve issues concerning uranium hydrides are summarized in Figure 6-3.

MT - Metric tons (1000 kg or 2,205 lb)

INEL - Defined here as the physical location; includes DOE-ID facilities, NRF, and ANL-W

Other - Includes other DOE sites, non-DOE domestic reactor fuel, research reactor fuel that will be owned and managed by DOE

RED 0955

Figure 6-1. Distribution of DOE SNF throughout all DOE sites. Comparison based on mass, volume, number of assemblies, uranium mass, mass of fissile material, and mass of heavy metal.

Figure 6-2a. Potentially RCRA hazardous DOE-owned SNF based on MTHM.

RED 0812

Figure 6-2b. Potentially RCRA hazardous DOE-owned SNF based on volume (m³).

Table 6-1. Distribution of potentially RCRA hazardous SNF (where total DOE-owned SNF exhibiting a RCRA characteristic = 100%).

Location	Total mass (kg)	Metric tons of heavy metal	Volume (m ³)
Hanford	< 1%	< 0.5%	≈ 3%
INEL ^a	≈ 66%	≈ 85%	≈ 66%
ANL-E	< 0.01%	— ^b	< 0.01%
LANL	— ^b	— ^b	— ^b
ORNL	< 0.1%	< 0.01%	≈ 0.1%
Sandia	— ^b	— ^b	— ^b
SRS	≈ 0.02%	≈ 0.04%	≈ 0.02%
Pub. Serv. CO	≈ 33%	≈ 15%	≈ 31%

a. Includes ANL-W.

b. Small quantity or data unavailable.

Table 6-2. RCRA characteristics of DOE-owned spent nuclear fuel.

Category	Excluded characteristic(s) ^a	Not excluded characteristic
7	None	Reactive sodium bonded
16	None	Reactive sodium bonded
17	Reactive uranium metal	None
18	Reactive uranium metal	Reactive sodium bonded
19	Reactive uranium-dicarbide	None Thorium-dicarbide
20	Reactive uranium-dicarbide	None
21	Reactive mixed uranium-plutonium-carbide	Reactive sodium bonded
40	None	Reactive sodium bonded
41	Reactive uranium metal	None
42	Reactive uranium metal	None
43	Reactive uranium metal	None
44	Reactive uranium metal	None
45	Reactive uranium metal	Reactive sodium bonded
46	Reactive uranium-dicarbide	Reactive sodium bonded
51	None	Toxic silver and cadmium
53	Reactive uranium metal	None

a. Material potentially considered excluded as Special Nuclear Material under 40 CFR §261.4(a)(4). Discussions are required with the NRC to clarify if SNF-carbide compounds and uranium metals are SNM.

Figure 6-3. Path forward for resolution of uranium hydrides concern.

Figure 6-4. Path forward for resolution of metallic carbide SNF concern.

Figure 6-5. Path forward for resolution of stable fission and activation products concern.

Figure 6-6. Path forward for resolution of materials of construction concern.

Figure 6-7. Path forward for resolution of disrupted SNF concern.

Figure 6-8. Path forward for resolution of sodium-bonded SNF concern.

Figure 6-9. Path forward integration.

Figure 6-10. Regulatory alternatives.

6.1.2 Metallic Carbide SNF

Metallic carbide fuels (Categories 13, 19, 20, 21, and 46) represent approximately 1% of DOE SNF by MTHM and 21.6% by volume. Currently the definition of SNM is not clear on whether uranium-dicarbide and other carbide fuel compounds are considered SNM. A position paper has been developed establishing the DOE position that nuclear fuel compounds primarily composed of SNM (the combination of SNM and another material used in fuel) should be considered excluded from RCRA regulation under the source, special nuclear, and byproduct material rule. Dialogue should be pursued between DOE, NRC, and EPA concerning the definition of SNM NRC action under 42 USC 2071, to include mixed carbide compounds with other broadly defined materials identified in 42 USC 2014(aa) as SNM, is recommended.

Specific recommendations and actions to resolve issues concerning metallic carbide SNF are summarized in Figure 6-4.

6.1.3 Stable Fission & Activation Products

Based on current process knowledge, SNF is not expected to leach regulated levels of metals listed in 40 CFR §261.24 from stable fission or activation products. Stable fission products are currently considered excluded from RCRA [40 CFR §261.4(a)(4)], and a position paper establishing the DOE position regarding the application of this exclusion is currently under development. However, additional evaluations of DOE SNF are currently being conducted to adequately address this issue. Calculated leachate concentrations derived from ORIGEN Runs are being generated for representative DOE-owned SNF types to confirm that stable fission products do not leach regulated levels of RCRA metals.

Because the quantity of fission and activation products are related to uranium enrichment and burnup, evaluations are being conducted on: (a) high enriched, high-burnup fuel (ATR); (b) low enriched, high-burnup fuel (commercial); and (c) low enriched, low-burnup fuel (N-Reactor). Evaluations are considering (a) total concentration of fission and activation products, (b) particle size reduction to meet TCLP requirements, (c) concentration of regulated metals in cladding, etc., and (d) use of existing corrosion data to develop process knowledge. These evaluations should be completed and results should be shared with regulatory agencies.

Specific actions to resolve issues concerning stable fission and activation products, as well as regulatory options to establish whether these materials are considered byproducts excluded under RCRA, are summarized in Figure 6-5.

6.1.4 Toxicity of Materials of Construction

Although SNF is not suspected to have significant amounts of leachable RCRA-regulated metals, additional evaluation of SNF materials of construction is necessary. Current data used in this evaluation should be reviewed to determine specific information needs, and additional data should be sought where necessary.

Leaching rates of some unirradiated metals found in SNF have been established through TCLP analysis. However, the effect of irradiation on the leachability of metals, if any, is not documented. Therefore, samples of irradiated stainless steel, which are composed of high enough levels of the constituents of concern to provide an enveloping analysis, should be collected for TCLP analysis to confirm that significant changes to their leachability have not occurred due to irradiation. Additional

information should be sought to confirm that control rods with RCRA-regulated metals are not shipped or stored with DOE-owned SNF. Serious consideration and final determination of whether nonfuel bearing components that may be present in a significant number of SNF storage configurations are to be managed and characterized as SNF must occur. This matter has far reaching implications regarding the overall management, interim storage, conditioning, and final disposition of SNF.

Specific recommendations and actions to resolve issues concerning the toxicity of materials of construction are summarized in Figure 6-6.

6.1.5 Toxicity of Disrupted SNF

Currently, TMI-2 core debris (in Category 51) is not expected to exhibit a RCRA characteristic. Samples of the debris are currently undergoing TCLP analysis; the results of which will determine the need for further evaluation.

Other disrupted SNF in Category 51 (LOFT and PBF) require further evaluation to assess their potential to leach RCRA hazardous levels of regulated metals due to melted silver-indium-cadmium control rods. Although the results of the analysis of the TMI-2 debris are expected to envelop these other disrupted fuels, further evaluation specific to these fuels may be required due to their current configuration. The LOFT and PBF fuel assemblies upon disruption were subjected to multiple examinations some of which required very thin cross-section slices. This condition may cause an increase in leachability due to the surface area exposure in excess of the TCLP requirements. Further negotiations with regulators may be required on these specific issues in gaining final resolution.

Current evaluations of unirradiated silver-indium-cadmium control rods indicate that they do not leach regulated levels of RCRA metals. However, neither the effects of irradiation, nor the effects of particle size on leaching rates are confirmed. Therefore, an evaluation of the leachability of regulated RCRA metals from irradiated silver-indium-cadmium control rods, which also focuses on the effects of particle size on leaching rates, should be conducted. Particle size evaluations should consider identified particle sizes of LOFT and PBF fuel.

Information gained from these analyses can then be extrapolated to LOFT and PBF fuel process knowledge evaluations. Information gained may also be useful in the management of control rods and additional evaluations of TMI-2 core debris if necessary.

Specific recommendations and actions to resolve issues concerning toxicity of disrupted fuels are summarized in Figure 6-7.

6.1.6 Reactivity of Sodium-Bonded SNF

DOE SNF containing nonexcluded materials which may exhibit a RCRA characteristic is predominantly represented by metallic sodium-bonded fuel types. Metallic sodium used in the bonding of these fuel types is expected to be water reactive. Therefore, the fuels would require management under RCRA if SNF were determined a waste. Sodium bonded, or metallic sodium containing SNF (Categories 7, 16, 18, 21, 40, 45, and 46) comprise approximately 3.2% of DOE-owned SNF by MTHM and 10.6 % by volume. Sodium-potassium containing SNF is represented by a single fuel type (WAPD-49, no category assigned).

Specific recommendations and actions to resolve issues concerning sodium-bonded fuels are summarized in Figure 6-8.

6.2 Integration

Information currently available concerning effected fuel type, reported storage location, SNF quantity, suspected characteristics, etc., has been summarized by site for confirmation with their personnel. Efforts to confirm this information and gain currently unavailable information are being coordinated through personnel responsible for these fuels at each of the effected sites.

Integration meetings have been conducted with effected sites to (a) evaluate potential concerns and inconsistencies, (b) ensure consensus on the path forward for characterization and evaluation of regulatory alternatives, (c) integrate the intent that any further analysis required for final characterization requirements are to be conducted by the sites currently responsible for the management of the particular fuel type, and (d) integrate actions being undertaken to evaluate potential costs of SNF compliance with current RCRA regulations. Specific recommendations and actions to integrate current information, information requests, and the path forward with other sites are summarized in Figure 6-9.

6.3 Management Alternatives

Current RCRA regulations do not appear to anticipate regulation of SNF. DOE has options to address the application of these regulations to SNF through (a) changes to the statute (RCRA the Law) to exclude SNF from RCRA, (b) rulemaking provisions set forth within RCRA regulations (40 CFR §260.20) to request other management options within the framework of RCRA Subtitle C (Figure 6-9), or (c) a no-action position could be adopted under which current regulations and subparts would apply to effected SNF if it is determined a waste. These options must be explored and steps must be initiated to develop a DOE-HQ position. Thereafter, efforts should be undertaken to implement the selected path.

To understand impacts of a no-action option, and provide baseline information to evaluate alternative statutory and regulatory options with regulators and stakeholders, a detailed cost estimate for SNF compliance with current RCRA regulations was prepared. A preliminary cost estimate summarizing two alternative, centralized management paths for effected SNF was issued to DOE-HQ in May 1995.⁷

7. REFERENCES

1. D. W. Akers and R. K. McCardell, "Core Materials Inventory and Behavior," Nuclear Technology, August 1989.
2. S. Cohen & Associates, *Evaluation of Spent Nuclear Fuel as Mixed Waste*, Prepared for the Environmental Protection Agency, 1990.
3. J. E. Lane, *Resource Conservation and Recovery Act Regulatory Exclusion of Uranium Compounds as Special Nuclear Material*, DOE/SNF/REP-004, Revision 1, June 1995.
4. K. H. Bergsman, *Hanford Irradiated Fuel Inventory Baseline*, February 1992.
5. NRC, Staff memorandum in Response to Licensing Board, January 19, 1995.
6. B. M. Palmer, *Unclassified Fuels in the CPP-603 Fuel Storage Basins*, WINCO-1215, March 1994.
7. Cost Evaluation of the Potential Impacts of RCRA Subtitle C to DOE-Owned Spent Nuclear Fuel, DOE-SNF-REP-003, Rev. 1, May 1995.

Appendix A

DOE-HQ (EH-22) Memorandum Mixed Waste and Materials Management Compliance Issues

United States Government

Department of Energy

memorandum

DATE: August 03, 1990

REPLY TO:
ATTN OF: EH-22

SUBJECT: Mixed Waste and Materials Management Compliance Issues

TO: Distribution

In January 1990, the Savannah River Operations Office and Westinghouse Electric Corporation raised a number of significant, cross-cutting mixed waste and materials management compliance issues to the Department of Energy (DOE) Headquarters for resolution. In accordance with DOE 5400.2A, the Office of Environment, Safety and Health (EH) was assigned the lead for resolving the cross-cutting issues. As you may be aware, EH established a workgroup to develop and/or clarify DOE's positions on these issues. The workgroup includes technical, regulatory and legal representatives of DOE Headquarters and field organizations, and Management and Operating contractors who have expertise in RCRA, DOE operations and/or DOE waste management. The issues are complex and require a consistent Departmental assessment of the applicability of Atomic Energy Act (AEA) and RCRA requirements. Some of the issues concern circumstances in which it is unclear how both RCRA and AEA requirements should be jointly implemented. Other issues concern the potential applicability of RCRA to the management of certain nuclear materials.

The workgroup has developed draft DOE position papers and proposed strategies for recommended DOE actions. As soon as DOE Headquarters management has been briefed, the position/strategy papers will be circulated to field and program offices and the General Counsel for review and comment. After the Department's positions and strategies are clarified, discussions will be held with the Environmental Protection Agency (EPA) and/or the Nuclear Regulatory Commission, as appropriate. Upon consideration of these agencies' views and recommendations, clear DOE-wide policies and guidance will be prepared. Of course, at various points in this process, DOE will need to seek input from the host State regulatory agencies.

Consistent with DOE's policy of full disclosure of compliance issues to the regulatory authorities, we request that all of the field offices, including the Power Administrations and facilities that report directly to Headquarters, notify their respective regulators (EPA regional offices and States) that DOE Headquarters is leading an effort to resolve certain mixed waste and materials handling compliance issues. We are aware that some of these issues have already come up in site-specific discussions. In these instances, we hope that the regulators

were advised that DOE has current efforts underway to address these issues, and that the Department is working towards consistent application of appropriate waste and materials management requirements and practices throughout the DOE complex. If such notification has not been made, we recommend that the notification be general in nature and that the regulators be assured that DOE's goal is to work with regulatory agencies to reach agreeable resolutions. However, at this time, DOE is still developing internally the information necessary to have meaningful discussions with the regulatory authorities.

A list of the issues under evaluation is attached to this memorandum. In addition, we have included an explanation of the rationale for DOE evaluating these issues on a national basis (Attachment).

We greatly appreciate your support and cooperation as we continue to work towards resolution of significant cross-cutting Departmental environmental compliance issues. We especially would like to thank those Offices which have provided representatives to the current workgroup effort. Questions regarding the workgroup or this memorandum may be addressed to Kathleen Taimi, Acting Director, Office of Environmental Compliance, at 586-2113 or FTS 896-2113.

Raymond P. Berube
Deputy Assistant Secretary
for Environment

Attachment

cc: General Counsel, GC-1
Assistant Secretary for Nuclear Energy, NE-1
Assistant Secretary for Fossil Energy, FE-1
Assistant Secretary for Conservation
and Renewable Energy, CE-1
Assistant Secretary for Defense Programs, DP-1
Director of Energy Research, ER-1
Director, Office of New Production Reactors, NP-1
Director, Office of Environmental Restoration
and Waste Management, EM-1

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Administrator, Southeastern Power Administration
Administrator, Southwestern Power Administration
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Director, Pittsburgh Energy Technology Center

ISSUES

1. **SCRAP OR EXCESS LEAD:** The applicability of RCRA to the storage of radioactively contaminated lead for the purpose of future use.
2. **SPENT/IRRADIATED FUEL:** The applicability of RCRA to the storage of spent or irradiated reactor fuel and the storage of other materials which are the principal products of facilities that process special nuclear material.
3. **SCRAP AND RESIDUE:** The applicability of RCRA to the management of materials that are "scrap" or "residues" which contain valuable source or special nuclear materials that can be reclaimed, recycled or recovered.
4. **TRANSPORTATION OF SPECULATIVELY ACCUMULATED HAZARDOUS MATERIAL:** The applicability of RCRA transportation requirements to certain recyclable materials.
5. **MANAGEMENT OF WASTES CONTAINING ONLY SOURCE, SPECIAL NUCLEAR OR BYPRODUCT MATERIAL:** Some RMW forms contain a hazardous waste characteristic which is solely attributable to source, special nuclear or byproduct material (i.e., the radionuclide itself).
6. **REPRESENTATIVE SAMPLING OF NON-HOMOGENOUS WASTE FORMS:** Representative sampling of non-homogenous waste forms to meet RCRA standard testing methodologies is difficult. The use of process knowledge in determining that a waste is not hazardous is often not enough to satisfy regulators.
7. **DOE COMPLIANCE WITH RCRA TECHNICAL STANDARDS:** Due to the hazards imposed by the radioactivity associated with certain RMW, strict compliance with some RCRA technical standards may not be achievable in all instances.
8. **DOE COMPLIANCE WITH RCRA LAND DISPOSAL RESTRICTIONS:** Compliance with certain provisions of the RCRA land disposal restriction (LDR) program is currently impossible for DOE's RMW streams, particularly those provisions involving storage and treatment of LDR waste.
9. **CERCLA REPORTING OF RELEASES INTO CONTAINMENT STRUCTURES:** DOE policy regarding CERCLA reporting requirements for releases into secondary containment systems needs to be developed.

10. RADIOACTIVE PCB STORAGE: Radioactive PCBs are stored at DOE sites with no treatment and disposal capacity available. EPA regulations require that PCBs be stored no longer than one year before disposal. No exceptions to the one year storage limit are available in the regulations.

Rationale for DOE-Wide Consideration and Resolution of Certain Mixed Waste and Materials Management Issues

- o The issues are applicable across the DOE complex. A basic understanding of the issues, and Headquarters' agreement on RCRA's applicability by EPA, and NRC in some instances, should facilitate consistency across EPA Regions and in the States, and expedite site-specific resolution of similar issues.
- o The applicability of RCRA to the management of materials such as nuclear products, spent fuels, valuable scrap, and excess useable or potentially usable lead and raw materials has not been consistently assessed within the context of the AEA.
- o The joint implementation of RCRA standards and AEA standards is unclear for certain waste forms of lead, cadmium, high level waste, tritiated mercury and contaminated silver saddles. Consistent application of requirements across the DOE complex is needed.
- o Treatment systems and capacity needs for all DOE waste forms should be assessed and developed across the complex to ensure that wastes are efficiently and effectively treated to appropriate levels.

Appendix B

Background to Mixed Waste Regulation and Applicability of SNF to RCRA

Applicability of SNF to RCRA Regulation

Background to Mixed Waste Regulation

RCRA addresses the management of solid and hazardous wastes. Section 1004(27) of RCRA excludes source, special nuclear and byproduct material from the definition of solid waste and therefore excludes them from regulation under RCRA.¹ Based on this exclusion, DOE's initial position was that RCRA only applied to certain mixtures of radioactive and hazardous wastes related to indirect process waste streams. The EPA and DOE entered into a memorandum of understanding on February 22, 1984 establishing a hazardous and mixed waste management program, although clarification was apparently required concerning the definition of Byproduct Material in the AEA. On May 1, 1987, DOE issued its Byproduct Rule [10 CFR 962 (52 FR 15937)] which states that "only the actual radionuclides in DOE waste streams will be considered byproduct material" subject to the RCRA exclusion for byproduct materials.

On September 23, 1988 [53 FR 37045], EPA issued a "Clarification Notice" stating that mixtures of AEA byproduct wastes and RCRA hazardous wastes were subject to RCRA based in part on DOE's Byproduct Rule. By enactment of the Federal Facilities Compliance Act of 1992 (FFCA), the term "mixed waste" was added to the general definition section [§1004] of RCRA.² This definition includes source and special nuclear material, as well as byproduct material, that is mixed with hazardous waste.

Therefore, wastes which includes non-excluded material that exhibits a characteristic or is listed, as well as an excluded material (source, special nuclear or byproduct), are subject to dual regulation under the AEA and RCRA.

¹ Wastes that are not solid wastes cannot be hazardous wastes under RCRA. (40 CFR 261.3 "Definition of Hazardous Waste")

² "Mixed Waste" means "waste that contains both hazardous waste and source, special nuclear material, or byproduct material subject to the Atomic Energy Act of 1954."

 

Appendix C

Responses to 40 CFR §261.21 through §261.24

**Responses to 40 CFR §261.21 through §261.24
EPA Hazardous Waste Characteristics**

Sec. 261.21 Characteristic of Ignitability.

(a) A solid waste exhibits the characteristic of ignitability if a representative sample of the waste has any of the following properties:

(1) It is a liquid, other than an aqueous solution containing less than 24 percent alcohol by volume and has flash point less than 60 deg.C (140 deg.F), as determined by a Pensky-Martens Closed Cup Tester, using the test method specified in ASTM Standard D-93-79 or D-93-80 (incorporated by reference, see Sec. 260.11), or a Setaflash Closed Cup Tester, using the test method specified in ASTM Standard D-3278-78 (incorporated by reference, see Sec. 260.11), or as determined by an equivalent test method approved by the Administrator under procedures set forth in Secs. 260.20 and 260.21.

DOE-Owned SNF is a NOT liquid and therefore this section does not apply.

(2) It is not a liquid and is capable, under standard temperature and pressure, of causing fire through friction, absorption of moisture or spontaneous chemical changes and, when ignited, burns so vigorously and persistently that it creates a hazard.

DOE-Owned SNF is not a liquid. NaK in WAPD-49 is potentially ignitable. Materials in other SNF NOT excluded under 40 CFR §261.4(a)4 are NOT capable, under standard temperature and pressure, of causing fire through friction, absorption of moisture or spontaneous chemical changes and, when ignited, burns so vigorously and persistently that it creates a hazard. Potentially pyrophoric uranium metal and other types of special nuclear, or byproduct material would be considered excluded from the definition of a solid waste, although they may exhibit this characteristic.

(3) It is an ignitable compressed gas as defined in 49 CFR 173.300 and as determined by the test methods described in that regulation or equivalent test methods approved by the Administrator under Secs. 260.20 and 260.21.

No DOE-Owned SNF contains an ignitable compressed gas.

(4) It is an oxidizer as defined in 49 §CFR 173.151.

DOE-Owned SNF is not an oxidizer nor does it contain oxidizers as defined in 49 CFR §173.

[45 FR 33119, May 19, 1980, as amended at 46 FR 35247, July 7, 1981; 55 FR 22684, June 1, 1990]

Sec. 261.22 Characteristic of Corrosivity.

(a) A solid waste exhibits the characteristic of corrosivity if a representative sample of the waste has either of the following properties:

(1) It is aqueous and has a pH less than or equal to 2 or greater than or equal to 12.5, as determined by a pH meter using Method 9040 in "Test Methods for Evaluating Solid Waste, Physical/Chemical Methods," EPA Publication SW-846, as incorporated by reference in Sec. 260.11 of this chapter.

DOE-Owned SNF is not aqueous.

(2) It is a liquid and corrodes steel (SAE 1020) at a rate greater than 6.35 mm (0.250 inch) per year at a test temperature of 55 deg.C (130 deg.F) as determined by the test method specified in NACE (National Association of Corrosion Engineers) Standard TM-01-69 as standardized in "Test Methods for Evaluating Solid Waste, Physical/Chemical Methods," EPA Publication SW-846, as incorporated by reference in Sec. 260.11 of this chapter.

DOE-Owned SNF is not liquid.

[45 FR 33119, May 19, 1980, as amended at 46 FR 35247, July 7, 1981; 55 FR 22684, June 1, 1990; 58 FR 46049, Aug. 31, 1993]

Sec. 261.23 Characteristic of Reactivity.

(a) A solid waste exhibits the characteristic of reactivity if a representative sample of the waste has any of the following properties:

(1) It is normally unstable and readily undergoes violent change without detonating.

Materials in the SNF NOT excluded under 40 CFR §261.4(a)4 are NOT normally unstable and do not readily undergo violent change without detonating in their post construction configuration.

(2) It reacts violently with water.

Metallic Sodium Bonding and NaK in certain DOE-Owned SNF, NOT excluded under 40 CFR §261.4(a)4, could react violently with water when the integrity of the SNF cladding has been compromised. Excluded Special Nuclear Material (Uranium Metal Fuels and Carbide Fuels) may exhibit this characteristic.

(3) It forms potentially explosive mixtures with water.

DOE-Owned SNF does not form potentially explosive mixtures with water.

(4) When mixed with water, it generates toxic gases, vapors or fumes in a quantity sufficient to present a danger to human health or the environment.

Metallic Sodium Bonding in DOE-Owned SNF, NOT excluded under 40 CFR §261.4(a)4, could react violently with water when the integrity of the SNF cladding has been compromised. Excluded Special Nuclear Material (Uranium Metal Fuels and Carbide Fuels) may exhibit this characteristic.

(5) It is a cyanide or sulfide bearing waste which, when exposed to pH conditions between 2 and 12.5, can generate toxic gases, vapors or fumes in a quantity sufficient to present a danger to human health or the environment.

DOE-Owned SNF is not a sulfide or cyanide bearing waste.

(6) It is capable of detonation or explosive reaction if it is subjected to a strong initiating source or if heated under confinement.

Materials in DOE-Owned SNF are NOT capable of detonation or an explosive reaction if it is subjected to a strong initiating source or if heated under confinement.

(7) It is readily capable of detonation or explosive decomposition or reaction at standard temperature and pressure.

NaK in WAPD-49 could be considered explosive. Other materials in DOE-Owned SNF are NOT capable of detonation or explosive decomposition or reaction at standard temperature and pressure.

(8) It is a forbidden explosive as defined in 49 CFR 173.51, or a Class A explosive as defined in 49 CFR 173.53 or a Class B explosive as defined in 49 CFR 173.88.

DOE-Owned SNF is NOT a forbidden explosive as defined in 49 CFR 173.51, or a Class A explosive as defined in 49 CFR 173.53 or a Class B explosive as defined in 49 CFR 173.88.

[45 FR 33119, May 19, 1980, as amended at 55 FR 22684, June 1, 1990]

Sec. 261.24 Toxicity Characteristic.

(a) A solid waste exhibits the characteristic of toxicity if, using the Toxicity Characteristic Leaching Procedure, test Method 1311 in "Test Methods for Evaluating Solid Waste, Physical/Chemical Methods," EPA Publication SW-846, as incorporated by reference in Sec. 260.11 of this chapter, the extract from a representative sample of the waste contains any of the contaminants listed in table 1 at the concentration equal to or greater than the respective value given in that table. Where the waste contains less than 0.5 percent filterable solids, the

waste itself, after filtering using the methodology outlined in Method 1311, is considered to be the extract for the purpose of this section.

Materials in certain DOE-Owned SNF NOT excluded under 40 CFR §261.4(a)4 may occur at concentrations which, when subjected to TCLP analysis may exceed RCRA allowable limits. These materials occur primarily in control rods which due to accidents of tests are integral to the SNF. Current process knowledge indicates that excluded Special Nuclear Material would not leach hazardous levels of regulated metals on analysis, however actual chemical analysis may result in data contrary to current knowledge.

[55 FR 11862, Mar. 29, 1990, as amended at 55 FR 22684, June 1, 1990; 55 FR 11862, June 29, 1990; 58 FR 46049, Aug. 31, 1993]

Appendix D

Process Knowledge References and SNF/Category Cross-References

DOE SNF Alphabetical Cross Reference to Category

Fuel Name	Category	Fuel Name	Category
GCRE can	9	MIT	15
GCRE pellets	12	ML-1	9
GENTR	14	MMW Thermonic	none
GETCF & SEFOR	32	MNR	15
GETR Filters	6	Monticello (BWR)	35
Ginna (PWR)	35	MSRE	48
GRR-1	15	MTR type	14, 15
Halden	35	MTR Omega West	none
HALDEN IFA	35	MURR	15
Hanford U-233	13	N Reactor	43
HB Robinson	35, 49	Naval	1
HB Robinson (PWR)	35, 49	Nereide	39
HFBR	14, 15	NIS	5
HFIR	5	non U Target	39
HFR	15	NRAD	2
HIFAR	15	NRCRR	15
HOR	15	NRU	15
HPRR	6	NRX	15
HTGR	none	Oconee-1	35, 49
HTRE	9	Oconee-1 (PWR)	35
HWCT HEU	17	Oconee-2	49
HWCT LEU	41	OMEGA-W	14
HWCTR	42	OPTRAN	35
IEA-R1	15	ORNL (S1W)	17
IFR-1	18	ORNL mixed oxide	32
IRR-1	15	ORPHEE	15
JASPER	26	ORR	14, 15
JMTR	14, 15	ORR-LEU	39
JRR-2	15	ORR experiments	none
JRR-4	15	OSIRIS	15
KUR	15	OSR	47
La Relna	15	PARR	15
LOFT FP-2	51	Pathfinder	6
LOFT LEAD ROD	35	PBF Driver	28
LOFT	35	PBF SFD 1-4	51
LOFT UD	51	PBF SFD 1-1	51
LOFT fines	50	PCM - TRA	11
LWR	none	Peach Bottom	19, 35, 49
LWR samples	35	Peach Bottom core 1	19
LWR	35	Peach Bottom core 2	19
MAPI	35	pins	35
Miscellaneous	none		

DOE SNF Alphabetical Cross Reference to Category

Fuel Name	Category	Fuel Name	Category
PNL mixed	12	SPSS (Spert)	6
Point Beach-1 (PWR)	49	SRE	8
PRR-1	15, 25	SRE-UC	46
Pulstar Buffalo	35	SRF-3 & 4	7
PULSTAR	35	SRS U-233	13
Quad City-1 (BWR)	35	Sterling Forest	15
R2	15	Surry	49
R2-0	15	Taiwan RR	39
RA-3/RA-6	15	target samples	39
RERTR	none	Target	39
RHF	15	TC	35
RIA	35	THOR	15
RINC	15	TMI-2	51
RPI	15	Tory-IIA	12
RRR	27	Tory-IIC	12
RSWF	none	TR-2	15
SAFARI	15	TREAT	22
SAPHIR	15	TRIGA FLIP	2
Saxton Mo	49	TRIGA SST	24
Saxton UO	35	TRIGA	23, 24, 25
Saxton	35	TRIGA AI	23
Scarabee	15	TRIGA AL OSU	23
Shippingport	38	TRR-1	15, 24
Shippingport PWR C1-S4	10	TSR	14
Shippingport PWR C2-S1	10	U of Michigan	39
Shippingport PWR C2-S2	10	U of Virginia	15
Shippingport PWR blanket	52	U of Wash	14
Shippingport PWR C2	10	US.Geol-TRIGA	24
Shippingport PWR C1	10	Various Commercial	35
Shippingport LWBR	37	VBWR (Geneva)	6
SILOE	15	VBWR	6
SM-1A	6	Veterans-TRIGA	23
SNAP	4	WAPD-49	none
SNAP-10	2	ZPPR	34
SPEC (Orme)	44	ZPR	14
SPERT	24	ZPTR	5
SPERT-3	35		
SPR-II	14		
SPR	53		
SPR-II&III	14		
SPR-III	14		

DOE SNF - Categories with Fuels Listed Alphabetically

Category	Fuel Name	Category	Fuel Name
1	Naval	10	EBWR
2	FREC	10	Shippingport PWR C1-S4
2	NRAD	10	Shippingport PWR C2-S1
2	SNAP-10	10	Shippingport PWR C2-S2
2	TRIGA FLIP	10	Shippingport PWR C1
		10	Shippingport PWR C2
3	Ber-II Triga	11	PCM - TRA
4	AI	12	GCRE pellets
4	SNAP	12	PNL mixed
		12	Tory-IIA
5	HFIR	12	Tory-IIC
5	NIS		
5	ZPTR	13	Hanford U-233
		13	SRS U-233
6	APPR (AGE-2)		
6	B&W Scrap	14	ARMF/CFRMF
6	BMI	14	ATSR
6	BORAX V	14	BMRR
6	EBWR	14	BSR
6	GETR Filters	14	GENTR
6	HPRR	14	HFBR
6	Pathfinder	14	JMTR
6	SM-1A	14	MTR type
6	SPSS (Spert)	14	OMEGA-W
6	VBWR	14	ORR
6	VBWR (Geneva)	14	SPR-II
		14	SPR-III
7	SRF-3 & 4	14	TSR
		14	U of Wash
8	ERR	14	ZPR
8	SRE		
		15	ANL Janus
9	ACRR	15	ARMF
9	GCRE	15	ASTRA
9	GCRE can	15	ATR
9	HTRE	15	ATR recycle
9	ML-1	15	ATR spent
9	experiments	15	Argonaut

DOE SNF - Categories with Fuels Listed Alphabetically

Category	Fuel Name	Category	Fuel Name
15	BER-2	15	SAFARI
15	BR-2	15	SAPHIR
15	DR-3	15	SILOE
15	Driver	15	Scarabee
15	FMRB	15	Sterling Forest
15	FRG-1	15	THOR
15	FRG-2	15	TR-2
15	FRJ-1	15	TRR-1
15	FRJ-2	15	U of Virginia
15	FRM		
15	Foreign from relief	16	Fermi core I & II
15	GRR-1		
15	HFBR	17	HWCT HEU
15	HFR	17	ORNL (S1W)
15	HIFAR		
15	HOR	18	EBR (LANL)
15	IEA-R1	18	EBR-II
15	IRR-1	18	EBR-II FFTF
15	JMTR	18	EBR-II ANL-6
15	JRR-2	18	EBR-II (ANL)
15	JRR-4	18	EBR-II (HEDL)
15	KUR	18	IFR-1
15	La Relna		
15	MIT	19	FSVR
15	MTR type	19	Peach Bottom
15	MURR	19	Peach Bottom core 1
15	MNR	19	Peach Bottom core 2
15	NRCRR		
15	NRU	20	AC-3
15	NRX	20	CX
15	ORPHEE	20	EBR-2 U-Pu carbide
15	ORR	20	FC-1
15	OSIRIS		
15	PARR	21	ACN-1
15	PRR-1		
15	R2	22	TREAT
15	R2-0		
15	RA-3/RA-6	23	Areotest TRIGA
15	RHF	23	TRIGA
15	RHF	23	TRIGA AI
15	RINC	23	TRIGA AI
15	RPI	23	TRIGA AL OSU
		23	Veterans-TRIGA

DOE SNF - Categories with Fuels Listed Alphabetically

Category	Fuel Name	Category	Fuel Name
24	AFRRI-TRIGA	35	EBWR
24	DOW-TRIGA	35	Ginna (PWR)
24	GA-TRIGA	35	HALDEN IFA
24	SPERT	35	HB Robinson
24	TRIGA	35	HB Robinson (PWR)
24	TRIGA SST	35	Halden
24	TRR-1	35	LOFT
24	US.Geol-TRIGA	35	LOFT LEAD ROD
		35	LWR
25	PRR-1	35	LWR samples
25	TRIGA	35	MAPI
		35	Monticello (BWR)
26	CVTR	35	OPTRAN
26	JASPER	35	Oconee-1
		35	Oconee-1 (PWR)
27	RRR	35	PULSTAR
		35	Peach Bottom
28	PBF Driver	35	Pulstar Buffalo
		35	Quad City-1 (BWR)
29	Dresden Power Rx	35	RIA
		35	SPERT-3
30	AGN	35	Saxton
		35	Saxton UO
31	EBWR	35	TC
		35	Various Commercial
32	FFTF	35	pins
32	GETCF & SEFOR		
32	ORNL mixed oxide	36	EBWR
		36	GAP CON
33	FFTF		
		37	Shippingport LWBR
34	EPR-1		
34	ZPPR	38	Shippingport
35	Belgium	39	Core Filter
35	Big Rock (BWR)	39	EBR-II Target
35	CANDU	39	Nereide
35	Commercial	39	ORR-LEU
35	Con Yankee	39	Taiwan RR
35	Con Edison	39	Target
35	Dresden SA-1	39	U of Michigan
		39	non U Target
		39	target samples

DOE SNF - Categories with Fuels Listed Alphabetically

Category	Fuel Name	Category	Fuel Name
40	Fermi blanket	51	LOFT FP-2
		51	LOFT UD
41	HWCT LEU	51	PBF SFD 1-1
		51	PBF SFD 1-4
42	HWCTR	51	TMI-2
43	N Reactor	52	Shippingport PWR blanket
44	SPEC (Orme)	53	SPR
45	EBR-II	none	Americium Target Elements
		none	DOE Demonstration (37B)
46	SRE-UC	none	Dresden II and others
		none	Dresden Scrap
47	OSR	none	LWR
		none	Miscellaneous
48	MSRE	none	MMW Thermonic
		none	MTR Omega West
49	Arkansas-1	none	ORR experiments
49	BCD B17	none	RERTR
49	CANDU	none	Shippingport
49	Calvert Cliffs (PWR)	none	RSWF
49	Con Edison	none	HTGR
49	Cooper (BWR)	none	HTRE
49	DRCT	none	WAPD-49
49	Dresden		
49	EBWR		
49	EMAD		
49	HB Robinson		
49	HB Robinson (PWR)		
49	Oconee-1		
49	Oconee-2		
49	Peach Bottom		
49	Point Beach-1 (PWR)		
49	Saxton Mo		
49	Surry		
50	BCD-LFRSB		
50	LOFT fines		

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Appendix E

Schematics of DOE Spent Nuclear Fuel

Single Pass Reactor Fuel Elements

Fast Flux Test Facility (FFTF) Standard Driver Fuel Assembly

Shippingport Core II Blanket Fuel Assembly

MTR Fuel Element

Fermi I Radial Blanket Subassembly

Fermi I Axial Blanket Subassembly

Horizontal Section - Enrico Fermi Reactor

EBR-II Subassembly and Fuel Element

Dimension (inches)	Fuel Element	
	Mark I A	Mark II
A	18.1	24.2
B	18.05	23.81
C	0.65	1.500

(dimensions on figure in inches)

EBR-II Fuel Element

Fort St. Vrain Graphite Fuel

Peachbottom Fuel Element

Pulstar Fuel Element

TYPICAL X-SECTION
WITHOUT COMB

24 FUEL PLATES

TYPICAL X-SECTION
WITH COMB

ELEVATION

MURR Fuel Element

Fuel Moderator Element for Mark I Reactor

TRIGA FLIP Fuel Rod

ATR Fuel Assembly

N Reactor Fuel Assembly (Production Reactor Fuel)

VBWR-Geneva Fuel Element

Intact TRIGA Fuel Element

E-21

End view

ICPP-A-15491
(9-88)

* all dimensions in cm

- Boron Carbide
- Steam Passage
- Cladding
- Fuel

Pathfinder Superheater Fuel Element

WAPD Capsules

WAPD Fuel Pins

Appendix F

Categorization of DOE Spent Nuclear Fuel

CATEGORIZATION OF DEPARTMENT OF ENERGY

SPENT NUCLEAR FUEL

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I. ABSTRACT

The Department of Energy (DOE) has over 200,000 units of Spent Nuclear Fuel (SNF) in storage at 13 different DOE facilities, and several universities and non-DOE institutions. These are presently planned for conditioning and dispositioning in a repository. Except for existing accountability purposes, no centralized inventory or characteristics database for SNF existed prior to September, 1994. This paper reports the results of an effort to gather information on the DOE SNF characteristics and to analyse some of the characteristics.

II. INTRODUCTION

The Department of Energy (DOE) has over 150 different types of Spent Nuclear Fuel (SNF), comprising over 200,000 units, in storage at DOE, private non-DOE and university facilities across the United States. The present DOE plan does not include reprocessing the fuel for the recovery of uranium, but 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 them in categories of SNF with similar characteristics to allow the evaluation of the SNF and the proposed dispositioning options.

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".

Information available about the SNF stored at the DOE facilities is as varied as the fuel itself. Fuel received in the past few years is well-characterized and documented. Older fuels, however, do not have the same level of information available. Much of the information existing at the fuel storage sites is incomplete. Over the years the information requirements before the SNF would be accepted for storage and reprocessing have increased significantly. The information needed for conditioning the fuel for final dispositioning may be different in character and amount than the information needed previously for reprocessing and may not be readily available.

The DOE has traditionally grouped fuel for reprocessing and the recovery of uranium by two main characteristics. These were the enrichment of the uranium and the cladding and construction materials of the fuel. The first of these was an economic consideration.

Enriched uranium was viewed as a valuable resource and worth the cost of recovery. The second was the process chemistry that could be used for a specific cladding material. Three main processes existed for reprocessing: an aluminum clad fuel process, a zirconium clad fuel process, and a stainless steel clad fuel process. These processes were located at three DOE facilities, the Savannah River Site, the Hanford site, and the Idaho National Engineering Laboratory. Fuel assignments to these sites were based at least partially on the site's capability to reprocess the fuel. Other criteria included the location of the reactor in relationship to the site and storage room available.

Spent Nuclear Fuels that met these criteria were routinely reprocessed at the three facilities for many years. SNF that did not meet the criteria for reprocessing, i.e. low enriched or peculiarities that did not fit the reprocessing flow sheet, were stored for future reprocessing when the need arose. These fuels were classified as "Special SNF" because no process existed for their reprocessing. Hence, four categories of SNF existed in the DOE: high enriched aluminum clad, high enriched stainless steel clad, high enriched zirconium clad, and special.

With the termination of SNF reprocessing for the recovery of uranium, the traditional groupings do not have as much significance as they did prior to the decision. No longer can many fuels be excluded from active planning. Now other characteristics may be much more important for conditioning and dispositioning.

VI. DESCRIPTION OF WORK

The 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. Next the SNF inventory was divided into categories based on the characteristics of each of the SNFs.

A. Important Characteristics

From the analysis of the requirements and proposed processes for dispositioning SNF several characteristics were judged important. These characteristics included: fuel

type and compound, matrix type and material, cladding type, uranium enrichment, fuel burn-up, RCRA and other 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, oxide, hydride, carbide, alloy, etc. These characteristics are important because of 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. Also, several of the proposed processes are for specific compounds such as the oxidation of uranium metal to uranium oxide, which will expand and crack the cladding.

Matrix type and material Possible categories of matrix types and materials include aluminum, zirconium, thorium, ternary, ceramic, powder, carbide, graphite, etc. Each of these types is important because of possible chemical reactions, both in the conditioning process and in the repository.

Cladding type Cladding materials include aluminum, stainless steel, zirconium, graphite, Hastelloy, clad fuel, etc. This characteristic is important because some are much more susceptible to corrosion, and some conditioning technologies will only work for certain types of cladding.

Uranium 235 enrichment The standard way of evaluating 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 the major criteria 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 none to very high. This characteristic coupled with the age of the fuel will influence the concentration of fission products in the SNF and will influence the heat generation rate.

RCRA and other hazardous material content This category specifically calls out RCRA hazardous material but can also include any other materials that are deemed to be hazardous. This characteristic is important because even

though at the present time SNF is not governed by RCRA it could be if Congress or the EPA decides that it should be.

Actinide content Plutonium and thorium are considered to be the most important actinides other than uranium; plutonium because of proliferation considerations, and thorium because of its high quantities in specific fuels. 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.

B. SNF Inventory

The SNF inventory was taken from the inventory documents used in the SNF & INEL EIS preparation. The inventory was prepared using a variety of information sources including: Spent Fuel Working Group Report, Spent Fuel Background Report, Directory of Nuclear Research Reactors, and information supplied to the DOE National SNF database.

The inventory was compiled in a Quattro Pro 5.0 for DOS spreadsheet. The spreadsheet contained fields for the Fuel Name, Location, Facility, Total Mass, Volume, Number of Units, Uranium Mass, Uranium Enrichment, Fissile Mass, and MTHM. These were used because they best represent the quantity of DOE SNF. The SNF was entered by site location, facility, and fuel name. The university fuels were all listed separately but

were treated as one site in the subtotals. The miscellaneous reactors were treated as one site. The foreign research reactors were listed but no quantitative information was entered, except for that foreign SNF already located at DOE sites.

As much information about the specific characteristics of interest for each fuel was gathered from all available sources such as those consulted for the inventory information. The spreadsheet containing the EIS inventory was then divided into categories based on the characteristics of interest. This created 53 categories of fuel each with distinct characteristics. Table 1 (next page) summarizes 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 53 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 are constructed with much more structural material for ruggedness and these will have more total mass. Table 2 shows the largest category in total mass and MTHM as well as the percent uranium in the total mass.

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	de clad	minor		low	SNAP
5.	High	oxide	Al	Al			high	HFIR
6.	High	oxide	SST	SST	minor	TiO2		APPR
7.	High	oxide		SST	minor	Na		FFTF Test
8.	High	oxide	ThO2	SST	minor	Th, U-233		ERR
9.	High	oxide	ceramic	Ferrous		Ti, Y, Be		GCRE
10.	High	oxide	ZrO2	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			U-233		SRS-U-233
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	Na	med.	FERMI-II
17.	High	metallic	Zr	Zr	minor		low	HWCT
18.	High	metallic	frissium	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		FFTF test
22.	High	oxide	graphite	Zr				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		ZrO2, CaO low		PBF
29.	Low	oxide	ThO2	SST	minor	Th, U-233 med.		Dresden
30.	Low	oxide	poly	none			low	AGN
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, UN ₃		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	metallic		Zr	Th		low	HWCTR
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				OSR
48.	Low	salt		none	none	Li, Be, Zr		MSRE
49.	Natural	oxide		Zr	Pu		high	Commercial
50.	Natural	oxide		Zr			High	LOFT
51.	Low	oxide	melted	Zr	Pu	Cd	med.	TMI
52.	Low	oxide	carbon	Zr	Pu	C coated	high	Shippingport PWR
53.	Depleted	metallic			Al	Pu	low	SPR

Notes

1. Enrichment: > 20% high, < 20% low, .7% natural, < .7% depleted
2. Cladding: Zr - zirconium or zirconium alloy, SST - stainless steel, Al - Aluminum
3. Matrix: 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

Table 2
Distribution of Largest Categories of SNF

SNF Category	Example Fuel	Total Mass	MTHM	% Uranium in total mass
1	Naval	539000	9.95	1.9 %
18	EBR-II	157690	48	30%
19	Graphite	351552	27.6	7.9%
35	Commercial low Burn	87300	40	46%
37	Shippingport	84000	42	50%
39	SRS Aluminum	365980	176	48%
40	Fermi	50000	34	68%
43	N-Reactor	2263000	2100	93%
49	Commercial High Burn	54614	42	77%
51	TMI	120000	82	68%

Twenty five of the 53 categories (47%) contain only one SNF type. This is indicative of the Reactor and Fuel development mission of the DOE where there were many one of a kind fuel manufactured.

Thirty two of the 53 categories (60%) 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 few SNF categories that are located at many DOE sites, as shown in Table 3.

Table 3
SNF Categories Located At Different Sites

Category	Example	Sites
14	MTR Type	8
35	Commercial	7
2	TRIGA FLIP	5
18	EBR-II	5
24	TRIGA	5

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.

The distribution of the SNF categories is shown in table 4.

Table 4 SNF Category Distribution By DOE Site	
Site	Number of Categories
INEL	26
SRS	21
Hanford	14
ORNL	9
University	9
Sandia	5
LANL	2

This distribution shows the diversity of SNF categories at each of the DOE sites. INEL and SRS have more different categories than any of the other sites.

B. Characteristics

The distribution of the fuel meat material is contained in table 5.

Table 5 Distribution of DOE SNF by Fuel Meat Material		
Fuel Meat Material	Total Mass (kg)	% of Total Mass
Oxide	64628	1.4%
Al-Alloy	43924	1.0%
Metal or Alloy	2470690	55%
Carbide	351552	7.9%
Hydride	12741	0.2%
Naval	539000	12%

The material of the fuel meat is

important because of potential chemical reactions that may occur or potential treatment that may be proposed. The majority of the meat material is metal or non-aluminum uranium alloys. These materials have the potential for chemical reactions with the environment of a repository. Carbides make up the third largest category of fuel meat material and they also have potential chemical reactions with a repository environment.

The type of cladding material is contained in table 6.

Table 6 Distribution of DOE SNF by Cladding Material		
Cladding Material	Total Mass (kg)	% of Total Mass
Zr	3360982	75%
SST	282992	6.3%
Al	451425	10%
Graphite	351552	7.8%

The cladding material is important for long term storage stability or for potential conditioning technologies. The largest majority of the SNF is clad with Zr, which is presently considered stable in most storage environments and is also inert to most chemicals that may be used for dissolution.

The present condition of the fuel may influence plans to interim store or for final treatment plans. The fuel that have known deteriorated conditions are listed in table 7.

Table 7 Reported Condition of DOE SNF		
Condition	Total Mass (kg)	% of Total DOE SNF
Melted	120000	2.7%
Clad Breach	1131500 ¹	25%
Declad or no Clad	5298	0.01%
Salt	12000	0.3%
Al clad	451425 ²	10%
Total	1710223	38%

Note:

1. Between 30 to 50% of the mass of the N-Reactor fuel is estimated to be breached. 50 % was assumed.
2. It is estimated that all Al clad fuel is corroded or will be corroded before a repository is opened

The SNF that has deteriorating cladding or no cladding represents potential problems if the fuel is scheduled for direct disposal. The primary barrier for the fuel meat including fission products is the cladding. Also corrosion products on the cladding will influence how dry the fuel can be made.

Highly uranium 235 enriched SNF presents some possible problems for treatment technologies as well a placement of the SNF into a repository. High enriched SNF (>20%) accounts for 28% of the total SNF. The distribution of the SNF at DOE sites by uranium enrichment is shown in table 8.

Table 8 Distribution of SNF Categories By Uranium Enrichment		
Site	High	Low
INEL	14	12
SRS	8	13
Hanford	4	10
ORNL	6	3
University	4	5
Sandia	5	0

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

VI. CONCLUSIONS

There is a wide range of SNF types and characteristics. Twenty of the 53 categories make up 95% of the total mass and 99% of the MTHM. Several categories have only one type of SNF and only small quantities of these fuels exist. Sixty percent of the SNF categories exist at only one site. Only a few categories are widely distributed.

The SNF characteristics vary greatly. The percent uranium in the SNF total mass varies from 1.9% to 93%. Treating these fuels the same may cause an incomplete analysis. Fifty five percent of the SNF has uranium metal or uranium metal non-aluminum alloy fuel meat. But, a process designed to treat these fuels may not work on 45% of the fuel.

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.

Appendix G

DOE-Owned Spent Nuclear Fuel Categories, Types, Locations and Quantities

Categories and RCRA Concerns

SNF Category	RCRA Concern #	Category Description
1		High uranium 235 enrichment, Zirconium clad, high burnup, classified
2		High uranium 235 enrichment, uranium zirconium hydride fuel, SST clad, graphite plugs, low burnup, minor Pu and Mo
3		High uranium 235 enrichment, uranium zirconium hydride fuel, Zr clad, graphite plugs, low burnup, minor Pu
4		High uranium 235 enrichment, uranium zirconium hydride fuel, clad, in Al cans, low burnup, some Mo
5		High uranium 235 enrichment, uranium oxide fuel, Al matrix, Al clad, high burnup
6		High uranium 235 enrichment, uranium oxide fuel, SST matrix, SST clad, some TiO ₂ , range of burnup
7	8	High uranium 235 enrichment, mixed U and Pu oxide fuel, SST clad, metallic sodium bonded
8		High uranium 235 enrichment, uranium oxide fuel, SST clad, thorium oxide in matrix, uranium 233
9	1	High uranium 235 enrichment, uranium oxide fuel, Be Mg Ti Zr Y ceramic matrix, ternary fuel, ferrous material clad
10		High uranium 235 enrichment, uranium oxide fuel, ZrO ₂ with Ca & B matrix, Zr clad, minor Pu
11		High uranium 235 enrichment, uranium oxide, Zr clad
12	1	High uranium 235 enrichment, uranium oxide powder or pellets, ceramic matrix containing Be and Ca, clad
13		High uranium 235 enrichment, uranium and thorium oxide fuel, microspheres, in SST pipe
14	2	High uranium 235 enrichment, U-Al or UAlx fuel, Al matrix, Al clad, low burnup
15	2	High uranium 235 enrichment, U-Al or UAlx fuel, Al matrix, Al clad, high burnup
16	2,8	High uranium 235 enrichment, U-Mo metallic fuel, Zr clad, possible MoH
17	2,3	High uranium 235 enrichment, uranium metal fuel, Zr matrix, Zr clad
18	2,3,8	High uranium 235 enrichment, uranium metal with fissium fuel, metallic Na bonded, SST clad, Pu
19	4	High uranium 235 enrichment, uranium carbide fuel, thorium carbide matrix, coated fuel particles, graphite matrix, U-233
20	4	High uranium 235 enrichment, uranium carbide fuel, possible graphite matrix, Zr or SST clad
21	4,8	High uranium 235 enrichment, mixed U and Pu carbide, metallic Na bonded, SST clad
22		High uranium 235 enrichment, uranium oxide fuel, graphite matrix, Zr clad, low burnup
23		Low uranium 235 enrichment, uranium zirconium hydride fuel, Al clad, graphite plugs, low burnup, minor Pu and Mo
24		Low uranium 235 enrichment, uranium zirconium hydride fuel, SST clad, graphite plugs, low burnup, minor Pu and Mo
25		Low uranium 235 enrichment, uranium zirconium hydride fuel, incoloy clad, graphite plugs, possible Mo
26		Low uranium 235 enrichment, uranium oxide fuel, SST clad, high burnup
27		Low uranium 235 enrichment, uranium oxide fuel, Al cermet, Al clad
28		Low uranium 235 enrichment, uranium oxide fuel, ZrO ₂ CaO ceramic matrix, ternary oxide fuel, SST clad, low burnup
29		Low uranium 235 enrichment, uranium oxide fuel, thorium oxide matrix, SST clad, U-233, low burnup
30		Low and natural uranium 235 enrichment, uranium oxide fuel, Zr matrix, Zr clad
31		Low uranium 235 enrichment, mixed U Pu oxide fuel, Zr clad
32		Low uranium 235 enrichment, Mixed U and Pu oxide fuel, SST clad, high burnup
33		Low uranium 235 enrichment, uranium zirconium metal fuel, U-Pu-Zr matrix, SST clad
34		Plutonium Oxide fuel, SST clad
35		Low uranium 235 enrichment, uranium oxide fuel, Zr clad, lower burnup
36		Low uranium 235 enrichment, uranium oxide fuel, ceramic matrix with Gd, Zr clad, high burnup
37		Low uranium 235 enrichment, uranium oxide fuel, thorium oxide ZrO ₂ CaO ceramic matrix, Zr clad, U-233
38		Low uranium 235 enrichment, uranium oxide fuel particles, carbon coated particles, Zr clad, SST brackets, high burnup
39		Low uranium 235 enrichment, U-Al fuel, Al matrix, Al clad
40	8	Low uranium 235 enrichment, U-Mo metallic fuel, SST clad, metallic Na bonded
41	3	Low and depleted uranium 235 enrichment, uranium metal fuel with some uranium oxide, Zr matrix, Zr clad
42	3	Low uranium 235 enrichment, uranium and thorium oxide fuel, Zr clad, low burnup
43	1,3	Low uranium 235 enrichment, uranium metal fuel, Zr clad, many elements have cladding breaches, medium burnup, Pu
44	3	Low uranium 235 enrichment, uranium metal fuel, Mo, SST clad
45	3,8	Low uranium 235 enrichment, uranium metal fuel, SST clad, metallic Na bonded, Pu
46	4,8	Low uranium 235 enrichment, uranium carbide fuel, SST clad, metallic Na bonded, medium burnup
47		Low uranium 235 enrichment, uranium silicon fuel, Al cermet, Al clad
48	1	Low uranium 235 enrichment, molten salt matrix, Li Be Zr U fluoride salts
49		Natural uranium 235 enrichment, uranium oxide fuel, Zr clad, high burnup, Pu
50		Natural uranium 235 enrichment, uranium oxide fuel, some Zr clad, much of the clad disrupted, SST containers, high burnup
51	7	Low uranium 235 enrichment, uranium oxide fuel, Zr clad, Damaged fuel, melted, not intact, melted Cd control rods
52		Natural uranium enrichment, uranium oxide fuel particles, carbon coated particles, Zr clad, SST brackets, high burnup, Pu
53	3	Depleted uranium, uranium metal fuel, Al clad, low burnup, Pu
54		Low uranium 235 enrichment, uranium nitride fuel, niobium clad
55		Natural uranium 235 enrichment, uranium metal block, contained in SST container

Note: RCRA concerns 5 and 6 (not shown) represent broad concerns potentially impacting a substantial number of SNF types.

55 CAT	SITE	CUSTODIAN	FACILITY	FUEL NAME	Tot Mass (kg)	Volume (m3)	Items	Units	U Mass (kg)	Enrichme	Fissile Mas (kg)	MTHM
1	High uranium 235 enrichment, Zirconium clad, high burnup, classified											
1	INEL	LITCO	CPP-603	Naval	40,000	10.00	150	unit	724.5	HEU	700.0	0.725
1	INEL	LITCO	CPP-666	Naval	330,000	100.00	700	unit	6,357.3	HEU	6,000.0	6.400
1	INEL	NRF	ECF	Naval	150,000	37.00	240	unit	2,500.0	HEU	2,500.0	2.500
1	INEL	NRF	Prototype	Naval	39,000	11.00	48	unit	570.0	HEU	570.0	0.600
1	NNPP	Other Navy	Shipyards	Naval	-	-	-	-	-	-	-	-
2	High uranium 235 enrichment, uranium zirconium hydride fuel, SST clad, graphite plugs, low burnup, minor Pu and Mo											
2	INEL	ANL-W	NRAD	TRIGA - NRAD	20	0.04	61	elem	11.0	64	7.0	0.010
2	INEL	LITCO	CPP-603	TRIGA FLIP	22	0.01	2	can	1.2	68	0.8	0.001
2	UNIV	OR St U	OR St Rx	OR St U - TRIGA	213	0.08	96	elem	17.4	70 / 19	11.4	0.017
2	UNIV	TX A&M U	Nuc Sci Cnt R	TX A&M - TRIGA	408	0.14	186	elem	30.0	70 / 19	12.5	0.030
2	UNIV	WA St U	WA St U Rx	WA St U - TRIGA	468	1.30	215	elem	36.8	70 / 19	13.3	0.037
2	FRR	FRR	FRR site	FRR HEU TRIGA								
3	High uranium 235 enrichment, uranium zirconium hydride fuel, Zr clad, graphite plugs, low burnup, minor Pu											
3	INEL	LITCO	CPP-IFSF	Ber-II Triga	254	0.24	21	elem	9.2	40	4.0	0.009
4	High uranium 235 enrichment, uranium zirconium hydride fuel, declad, in Al cans, low burnup, some Mo											
4	INEL	LITCO	CPP-603	SNAP	50	0.10	19	can	21.0	93	19.6	0.021
4	INEL	LITCO	CPP-603	Atomics International	10	0.04	12	can	7.8	93	7.2	0.008
5	High uranium 235 enrichment, uranium oxide fuel, Al matrix, Al clad, high burnup											
5	ORR	ORR	HFIR	HFIR	8,674	7.38	62	assem	626.0	93	583.0	0.626
5	OTHER	NIST, Gaithe	NBSR (NIST)	NIST	831	0.79	190	elem	25.3	81	20.5	0.025
5	SRS	SRS	RBOF	Sterling Forest oxide	650	3.25	226	bundl	102.1	91	94.6	0.102
6	High uranium 235 enrichment, uranium oxide fuel, SST matrix, SST clad, some TiO2, range of burnup											
6	INEL	LITCO	CPP-603	Pathfinder	960	1.36	417	rod	53.4	92	49.2	0.053
6	INEL	LITCO	CPP-603	VBWR (Geneva)	24	0.07	4	can	12.4	21	2.6	0.012
6	INEL	LITCO	CPP-603	GENTR Filters	50	0.19	10	bskt	4.4	92	4.1	0.004
6	INEL	LITCO	CPP-603	BORAX V	150	0.30	36	assem	20.1	93	19.4	0.020
6	INEL	LITCO	CPP-603	APPR (AGE-2)	2	0.01	1	can	0.2	91	0.2	0.000
6	INEL	LITCO	CPP-603	BMI	23	0.02	3	can	1.8	67	1.2	0.002
6	INEL	LITCO	CPP-603	SPSS (SPERT)	6	0.01	1	can	0.6	93	0.5	0.001
6	INEL	LITCO	CPP-603	SM-1A	786	1.20	93	assem	65.8	86	56.6	0.066
6	SRS	SRS	RBOF	B&W Scrap	0.1	0.00	1	can	0.0	43	0.1	0.000
6	SRS	SRS	RBOF	EBWR Plates	5	0.01	4	can	1.7	93	1.6	0.002
7	High uranium 235 enrichment, mixed U and Pu oxide fuel, SST clad, metallic sodium bonded											
7	Hanford	Hanford	FFTF	SRF				2 assem				
8	High uranium 235 enrichment, uranium oxide fuel, SST clad, thorium oxide in matrix, uranium 233											
8	SRS	SRS	RBOF	ERR	500	3.10	38	bundl	224.0	83	201.0	5.043
8	SRS	SRS	RBOF	SRE	400	0.01	36	can	154.9	93	144.0	2.127
8	SRS	SRS	RBOF	HWCT - U-Th	1,103	0.11	1	assem	1.2	80	0.9	0.079
9	High uranium 235 enrichment, uranium oxide fuel, Be Mg Ti Zr Y ceramic matrix, ternary fuel, ferrous material clad											
9	INEL	LITCO	CPP-603	GCRE can	2	0.01	1	can	0.9	93	0.8	0.001
9	O-DOE	SNL	ACRR	ACRR	100	1.00	256	elem	26.0	35	5.0	0.030
9	SRS	SRS	RBOF	GCRE	100	0.01	72	unit	61.3	92	56.6	0.061
9	SRS	SRS	RBOF	ML-1	100	1.00	68	assem	58.6	93	54.0	0.059
9	SRS	SRS	RBOF	HTRE	10	0.10	13	can	4.0	84	3.4	0.004
10	High uranium 235 enrichment, uranium oxide fuel, ZrO2 with Ca & B matrix, Zr clad, minor Pu											
10	INEL	LITCO	CPP-666	Shippingport PWR C2-	6,800	1.80	19	clust	219.1	66	151.3	0.219
10	INEL	LITCO	CPP-666	Shippingport PWR C2-	7,100	1.80	20	clust	300.6	80	243.0	0.300
10	INEL	LITCO	CPP-666	Shippingport PWR C1-	3	0.19	1	cluster	2.0	80	1.6	0.002

55 CAT	SITE	CUSTODIAN	FACILITY	FUEL NAME	Tot Mass (kg)	Volume (m3)	Items	Units	U Mass (kg)	Enrichme	Fissile Mas (kg)	MTHM
10	SRS	SRS	RBOF	EBWR	150	0.01	32	assem	29.0	92	26.7	0.029
11	High uranium 235 enrichment, uranium oxide, Zr clad											
11	INEL	LITCO	TRA-603	PCM	8	0.12	7	canst	5.4	29	1.6	0.006
12	High uranium 235 enrichment, uranium oxide powder or pellets, ceramic matrix containing Be and Ca, clad											
12	INEL	LITCO	CPP-603	TORY-IIA	2,000	0.84	146	can	48.6	93	45.3	0.049
12	INEL	LITCO	CPP-603	GCRE pellets	1	0.01	1	can	0.1	93	0.1	0.000
12	INEL	LITCO	CPP-IFSF	TORY-IIC	2,500	3.50	655	tube	59.1	93	55.0	0.059
12	O-DOE	SNL	Hot Cell Fac	PNL mixed	20	0.01	-	-	8.7	23	2.0	0.009
12	O-DOE	SNL	Manzano	PNL mixed	50	0.10	-	-	24.8	20	5.0	0.025
12	FRR	FRR-East	FRR sites	FRR-East Targets	-	-	-	-	-	-	-	-
13	High uranium 235 enriched, uranium and thorium oxide fuel, microspheres, in SST pipe											
13	ORR	ORR	SWSA6	KEMA	132	0.01	1	pipe	5.8	90	5.2	0.023
14	High uranium 235 enrichment, U-Al or UAlx fuel, Al matrix, Al clad, low burnup											
14	INEL	LITCO	CPP-603	ORR	85	0.07	17	assem	3.3	80	2.6	0.003
14	INEL	LITCO	CPP-666	U of WA	70	0.07	26	bundl	3.9	93	3.6	0.004
14	INEL	LITCO	TRA-660	ARMF/CFRMF	360	0.40	66	unit	12.7	93	11.7	0.013
14	O-DOE	ANL-E	CP-5	CP-5 flux converter	2	0.02	2	tubes	1.2	93	1.1	0.001
14	O-DOE	BNL	BMRR	BMRR	160	0.15	36	assem	3.4	84	2.9	0.003
14	O-DOE	BNL	HFBR	HFBR	3,000	3.20	944	unit	242.0	77	185.0	0.242
14	O-DOE	LANL	CMR	OMEGA-W	507	0.60	86	elem	14.8	93	12.7	0.015
14	O-DOE	SNL	SNM storage	SPR-II	20	0.10	-	-	12.0	93	10.0	0.010
14	O-DOE	SNL	SPR	SPR-III	500	0.10	18	elem	227.0	93	220.0	0.220
14	O-DOE	SNL	SPR	SPR-II&III	60	0.10	-	-	31.0	93	30.0	0.030
14	O-DOE	SNL	SPR	SPR-II	200	0.10	6	elem	92.0	93	90.0	0.090
14	ORR	ORR	BSR	ORR	143	0.18	32	elem	52.0	20	10.3	0.052
14	ORR	ORR	BSR	BSR	184	0.21	41	elem	7.0	93	6.0	0.007
14	ORR	ORR	TSR	TSR	182	0.10	1	assem	9.2	93	8.6	0.009
14	OTHER	GE, Pleasant	GENTR	GENTR	80	0.10	32	elem	8.0	93	7.2	0.008
14	SRS	SRS	RBOF	ATSR	30	0.10	4	bundl	3.2	93	3.0	0.003
14	SRS	SRS	RBOF	JMTR	200	20.00	15	bundl	16.7	89	14.8	0.017
14	UNIV	IA St U	IA St U Rx	MTR type	100	0.10	14	elem	4.1	93	3.9	0.004
14	UNIV	U of VA	U of VA Rx	U of VA - MTR	500	0.38	32	elem	25.1	93 / 19	13.0	0.025
15	High uranium 235 enrichment, U-Al or UAlx fuel, Al matrix, Al clad, high burnup											
15	FRR	FRR-East	FRR sites	FRR-East Alum SNF	-	-	-	-	-	-	-	-
15	FRR	FRR-West	FRR sites	FRR-West Alum SNF	-	-	-	-	-	-	-	-
15	INEL	LITCO	CPP-603	MURR-Columbia	158	0.24	24	assem	16.1	88	14.1	0.016
15	INEL	LITCO	CPP-603	HFBR	87	0.08	20	assem	4.9	78	3.8	0.005
15	INEL	LITCO	CPP-603	ATR	1,101	1.17	128	assem	99.2	82	79.2	0.099
15	INEL	LITCO	CPP-666	ATR	6,950	7.41	808	assem	674.7	83	558.0	0.680
15	INEL	LITCO	CPP-666	HFBR	1,013	0.87	220	assem	58.5	80	46.9	0.059
15	INEL	LITCO	CPP-666	ARMF	4	0.01	15	plate	0.2	90	0.2	0.000
15	INEL	LITCO	CPP-666	MURR-Columbia	198	0.30	32	assem	21.9	88	19.2	0.022
15	INEL	LITCO	TRA-670	ATR	7,197	7.36	836	assem	764.7	86	662.1	0.766
15	O-DOE	ANL-E	Alpha-gamma	ORR	80	0.05	16	elem	2.0	93	2.0	0.002
15	SRS	SRS	H-Canyon	Driver (H-canyon)	430	0.42	13	assem	67.6	61	41.4	0.068
15	SRS	SRS	K-Basin	Driver (K)	20,400	29.00	902	assem	3,237.0	66	2,113.5	3.256
15	SRS	SRS	L-Basin	Driver (L)	17,250	16.70	516	assem	2,593.0	60	1,546.0	2.613
15	SRS	SRS	P-Basin	Driver (P)	10,700	14.80	449	assem	1,391.2	66	921.3	1.408
15	SRS	SRS	RBOF	Sterilizing Forest fuel	160	0.80	34	bundl	24.6	93	20.9	0.025
15	SRS	SRS	RBOF	Foreign from relief	342	0.07	153	elem	18.7	60	13.6	0.019
15	SRS	SRS	RBOF	MURR-Columbia	3,900	14.44	52	bundl	70.2	87.00	61.2	0.070
15	SRS	SRS	RBOF	RINSC	65	0.22	13	bundl	8.5	90	7.7	0.009
15	SRS	SRS	RBOF	ORR-HEU	1,000	1.00	17	bundl	20.5	27	16.0	0.021
15	SRS	SRS	RBOF	MIT	200	0.10	16	bundl	15.9	81	12.9	0.016
15	SRS	SRS	RBOF	RHF	300	0.30	4	assem	25.5	81	20.8	0.026
15	SRS	SRS	RBOF	ANL anus	20	0.10	4	bundl	2.8	93	2.6	0.003
15	SRS	SRS	RBOF	Product fuel samples	10	0.10	5	unit	6.0	32	1.9	0.006
15	SRS	SRS	RBOF	OH St U - MTR	200	0.30	4	bundl	3.3	93	3.1	0.003

55 CAT	SITE	CUSTODIAN	FACILITY	FUEL NAME	Tot Mass (kg)	Volume (m3)	Items	Units	U Mass (kg)	Enrichme	Fissile Mas (kg)	MTHM
15	SRS	SRS	RBOF	U of VA	36	14.44	8	bundl	6.9	89	6.1	0.007
15	SRS	SRS	SRTC	Driver	5	0.01	4	unit	0.8	38	0.3	0.001
15	UNIV	Georgia Tec	Georgia Tech	MTR type	290	0.31	27	elem	5.0	93	4.5	0.005
15	UNIV	MIT	MIT RRx	MTR type	260	0.13	68	elem	30.6	90	27.1	0.031
15	UNIV	MURR-Colu	MURR-Colum	MTR type	549	0.88	90	elem	67.7	93	61.2	0.068
15	UNIV	Purdue U	Purdue U Rx-	Purdue - MTR	200	0.003	124	plate	2.2	93	2.0	0.002
15	UNIV	U of FL	U of FL Trng	U of FL - Argonaut	313	0.65	256	plate	4.0	93	3.7	0.004
15	UNIV	U of Lowell	U of Lowell N	U of Lowell - MTR	230	0.15	26	elem	4.3	93	4.0	0.004
16	High uranium 235 enrichment, U-Mo metallic fuel, Zr clad, possible MoH											
16	INEL	LITCO	CPP-666	Fermi core I & II	4,600	1.20	214	can	3,911.1	25	997.4	3.900
17	High uranium 235 enrichment, uranium metal fuel, Zr matrix, Zr clad											
17	SRS	SRS	RBOF	HWCT - HEU	200	0.01	64	unit	38.7	85	32.9	0.039
17	SRS	SRS	RBOF	ORNL (S1W)	1	0.01	3	can	0.2	93	0.2	0.000
18	High uranium 235 enrichment, uranium metal with fissium fuel, metallic Na bonded, SST clad, Pu											
18	Hanford	Hanford	Area 200	EBR-II (LANL)	400	16.40	24	cask	158.5	100	190.0	0.200
18	Hanford	Hanford	FFTF	IFR-1			1	assem				
18	INEL	ANL-W	EBR-II	EBR-II	90,000	100.00	416	assem	14,255.0	66 & 2	313.0	14.260
18	INEL	ANL-W	HFEF	EBR-II	5,000	5.00	4344	elem	2,013.0	66 & 2	252.0	2.060
18	INEL	ANL-W	RSWF	EBR-II	15,000	33.00	1350	liners	11,854.0	66 & 2	469.0	11.910
18	INEL	LITCO	CPP-603	EBR-II ANL-6	5	0.01	4	can	1.6	52	0.8	0.002
18	INEL	LITCO	CPP-603	EBR-II	1,309	2.85	2164	can	1,170.1	60	723.1	1.200
18	INEL	LITCO	CPP-666	EBR-II	900	1.96	1472	can	796.7	62	501.7	0.800
18	SRS	SRS	RBOF	EBR-II (ANL)	1	0.01	1	can	0.4	85	0.5	0.001
18	SRS	SRS	RBOF	EBR-II (HEDL)	5	0.01	1	can	2.0	79	2.3	0.003
19	High uranium 235 enrichment, uranium carbide fuel, thorium carbide matrix, coated fuel particles, graphite matrix, U-233											
19	INEL	LITCO	CPP-749	Peach Bottom C-1	32,270	36.20	796	elem	201.8	76	173.5	1.627
19	INEL	LITCO	CPP-IFSF	FSVR	95,000	80.00	744	assem	308.3	84	257.9	8.600
19	INEL	LITCO	CPP-IFSF	Peach Bottom C-2	33,000	15.70	786	elem	125.2	53	92.3	1.300
19	INEL	LITCO	CPP-IFSF	Peach Bottom C-1	730	0.82	18	elem	5.2	76	4.5	0.035
19	ORR	ORR	Bld-7829	Peach Bottom	552	0.50	13	can	1.8	78	1.5	0.014
19	ORR	ORR	Bld-3525	Misc	1	0.10	1	unit	0.1	-	-	0.000
19	OTHER	GA, San Die	GA Hot Cell	HTGR fuel	2	0.01	1	unit	0.2	62	0.1	0.002
19	Spec Case	PSC	FSVR	FSVR	190,000	160.00	1464	assem	616.0	54	333.0	16.000
20	High uranium 235 enrichment, uranium carbide fuel, possible graphite matrix, Zr or SST clad											
20	Hanford	Hanford	FFTF	AC-3			1	assem				
20	Hanford	Hanford	FFTF	FC-1			1	assem				
20	O-DOE	SNL	SNL facility	CX	50	0.10	19	elem	23.0	93	20.0	0.020
21	High uranium 235 enrichment, mixed U and Pu carbide, metallic Na bonded, SST clad											
21	Hanford	Hanford	FFTF	ANC-1			1	assem				
22	High uranium 235 enrichment, uranium oxide fuel, graphite matrix, Zr clad, low bumup											
22	INEL	ANL-W	TREAT	TREAT	15	11.00	390	assem	15.0	93	14.0	0.020
23	Low uranium 235 enrichment, uranium zirconium hydride fuel, Al clad, graphite plugs, low bumup, minor Pu and Mo											
23	Hanford	Hanford	Area 200	OR St U - TRIGA	216	2.70	90	assem	17.2	19	3.3	0.020
23	Hanford	Hanford	Bld-308	TRIGA Alum	160	0.04	66	assem	12.2	19	2.4	0.010
23	INEL	LITCO	CPP-603	TRIGA Alum	1,700	0.45	556	rod	102.5	19	20.2	0.100
23	OTHER	Aerotest, Sa	Aerotest R&R	Aerotest-TRIGA	225	0.50	91	elem	14.9	19	3.0	0.015
23	OTHER	VA Hospital,	Omaha VA M	VA-TRIGA	150	0.05	56	elem	10.3	19	2.0	0.001
23	UNIV	U of UT	U of UT Nuc	U of UT - TRIGA	309	0.11	139	elem	25.6	19	5.0	0.026
23	FRR	FRR-East	FRR sites	FRR-East TRIGA	-	-	-	-	-	-	-	-
24	Low uranium 235 enrichment, uranium zirconium hydride fuel, SST clad, graphite plugs, low bumup, minor Pu and Mo											

SS CAT	SITE	CUSTODIAN	FACILITY	FUEL NAME	Tot Mass (kg)	Volume (m3)	Items	Units	U Mass (kg)	Enrichme	Fissile Mas (kg)	MTHM
24	Hanford	Hanford	Bld-308	TRIGA SST	80	0.02	35	assem	6.7	19	1.3	0.010
24	INEL	LITCO	CPP-603	TRIGA SST	84	0.21	296	elem	51.0	19	9.6	0.057
24	O-DOE	SNL	ACRR	FREC	50	0.10	182	elem	9.8	19	2.0	0.010
24	OTHER	AFRRI, Beth	AFRRI TRIGA	AFRRI-TRIGA	219	0.07	95	elem	18.1	19	3.6	0.018
24	OTHER	DOW, Midla	DOW Rx	DOW-TRIGA	200	0.50	78	elem	14.1	19	2.8	0.014
24	OTHER	GA, San Die	GA Mk I & F	GA-TRIGA	800	0.80	263	elem	57.8	93/70/19	23.9	0.058
24	OTHER	McClellan, S	Statnry Neut	McClellan - TRIGA	200	0.50	90	elem	15.0	19	3.0	0.015
24	OTHER	USGS, Denv	GS TRIGA Rx	USGS-TRIGA	300	0.50	161	elem	35.0	19	7.0	0.032
24	UNIV	Cornell U	Cornell TRIGA	Cornell - TRIGA	273	0.10	123	elem	23.2	19	4.4	0.023
24	UNIV	KS St U	KS St U Nuc	KS St U - TRIGA	238	0.08	107	elem	20.0	19	3.6	0.020
24	UNIV	PA St U	PA St Breazea	PA St - TRIGA	402	0.13	175	elem	36.0	19	6.5	0.036
24	UNIV	Reed Colleg	Reed Rx Facili	Reed - TRIGA	149	0.05	67	elem	12.6	19	2.5	0.013
24	UNIV	U of AZ	U of AZ TRIG	U of AZ - TRIGA	215	0.08	97	elem	18.1	19	3.3	0.018
24	UNIV	U of IL	U of IL TRIGA	U of IL - TRIGA	440	0.15	198	elem	37.4	19	7.0	0.037
24	UNIV	U of MD	U of MD Trng	U of MD - TRIGA	207	0.10	93	elem	16.3	19	3.2	0.016
24	UNIV	U of TX	U of TX Mk II	U of TX - TRIGA	342	0.14	154	elem	29.2	19	5.6	0.029
24	UNIV	U of WI	U of WI Nuc R	U of WI - TRIGA	492	1.30	228	elem	39.4	70 / 19	16.1	0.039
24	UNIV	UC Irvine	UC-Irvine Mk I	UC-Irvine - TRIGA	251	0.09	113	elem	21.4	19	4.1	0.021
24	FRR	FRR-E & W	FRR sites	FRR TRIGA	-	-	-	-	-	-	-	-
25	Low uranium 235 enrichment, uranium zirconium hydride fuel, incoloy clad, graphite plugs, possible Mo											
25	FRR	FRR	FRR sites	FRR TRIGA								
26	Low uranium 235 enrichment, uranium oxide fuel, SST clad, high burnup											
26	SRS	SRS	RBOF	CVTR	100	0.05	1	can	67.3	1	0.8	0.067
26	SRS	SRS	RBOF	VBWR	100	0.003	3	bundl	11.9	10	1.3	0.012
27	Low uranium 235 enrichment, uranium oxide fuel, Al cermet, Al clad											
27	UNIV	MURR-Rolla	MURR-Rolla R	MURR-Rolla - MTR	173	0.10	28	elem	4.8	19	4.3	0.005
28	Low uranium 235 enrichment, uranium oxide fuel, ZrO2 CaO ceramic matrix, ternary oxide fuel, SST clad, low burnup											
28	INEL	LITCO	PER-620	PBF Driver	12,000	0.84	2425	rod	563.0	18	103.1	0.563
28	INEL	LITCO	TRA-603	PBF Driver Core - canal	50	0.50	14	can	21.3	18	3.9	0.021
28	INEL	LITCO	TRA-603	PBF Driver Core - plug st	10	0.10	3	can	5.1	18	0.9	0.005
28	INEL	LITCO	TRA-603	PBF experiment rods	50	0.50	19	can	23.0	18	4.2	0.023
28	O-DOE	SNL	ACRR	experiments	1	0.00	-	-	0.6	17	0.1	0.001
29	Low uranium 235 enrichment, uranium oxide fuel, thorium oxide matrix, SST clad, U-233, low burnup											
29	SRS	SRS	RBOF	Dresden	3,000	1.10	30	unit	684.0	6	54.8	2.540
30	Low and natural uranium 235 enrichment, uranium oxide fuel Zr matrix, Zr clad											
30	SRS	SRS	RBOF	EBWR - oxide	35,000	3.90	170	assem	7,409.0	1	83.0	7.420
31	Low uranium 235 enrichment, mixed U Pu oxide fuel, Zr clad											
31	SRS	SRS	RBOF	EBWR - MOX	5,000	0.50	20	assem	918.0	0.2	16.0	0.932
32	Low uranium 235 enrichment, Mixed U and Pu oxide fuel, SST clad, high burnup											
32	Hanford	Hanford	FFTF	FFTF	5,800	16.50	324	assem	8,600.0	0.7	4,860.0	11.000
32	SRS	SRS	RBOF	ORNL -MOX	2	0.002	1	can	0.4	0.8	0.1	0.000
32	Hanford	Hanford	Area 200	GETCF & SEFOR								
33	Low uranium 235 enrichment, uranium zirconium metal fuel, U-Pu-Zr matrix, SST clad											
33	Hanford	Hanford	FFTF	MFF			7	assem				
34	Plutonium Oxide fuel, SST clad											
34	SRS	SRS	RBOF	EPR-1	0	0.01	1	can	0.0		0.0	0.000
35	Low uranium 235 enrichment, uranium oxide fuel, Zr clad, lower burnup											

55 CAT	SITE	CUSTODIAN	FACILITY	FUEL NAME	Tot Mass (kg)	Volume (m3)	Items	Units	U Mass (kg)	Enrichme	Fissile Mas (kg)	MTHM
35	Hanford	Hanford	Bld-324, 325,	LWR Commercial	3,183	5.21	7	assem	2,183.0	3	70.0	2.200
35	INEL	LITCO	CPP-603	PULSTAR - Buffalo	332	0.10	24	can	251.4	5	12.9	0.252
35	INEL	LITCO	TAN-607	Peach Bottom 2	560	0.17	2	assem	354.6	1.5	5.2	0.356
35	INEL	LITCO	TAN-607	LOFT	3,657	0.94	14	assem	2,194.0	4	92.5	2.200
35	INEL	LITCO	TAN-607	CT Yankee	667	0.18	1	assem	378.5	3	10.9	0.382
35	INEL	LITCO	TRA-603	RIA	18	0.01	8	canst	6.1	7	0.4	0.006
35	INEL	LITCO	TRA-603	MAPI	115	1.04	8	canst	23.0	6	1.3	0.023
35	INEL	LITCO	TRA-603	CANDU	14	0.40	2	canst	2.7	10	0.3	0.003
35	INEL	LITCO	TRA-603	LP-FP-1	12	0.01	1	canst	0.0	6	0.0	0.000
35	INEL	LITCO	TRA-603	Halden IFA-431	25	0.03	2	canst	2.3	10	0.2	0.002
35	INEL	LITCO	TRA-603	Halden IFA-226	62	0.09	5	canst	4.6	10	0.5	0.005
35	INEL	LITCO	TRA-603	HB Robinson	524	0.07	4	canst	6.3	2	0.1	0.006
35	INEL	LITCO	TRA-603	Saxton	19	0.01	1	canst	7.1	10	0.7	0.007
35	INEL	LITCO	TRA-603	Peach Bottom 2	55	0.07	5	canst	9.5	2	0.2	0.009
35	INEL	LITCO	TRA-603	OPTRAN	65	0.09	5	canst	19.7	3	0.6	0.020
35	INEL	LITCO	TRA-603	Belgian	89	0.26	7	canst	62.4	5	3.2	0.063
35	INEL	LITCO	TRA-603	LOFT Lead rod	15	0.01	1	canst	3.5	9	0.3	0.004
35	INEL	LITCO	TRA-603	Dresden	157	0.21	2	canst	18.6	2	0.5	0.019
35	INEL	LITCO	TRA-603	TC	26	0.03	2	canst	4.1	12	0.5	0.004
35	O-DOE	ANL-E	Alpha-gamma	Commercial	40	-	1	canst	19.5	5	0.9	0.002
35	SRS	SRS	RBOF	SPERT-3	50	0.01	3	can	9.7	5	0.6	0.010
35	SRS	SRS	RBOF	Saxton UO	100	0.50	5	can	89.2	8	7.1	0.089
35	SRS	SRS	RBOF	LWR samples	15	0.03	5	can	12.6	2	0.3	0.013
35	Spec Case	B&W-Lynch	B&W Hot Cell	Oconee-1	10	0.03	4	canst	7.9	1	0.1	0.008
35	Spec Case	WVDP	WV FRS	Gina (PWR)	23,944	6.84	40	assem	15,060.2	3	484.3	15.120
35	Spec Case	WVDP	WV FRS	Big Rock (BWR)	18,836	4.90	85	assem	10,505.5	3	333.0	10.570
35	UNIV	NC St U	NC St U PUL	NC St - PULSTAR	680	0.18	34	units	432.6	4	16.6	0.433
35	UNIV	SUNY - Buff	Buffalo	SUNY Buffalo - PULSTA	2,000	1.00	43	assem	655.0	5	32.0	0.655
36	Low uranium 235 enrichment, uranium oxide fuel, ceramic matrix with Gd, Zr clad, high burnup											
36	INEL	LITCO	TRA-603	GAP CON	124	0.17	10	canst	11.5	10	1.2	0.011
36	SRS	SRS	RBOF	EBWR - MEU	75,000	0.86	5	unit	1,603.0	6	96.0	1.600
37	Low uranium 235 enrichment, uranium oxide fuel, thorium oxide ZrO2 CaO ceramic matrix, Zr clad, U-233											
37	INEL	LITCO	CPP-749	Shippingport LWBR	84,000	31.10	48	can	550.5	13	519.2	42.570
38	Low uranium 235 enrichment, uranium oxide fuel particles, carbon coated particles, Zr clad, SST brackets, high burnup											
38	SRS	SRS	RBOF	Shippingport	80	0.02	1	can	16.0	0.1	0.1	0.016
39	Low uranium 235 enrichment, U-Al fuel, Al matrix, Al clad											
39	SRS	SRS	F-Canyon	Targets (F-canyon)	23,200	5.20	1224	slug p	22,612.0	0.2	42.0	22.634
39	SRS	SRS	K/L/P-Basin	Non-U targets (Mk 42, 50)	80	0.38	104	unit	0.0	0	4.2	0.059
39	SRS	SRS	L-Basin	Targets (L)	118,900	26.50	6246	slug p	115,383.0	0.2	211.0	115.498
39	SRS	SRS	RBOF	EBR-II Target	20,000	3.00	60	slugs	16,983.0	0.3	118.0	17.000
39	SRS	SRS	RBOF	Nereide	500	0.40	8	bundl	35.4	19	7.0	0.035
39	SRS	SRS	RBOF	U of MI	300	10.00	48	assem	33.9	15	5.1	0.034
39	SRS	SRS	RBOF	Target samples	400	0.50	42	slugs	369.3	0.2	0.7	0.370
39	SRS	SRS	RBOF	ORR-LEU	1,000	1.00	12	bundl	95.0	16	15.0	0.095
39	SRS	SRS	RBOF	Taiwan RR	200,000	3.40	143	can	20,469.0	0.6	144.0	20.480
39	UNIV	Worcester P	Worcester Poly	Worcester - MTR	300	0.16	27	elem	22.8	19	4.5	0.023
39	UNIV	U of MI	Ford NRx	U of MI - MTR	598	0.55	103	elem	74.9	19	11.9	0.072
40	Low uranium 235 enrichment, U-Mo metallic fuel, SST clad, metallic Na bonded											
40	INEL	LITCO	CPP-749	Fermi blanket	50,000	18.70	14	can	34,165.0	0.4	126.5	34.170
41	Low and depleted uranium 235 enrichment, uranium metal fuel with some uranium oxide, Zr matrix, Zr clad											
41	SRS	SRS	RBOF	HWCT DU	4,000	0.50	40	unit	1,466.0	0.6	10.3	1.468
41	SRS	SRS	RBOF	HWCT - LEU	5,000	0.50	49	unit	358.0	1	4.6	0.358
42	Low uranium 235 enrichment, uranium and thorium oxide fuel, Zr clad, low burnup											

55 CAT	SITE	CUSTODIAN	FACILITY	FUEL NAME	Tot Mass (kg)	Volume (m3)	Items	Units	U Mass (kg)	Enrichme	Fissile Mas (kg)	MTHM
42	Hanford	Hanford	FFTF	WB018 & 042				2 assem				
43	Low uranium 235 enrichment, uranium metal fuel, Zr clad, many elements have cladding breaches, medium burnup, Pu											
43	Hanford	Hanford	105-K East B	N-Reactor	1,234,765	112.00	3667	can	1,143,545	0.95	15,139.0	1145.8
43	Hanford	Hanford	105-K West B	N-Reactor	1,027,947	93.00	3815	can	951,900	1.1	14,039.0	953.7
43	Hanford	Hanford	PUREX	N-Reactor	288	0.03	20	assem	267.0	0.9	3.0	0.300
44	Low uranium 235 enrichment, uranium metal fuel, Mo, SST clad											
44	INEL	LITCO	CPP-603	SPEC (ORME)	8	0.01	1	can	2.4	5	0.1	0.002
45	Low uranium 235 enrichment, uranium metal fuel, SST clad, metallic Na bonded, Pu											
45	Hanford	Hanford	Bld-327	EBR-II	15	0.19	1	cask	14.2	10	14.0	0.020
45	O-DOE	ANL-E	Alpha-gamma	EBR-II, FFTF, & Misc	70	-	4	unit	52.6	11	16.8	0.060
46	Low uranium 235 enrichment, uranium carbide fuel, SST clad, metallic Na bonded, medium burnup											
46	SRS	SRS	RBOF	SRE-UC	100	0.10	1	can	44.3	10	4.4	0.044
47	Low uranium 235 enrichment, uranium silicon fuel, Al cermet, Al clad											
47	OTHER	GA, San Die	GA Hot Cell	GA - RERTR	0.4	0.01	1	unit	0.4	91	0.4	0.004
47	UNIV	Georgia Tec	Georgia Tech	Georgia Tech - MTR-Si	-	-	-	-	-	-	-	-
47	UNIV	IA St U	IA St U Rx	IA St - MTR-Si	170	0.10	13	elem	20.2	19	4.0	0.020
47	UNIV	MURR-Rolla	MURR-Rolla R	MURR-Rolla - MTR-Si	200	0.10	28	elem	26.5	19	5.2	0.027
47	UNIV	OH St U	OH St U RRx	OH St U - MTR-Si	200	0.10	414	plate	26.1	19	5.2	0.026
47	UNIV	Purdue U	Purdue U Rx I	Purdue - MTR-Si	-	-	-	-	-	-	-	-
47	UNIV	RINSC	RINSC	RINSC - MTR-Si	100	0.10	18	elem	24.9	19	4.8	0.025
47	UNIV	U of FL	U of FL Trng	U of FL - MTR-Si	-	-	-	-	-	-	-	-
47	UNIV	U of Lowell	U of Lowell N	U of Lowell - MTR-Si	-	-	-	-	-	-	-	-
47	UNIV	U of MI	Ford NRx	U of MI - MTR-Si	-	-	-	-	-	-	-	-
47	UNIV	U of VA	U of VA Rx	U of VA - MTR-Si	200	0.10	33	elem	41.4	19	8.1	0.041
48	Low uranium 235 enrichment, molten salt matrix, Li Be Zr U fluoride salts											
48	ORR	ORR	MSR	MSRE fuel & flush	8,940	1.80	1	core	37.0	86	33.0	0.038
49	Natural uranium 235 enrichment, uranium oxide fuel, Zr clad, high burnup, Pu											
49	INEL	LITCO	TAN-607	Dresden	300	0.08	55	rod	165.0	1	1.4	0.166
49	INEL	LITCO	TAN-607	HB Robinson	600	0.19	125	rod	257.6	2	5.0	0.260
49	INEL	LITCO	TAN-791	DRCT	30,475	4.52	24	can	20,971.0	2.0	420.1	21.150
49	INEL	LITCO	TAN-791	BCD B17	645	0.19	1	assem	408.6	2.0	8.2	0.412
49	INEL	LITCO	TAN-791	Turkey Point	3,225	0.94	5	assem	2,203.0	1.7	36.6	2.220
49	INEL	LITCO	TAN-791	Surry	22,029	13.00	33	assem	14,455.0	1.9	272.2	14.600
49	SRS	SRS	RBOF	HB Robinson	1	0.01	1	can	0.5	0.7	0.0	0.001
49	SRS	SRS	RBOF	Saxton MOX	300	0.48	13	can	283.0	0.5	16.9	0.298
49	SRS	SRS	RBOF	CANDU	100	0.16	6	can	50.1	0.5	0.2	0.050
49	Spec Case	B&W-Lynch	B&W Hot Cell	Oconee-2	30	0.05	7	canst	19.5	1	0.2	0.021
49	Spec Case	B&W-Lynch	B&W Hot Cell	Arkansas-1	20	0.03	4	canst	11.8	0.4	0.1	0.015
50	Natural uranium 235 enrichment, uranium oxide fuel, some Zr clad, much of the clad disrupted, SST containers, high burnup											
50	INEL	LITCO	TAN-607	BCD-LFRSB	450	0.19	1	assem	309.4	0.5	5.3	0.312
50	INEL	LITCO	TAN-607	LOFT fines	6	0.00	5	can	4.3	11	0.5	0.004
50	ORR	ORR	Bld-7827	Misc	1,400	1.00	69	can	122.9	9	10.6	0.138
50	ORR	ORR	Bld-7920	Dresden	6	0.10	2	can	4.0	1	0.0	0.004
50	ORR	ORR	Bld-7823A	Misc	175	1.00	9	can	0.1	10	0.8	0.001
51	Low uranium 235 enrichment, uranium oxide fuel, Zr clad, Damaged fuel, melted, not intact, melted Cd control rods											
51	INEL	LITCO	TAN-607	TMI-2	325,105	129.20	342	canst	81,444.0	3	2,096.9	81.600
51	INEL	LITCO	TRA-603	Scrap in plug storage	3	0.05	4	canst	11.1	8	0.8	0.011
51	INEL	LITCO	TRA-603	LOCA	31	0.03	2	canst	7.8	10	0.8	0.008
51	INEL	LITCO	TRA-603	IE	56	0.03	2	canst	6.1	10	0.7	0.006

55 CAT	SITE	CUSTODIAN	FACILITY	FUEL NAME	Tot Mass (kg)	Volume (m3)	Items	Units	U Mass (kg)	Enrichme	Fissile Mas (kg)	MTHM
52	Natural uranium enrichment, uranium oxide fuel particles, carbon coated particles, Zr clad, SST brackets, high burnup, Pu											
52	Hanford	Hanford	T-plant	Shippingport C2 PWR bl	38,500	9.60	72	assem	15,700.0	2	287.0	15.800
52	INEL	NRF	ECF	Shippingport PWR C1 bl	25,000	7.00	36	unit	568.0	0.7	7.3	0.600
52	INEL	NRF	ECF	Shippingport PWR C2 bl	55,000	16.00	17	unit	1,039.0	0.7	27.3	1.000
53	Depleted uranium, uranium metal fuel, Al clad, low burnup, Pu											
53	Hanford	Hanford	105-K East Ba	Single Pass Rx	408	0.04	4	can	400.0	0.95	4.0	0.400
53	Hanford	Hanford	105-K West B	Single Pass Rx	102	0.01	2	can	100.0	1.2	1.2	0.100
53	Hanford	Hanford	PUREX	Single Pass Rx	2,927	0.20	779	elem	2,870.0	0.1	2.0	2.870
54	Low uranium 235 enrichment, uranium nitride fuel, niobium clad											
54	Hanford	Hanford	FFTF	FSP				2 assem				
55	Natural uranium 235 enrichment, uranium metal block, contained in SST container											
55	INEL	LITCO	TRA-660	Core Filter	219	0.01	1	unit	218.0	0.7	1.4	0.218

Appendix H

Published Summary
U.S. Navy Fuel Process Knowledge

NOV 22 1993

OFFICE OF
SOLID WASTE AND EMERGENCY RESPONSE

Mr. Richard A. Guida
Associate Director for Regulatory Affairs
Office of Naval Reactors
Department of Energy
Washington, DC 20585

Dear Mr. Guida:

Thank you for the opportunity to review the reports which you recently submitted to me regarding the Naval Nuclear Propulsion Program's (NNPP) spent nuclear reactor fuels and the RCRA hazardous waste determination. In these reports, the NNPP detailed its efforts at characterizing the Program's spent fuels based both on "process knowledge" and actual analyses conducted in hot cells in accordance with the Toxicity Characteristic Leachate Procedure (TCLP).

First, I want to commend your staff for the extraordinary efforts undertaken to characterize actual samples of irradiated fuel for the Toxicity Characteristic. I recognize that it is a fairly daunting task to sample and analyze these highly radioactive materials, and I believe your Program's efforts are unprecedented in this respect. I also would like to thank Mark Neblett of your staff for his efforts to clarify for my staff portions of the draft report that accompanied your September 20, 1993 letter to EPA, and to hand deliver additional materials to assist the Office of Solid Waste (OSW) in its review.

The entire report was reviewed by both EPA mixed waste policy staff in the Permits and State Programs Division, and RCRA testing methods experts in our Characterization and Assessment Division. Based on my staff's review, the Office of Solid Waste concurs with the reports' conclusion that the NNPP's spent reactor fuels and assemblies should not present any of the characteristics that identify RCRA hazardous wastes. Our concurrence is based on our review and agreement with the NNPP's "process knowledge" analysis, the TCLP analytical procedures used, and the TCLP/quality control measures described in your report. We also believe, given the conservative assumptions which the NNPP employed in selecting representative spent fuel samples (i.e., selecting samples that contained the highest possible concentrations of RCRA hazardous metals), that the reports support a general determination that none of the Program's spent reactor fuels would be classified as RCRA

hazardous wastes. This latter conclusion is, of course, conditioned on the completeness and accuracy of the information shared with EPA on the Program's "process knowledge," particularly with regard to projecting the TCLP test results obtained to other fuels than those that were actually involved in the testing.

As you are aware, EPA delegates the authority to implement the Subtitle C RCRA program to the States. Currently, 35 States and one territory have received from EPA the approval to regulate RCRA mixed waste. We recommend that you share your results with the appropriate hazardous waste personnel in those States where the spent reactor fuel is managed.

Again, we appreciate the opportunity to evaluate the results of the spent fuel "process knowledge" analysis and TCLP test. If you have any questions on EPA's review, please contact Susan Jones, at (703) 308-8762.

Sincerely,

Elizabeth A. Cotsworth
for Michael Shapiro, Director
Office of Solid Waste

SUMMARY OF NAVAL FUEL RCRA HAZARD "PROCESS KNOWLEDGE" ANALYSIS

1. Does spent naval fuel contain any "listed" hazardous wastes?

a. 40 C.F.R. § 261.31 Non-specific sources (F-wastes):

Solvents (F001 - F005)	None
Wastewater-Electroplating Sludges	
(F006 & F019)	None
Cyanide bath wastes (F007 - F012)	None
Organic related wastes (F020 - F038)	None
Leachate from listed wastes (F039)	None

b. 40 C.F.R. § 261.32 Specific sources (K-wastes):

Sludges/bottoms/ends/tars/filters, organic & inorganic, explosives, petroleum refining, iron & steel (manufacture), primary copper/lead/zinc/aluminum production, veterinary pharmaceuticals, ink production, and coking None

c. 40 C.F.R. § 261.33 Discarded commercial chemical products (commercially pure grade chemicals), off-specification species, & their residues None

2. Does spent naval fuel exhibit any of the "characteristics" of a hazardous waste?

a. 40 C.F.R. § 261.21 Ignitability:

Spent naval fuel is not "capable under standard temperature and pressure of causing fire through friction, adsorption of moisture or spontaneous chemical changes."

b. 40 C.F.R. § 261.22 Corrosivity:

Not applicable - spent naval fuel is not a liquid with pH less than 2 or greater than 12.5.

c. 40 C.F.R. § 261.23 Reactivity:

Spent naval fuel is not unstable, potentially explosive, capable of detonation, does not generate toxic gases, and does not react violently with water.

d. 40 C.F.R. § 261.24 Toxicity Characteristic:

Spent naval fuel does not contain any of the organic materials listed in Table 1 of § 261.24. Accordingly, only the metals listed in Table 1 need be evaluated. The Toxicity Characteristic Leachate Procedure (TCLP) test limits for these metals are:

<u>Metal</u>	<u>TCLP Concentration Limit</u>
Arsenic	5.0 mg/liter (ppm)
Barium	100.0 mg/l
Cadmium	1.0 mg/l
Chromium	5.0 mg/l
Lead	5.0 mg/l
Mercury	0.2 mg/l
Selenium	1.0 mg/l
Silver	5.0 mg/l

Assumptions Used in the "Process Knowledge" Analysis:

Based on a 100 gram sample, all constituents are assumed to be exposed to the leaching fluid (2000 grams of leaching fluid $\approx$ 2 liters) - no credit taken for unexposed surfaces within the sample particles.

The representative sample includes only the fuel-bearing region of a reactor core, which is where the maximum concentrations of the above metals, with the exception of chromium, are found. The maximum concentration of chromium is found in the Zircaloy-4 core structural material (small amounts of chromium are added to the zirconium as an alloying element), therefore the representative sample used for the chromium extraction calculation is Zircaloy-4 structural material.

Fission products with decay chains that end with a TCLP metal are assumed to be fully decayed to their stable state (thereby maximizing their concentrations) and are present in the proportions observed with the parent radionuclides from Uranium-235 fission.

All of the TCLP metals present in the sample are assumed to be released to the leaching solution during the test period. No credit is taken for the highly corrosion-resistant nature of naval fuel, except in the chromium analysis (see note below).

Calculated Theoretical Maximum Concentrations:

<u>Metal</u>	<u>Leachate Concentration</u>	<u>TCLP Limit</u>
Arsenic	1.25 mg/l	5.0 mg/l
Barium	30.0	100.0 mg/l
Cadmium	0.22	1.0 mg/l
Chromium	---	5.0 mg/l
Lead	3.4	5.0 mg/l
Mercury	0.0	0.2 mg/l
Selenium	1.1	1.0 mg/l
Silver	0.93	5.0 mg/l

* Due to the presence of chromium as an alloying agent in Zircaloy-4, the TCLP test's 20 to 1 dilution into the leachate solution results in a calculated chromium concentration on the order of 50 mg/l. The extremely high corrosion resistance of Zircaloy-4 would not permit such a high concentration to actually occur. The calculated leachate concentration even using a corrosion rate significantly higher than any ever actually observed, is on the order of 0.001 mg/l.

- This value does not consider corrosion resistance, surface area exposed, etc. Actual TCLP results would be far below the TCLP limit.

Appendix I

Stability of UZrH Spent Fuels in Wet Storage

Idaho National Engineering Laboratory

MAE-03-94

From : M. A. Ebner

Phone : 6-3089/MS 3423

Date : July 8, 1994

Subject: Stability of Uranium-Zirconium Hydride Spent Fuels in Wet Storage

To : J. E. Sailer

RCRA Compliance

cc: J. A. Carter
K. C. Coughlan
R. D. Denney
D. L. Fillmore
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Spent nuclear fuels (SNF) are not currently considered a hazardous waste by the Department of Energy as defined in the Resource Conservation and Recovery Act (RCRA). However, some SNF, or the materials or by-products from ageing or deterioration of spent fuels in storage, may potentially exhibit characteristics of a RCRA hazardous waste.

In principle, the deterioration of uranium-zirconium hydride (UZrH) SNF during storage may produce or release materials that might be hazardous under RCRA. Issues of concern stem from the possible corrosion or the thermal disassociation of the UZrH SNF during storage, with the formation of products that might be considered reactive. Specifically, these issues pertain to the production of materials from ageing UZrH fuel by the following mechanisms:

- Extensive corrosion of the UZrH by the basin water, forming significant amounts of pyrophoric UH_3 within the spent fuel matrix.
- Release of significant amounts of toxic metals (fission products) by spallation of surface of the corroding fuel.
- Release of highly-reactive particulate UZr_x intermetallics due to corrosion of the fuel matrix.
- Release of ignitable quantities of hydrogen, either by extensive thermal disassociation of the metal hydride, or by extensive corrosion of the fuel matrix.

J. E. Sailer
Page 2
MAE-03-94
July 8, 1994

This letter is a summary of the available literature in response to the concern of RCRA reactivity of UZrH, particularly with respect to the above issues. The magnitude of the above issues is qualitatively discussed below.

The literature of the last 40 years is definitive on the extraordinary stability of zirconium hydride in various environments and at moderately high temperatures. Zirconium hydride is one of the most chemically, thermally, and radiolytically stable hydrides, particularly in monolithic form.¹⁻³ The monolithic hydride is essentially stable in underwater storage. At ambient temperatures, zirconium hydride reacts very slowly with air or water, and is protected from further reaction by the formation of a tenacious, impermeable oxide film.^{2,3} Furthermore at ambient temperatures the hydride is thermodynamically stable compared to the parent elements, and will not lose hydrogen by dissociation or by diffusion.^{1,3} In fact, at ambient temperatures, pure zirconium metal (if not contaminated with an oxide film) will rapidly absorb hydrogen to form the hydride.¹

However, definitive literature on uranium-zirconium hydride reactivity is rather limited, particularly for long-term exposures at ambient temperature to corrosive environments. Uranium, which can be highly reactive as a dispersed metal or as a hydride, does decrease the durability of the zirconium hydride matrix to some extent. The magnitude of the effect depends on the uranium loading and specific environmental conditions.

Nevertheless, for compositions typical of UZrH spent nuclear fuel stored at the ICPP, the fuel is very stable to most environmental conditions, and is comparable to pure ZrH₂. For uranium loadings of less than 20 wt%, the UZrH consists of a uranium metal dispersion in a continuous ZrH_x matrix. Such systems retain the stability characteristics of the matrix ZrH₂, imparted by the impervious oxide film on the surface of the ZrH₂. Such UZrH fuels may exhibit a slight reduction in the corrosion durability of the UZrH, due to the spallation induced by the oxidation of the dispersed uranium inclusions.

Corrosion by Water

UZrH fuels with low uranium loadings ($\approx 20\%$ uranium) consist of fine uranium metal particles dispersed in a continuous zirconium hydride matrix. Such UZrH fuels are generally considered highly stable and resistant to oxidation by air and water. The corrosion resistance of these fuels is generally comparable to the parent ZrH_x and zirconium metal. The excellent corrosion resistance of these materials is due to the formation of a tenacious thin surface film of ZrO₂ that is a highly effective barrier to diffusion of water, oxygen, hydrogen and other species.^{4,5,6}

The corrosion rate of Zr, ZrH_x and UZrH is governed by the barrier characteristics of the initial ZrO_2 film formed by corrosion. The diffusion properties of the film, as well as the strength and adhesion, are the primary factors that render the substrates highly resistant to further reaction by water and oxygen, and prevent the loss of hydrogen from the matrix. The diffusion characteristics of ZrO_2 are such that only thin sub-micron films are required for protection of the substrate from further corrosion.⁶ Films of controlled thickness are usually generated during manufacture to protect the fuel in reactor service.

The mechanisms and kinetics of ZrH_x and UZrH corrosion have not been detailed in the literature. However, the mechanisms, rates of formation and the characteristics of ZrO_2 corrosion films have been studied extensively in the corrosion of zircaloy alloys.⁷⁻¹⁸ The corrosion rate of zircaloy alloys in water is strongly dependent on the temperature and the oxygen content of the water. For corrosion conditions above approximately 300°C, the corrosion behavior is complex, consisting of as many as four different rate laws⁷, wherein the transition between mechanisms is governed by the thickness and microstructure of the accumulated oxide layer.^{7,11,12,13,18} Below approximately 300°C, the rate of corrosion is a cube root function of time ("cubic" law). The rate law indicates that the rate of corrosion is primarily controlled by diffusion of water through the forming ZrO_2 film, and rapidly decreases with increasing time of reaction and accumulation of oxide.

Because of the barrier properties of the ZrO_2 film, zircaloy alloys and ZrH_x corrode very slowly compared to other metals and alloys. In 300°C water, zircaloy corrodes at less than 0.6 μm per year.⁷ For zircaloy alloy held above 200°C in water for 12 years, the thickness of the ZrO_2 corrosion film increased from an initial 2.5 μm to 13.5 μm ($\approx 0.9 \mu\text{m/yr}$).¹⁹

At temperatures below 100°C, the ZrO_2 layer is a particularly effective barrier to further corrosion of the substrate. For example, zircaloy-2 process tubes at the Hanford K-East reactor corroded at an average rate of 0.005 $\mu\text{m/year}$ at 85°C, for a projected oxide thickness increase of only 0.1 μm in 20 years.¹⁹ Two bundles of zircaloy-clad Shippingport PWR Core 1 blanket fuel rods were stored underwater at the ECF facility at the INEL, one for 16 and the other for 21 years. The water temperature in the basin ranged from 15 to 25°C. In that time, the average thickness of the oxide layers (initially 2.3 μm and 1.7 μm , respectively) did not change.¹⁹

Because similar ZrO_2 protective films form upon corrosion of ZrH_x , the characteristics of the ZrO_2 protective film govern ZrH_x corrosion. However, UZrH may be slightly more susceptible to corrosion. Because the continuous phase of UZrH fuels with low loadings of uranium consists of zirconium hydride, initial corrosion of the matrix will produce a continuous film of ZrO_2 that may contain inclusions of UO_2 or U_3O_8 . Upon further hydration or reaction, the occluded material will expand in volume and can cause spallation. This mechanism may result in the lower resistance of UZrH fuels to corrosion.

Unfortunately, published data on the corrosion rates of UZrH alloys and on the effects of long-term storage of UZrH in water at ambient temperatures is not available. The literature does contain a few references to accelerated corrosion tests in hot water.^{3,20,21} These references consistently report a high resistance for UZrH fuels to corrosion in accelerated tests in hot water, although not as high as for Zr or ZrH_x fuels. For example, Merten reported that UZrH alloy containing 7 wt% uranium (Zr/U/H atom ratio of 1/0.03/1), when immersed in water at 100°C, corroded slowly with a mass loss of 0.2 mg/cm² in 90 days. Assuming the worst-case condition of a corrosion rate linear with time (rather than a $t^{1/3}$ relationship), this rate extrapolates to a corrosion rate of 1 μ m per year.^{3,20}

The UZrH fuel exhibited excellent corrosion resistance in highly aggressive environments, although again not as resistant as Zr or ZrH_x. Simnad reported corrosion test results for UZrH fuel containing 8.5 to 12 wt% uranium. When hydride fuel was heated in pressurized water at 1230 psi and 570°F (300°C), the extent of corrosion penetration was less than 50 μ m after 400 hours.²¹ For these compositions and corrosion conditions, the samples formed an adherent oxide film that was not as protective as films on zircaloy or ZrH_x. Similar samples of UZrH were quenched in water after being heated to temperatures as high as 1200°C. No reaction was observed during quenching of the alloy; only a thin surface film of zirconium oxide formed on the surface, as indicated by the slight discoloration of the samples.^{21,22}

The decreased corrosion resistance of UZrH fuels is qualitatively comparable to that of uranium-zirconium alloys. Uranium compositions greater than 30 wt% U result in increasing corrosion rates, as the zirconium matrix becomes increasingly discontinuous.⁹ Whereas the corrosion rate of zircaloy at 300°C is less than 0.6 μ m/yr, the corrosion rate of zirconium containing 7 wt% uranium is 40 μ m/yr at 288°C and 8 μ m/yr at 260°C.⁹ The uranium content appeared to increase the corrosion rate by a factor of 10 to 100.

As indicated by the data for zircaloy corrosion given above, the rate of corrosion, like other chemical reactions, increases exponentially with increasing temperature. Therefore, a qualitative extrapolation of the accelerated test data from UZrH in 100°C water suggests that the corrosion rates for ambient or near-ambient temperatures will be significantly less than 1 μ m per year. This constitutes a very slow corrosion rate, involving an infinitesimally small mass fraction of the usual fuel element.

Formation of Uranium Hydride

The presence of uranium hydride, UH₃, either as a consequence of fuel fabrication or from corrosion, presents the potential risk of pyrophoricity.

While the manufacture of UZrH fuels includes hydriding of the parent metal mixture, the process does not produce significant, measurable levels of uranium hydride in the product. UZrH fuels with low uranium contents (<20wt%) are formed by hydriding a dispersion of uranium in zirconium at high temperature. Metallographic analyses indicate that the resulting alloy does not consist of a mixture of UH_3 and ZrH_2 . Instead, the UZrH fuel consists of particulate metallic uranium, about 1 to 5 μm in size, uniformly dispersed in the zirconium hydride matrix.^{21,23-28} Thus the hydriding process, which was stopped short of stoichiometric completion (H/Zr is nominally 1.6, not the stoichiometric value of 2), resulted in the preferential, but incomplete, hydriding of zirconium. The uranium, precipitated as a metal rather than a hydride, is probably present as two phases, i.e. as an intermetallic compound (50 wt% zirconium), and as a solid solution in the unreacted zirconium metal.^{21,22}

The metallographic analyses are consistent with the thermodynamic data for UH_3 and ZrH_2 . The thermodynamic data indicate that zirconium hydride is thermodynamically more stable than UH_3 , and would be formed at the expense of UH_3 until the free elemental zirconium was depleted. These conclusions have been corroborated experimentally. The disassociation pressures as a function of temperature are greater for UH_3 than those for ZrH_2 by at least a factor of ten²⁹, clearly indicating that ZrH_2 is more stable than UH_3 , and would form at the expense of UH_3 . In addition, when delta phase U-Zr alloy, consisting of 50 wt% Zr (i.e., an alloy with ≈ 30 atom% uranium), was exposed to hydrogen, zirconium hydride was preferentially formed:²⁹

The matrix of UZrH fuels such as SNAP and TRIGA consists of incompletely hydrided zirconium. The nominal atom ratio is $\text{ZrH}_{1.6}$, and much of the fuel composition lies in the range of $\text{ZrH}_{1.5}$ to $\text{ZrH}_{1.8}$. Therefore, the matrix contains a considerable amount of elemental zirconium, probably as an alpha-zirconium phase and an epsilon U-Zr intermetallic phase.²²

The mass of zirconium metal dispersed in the zirconium hydride matrix would serve as a preferential getter for any molecular hydrogen that is produced by disassociation of UH_3 , and by corrosion of the outer skin of the fuel matrix. In any case, since corrosion penetration is measured in microns per decade, the mass of the corrosion layer is a small fraction of the total fuel element mass. The existing data indicate that the molecular hydrogen produced by the corrosion will be gettered by the elemental zirconium to form the more stable zirconium hydride.

Release of Toxic Metals

The release of any toxic materials by corroding UZrH fuel elements will be governed by the corrosion rate of the fuel matrix. On the basis of the limited UZrH corrosion data cited

above, the corrosion penetration of the ZrH matrix is no worse than a few microns per year, depending upon the actual uranium content of the fuel. Furthermore, data on the temperature dependence of the corrosion of Zr alloys indicate that the corrosion rate will be orders of magnitude lower at ambient temperatures typical of basin storage.¹⁴

The tenaciously adherent ZrO₂ corrosion film is highly protective of the underlying matrix. The oxide film serves as a highly effective barrier that effectively prevents the diffusion of materials through the film. Therefore, as long as a thin continuous film of ZrO₂ remains on the surface, the oxide film will prevent the release of metals by interdiffusion or ion exchange. The only mechanism for release is by spallation of the oxide film, which tends to occur for films thicker than 10-30 μm .^{9,12,13,15,16,32} However, the available data indicate that the probably thickness of the corrosion layers on the stored spent fuel is significantly lower than this limit. Spallation of the oxide layer will result in only a very slow release rate of any material.

Production of Hydrogen

Molecular hydrogen can be produced by corrosion of the UZrH fuel or by thermal disassociation of the zirconium hydride.

Given the low rate of corrosion penetration of the UZrH, the mass fraction of fuel material consumed by the annual corrosion is relatively low, on the order of 10^{-4} for SNAP and TRIGA fuels. The consequent release of molecular hydrogen will be similarly low; for a typical SNAP fuel element, less than 0.1 liter-atmospheres of hydrogen will be produced annually by corrosion of the matrix.

Loss of hydrogen by thermal dissociation of the hydride to its component elements is not an issue in wet fuel storage. The surface temperatures and the average fuel temperature are kept relatively low by water cooling in basin storage. As mentioned above, the protective zirconium oxide film is quite impermeable to hydrogen, and effectively prevents the desorption of free hydrogen and the decomposition of the hydride.

Almost all metal hydrides will dissociate to the metal and hydrogen at temperatures well below the hydride melting points.^{2,3} The decomposition temperature may be as low as ambient temperature for unstable hydrides, or as high as 1000°C for stable hydrides. The degree of dissociation will be a function of temperature, hydrogen pressure and the type of metal hydride. The extent of hydrogen loss by a hydride will depend on the extent of dissociation at a given temperature, the diffusion rate of hydrogen through the fuel matrix, and the diffusion rate through any barrier films or cladding.

Zirconium hydride has a moderately high thermal stability for hydride phases ranging from ZrH_{1.33} to ZrH₂. Zirconium hydride will dissociate slightly at elevated temperatures; at 635°C, the equilibrium hydrogen pressure is 1 mm Hg; at 500°C, 10^{-1} mm Hg; and at

370°C, 10^{-3} mm Hg.^{27,30,31} For TRIGA and SNAP fuels with a canonical composition of $ZrH_{1.6}$, the disassociation pressure is 8mm Hg (0.01 atm.) at 600°C.²¹ These data suggest that hydrogen losses even at reactor temperatures will be relatively low, for the free hydrogen will be retained by the impervious oxide film. Performance measurements have indicated that the equilibrium hydrogen pressure at 760°C results in negligible hydrogen loss, and thus is insufficient to drive measurable diffusion of H_2 through the oxide film.³

Conclusion

The review of the available literature has indicated that uranium-zirconium hydride is a very stable hydride, due to the formation of a tenacious, impervious and relatively non-reactive zirconium oxide film during the initial stages of corrosion. The uranium-zirconium hydride fuels are highly unlikely to have experienced extensive corrosion as consequence of underwater storage in the CPP basins. On the basis of the limited data available, we expect that, at worst, the corrosion layer on the UZrH fuels is only a few tens of microns (a few mils) deep, and that the corrosion layer has good integrity and tenacity.

The available literature reports and thermodynamic data indicate that UH_3 was not formed during manufacture of the fuel elements. As long as a significant mass fraction of elemental zirconium remains in the zirconium hydride fuel matrix, UH_3 cannot form by thermal or radiolytic disassociation of ZrH_2 , or by reaction with elemental hydrogen produced by corrosion of the fuel matrix. Because of the negligible extent of corrosion of the hydride matrix, the inventory of excess elemental zirconium has not been affected, and the amount of hydrogen produced by corrosion has been insignificant.

Therefore, uranium-zirconium hydride fuels would not be considered reactive according to RCRA (40CFR 261.23) due to concerns of hazardous materials from corrosion of uranium-zirconium hydride.

M. A. Ebner, Principal Scientist
Fuel Technology Development

/idh

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28. J. C. Bokros, J. Nuc. Materials, 3(2), 216-221 (1961).
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Appendix J

Resource Conservation and Recovery Act Compliance Assessment of Molten Salt Reactor Experiment

June 4, 1992

T. W. Burwinkle

Resource Conservation and Recovery Act Compliance Assessment of Molten Salt Reactor Experiment

The fuel, flush, and coolant salts associated with the operation of the Molten Salt Reactor Experiment (MSRE) which were placed in critically safe storage following reactor shutdown were evaluated in 1987 relative to Resource Conservation and Recovery Act (RCRA) regulatory status (Attachments 1, 2, and 3). It has been concluded that the salts are neither listed or characteristically RCRA hazardous waste. There is no evidence that chromium is present in the solidified salts in measurable quantities; only lead and silver (of RCRA regulated metals) has been detected. A search of available records which might include additional analytical data would serve to further document the concentration of RCRA metals.

Concerns expressed by Ebasco include a determination that the salts are subject to RCRA regulation due to generation of fluorine by radiolysis. This determination is incorrect (Attachment 3). The stored salts are not subject to RCRA regulation.

Another concern pertains to regulations on the determination of reportable quantities (RQ) of hazardous substances contained in 40 C.F.R. § 117. They indicate that beryllium fluoride (BeF_2) has a reportable quantity of less than 1 kg; it is one (1) pound or 0.454 kg. It is true that BeF_2 is stored in quantities far in excess of the RQ; however, this is not reportable unless there is a release into the environment within a 24-hour period which exceeds the RQ. The RQ for fluorine is 10 pounds (4.54 kg).

The National Environmental Standards for Hazardous Air Pollutants (NESHAP) contained in 40 C.F.R. § 61 are relevant since beryllium and its compounds are listed as a hazardous air pollutants (the Clean Air Act Amendments of 1990 expanded the NESHAP list to include 189 toxic air pollutants). Fluorine is not listed under NESHAPs (only hydrogen fluoride under the 1990 amendments). The beryllium fluoride stored in a solid state at the MSRE represents little potential as an air emission source. The stack at MSRE is, however, permitted with the TDEC (Attachment 4).

In conclusion, Environmental Compliance staff members do not agree with Ebasco's determination that the stored salts at MSRE are RCRA regulated and, as such, should be managed in RCRA permitted facilities. Furthermore, there is little concern relative to release reporting of beryllium fluoride since several layers of containment must be breached in order for the hazardous substance to reach the environment.

If you have any questions or if we can be of further assistance, please call N. S. Dailey (RCRA) at 4-8774, J. M. Wolfe (Air) at 4-8773, or myself.

Carroll E. Nix, 6026C, MS-6395, ORNL (4-7363)
Environmental Compliance Section

CEN:vmm

Attachments (4)

c/att: N. S. Dailey
H. R. Gaddis
F. C. Kornegay

L. E. McNeese
D. D. Skipper
J. M. Wolfe

ornl

Attachment 1

Molten Salt Reactor Experiment (MSRE) - RCRA Evaluation

I. Description

The reactor was operated from 1965 to 1969 using a fuel solution that was a mixture of lithium, beryllium and zirconium fluoride along with uranium fluoride. Following reactor shutdown the fuel solution was drained to three critically safe storage tanks. The solidified salts contained in the tanks contain about 38,000 Ci, with an estimated TRU inventory of about 400,000 nCi/g in the fuel salt. There are about 4600 Kg of fuel salt contained in 2 tanks that are isolated in the fuel storage cell of the reactor (4300 Kg of flush salt is contained in a separate tank).

In addition to the lithium, beryllium, zirconium, uranium, plutonium, and fission products, the fuel and flush salts contain lead and silver in measurable quantities (0.06 g and 10^{-6} g, respectively).

II. RCRA Analysis

A. Type of Unit

The material is contained in tanks; hence the Subtitle C tank standards would apply if the material is determined to be RCRA hazardous. If Subtitle C is not applicable, then Subtitle I (UST) standards would apply as the material is a hazardous substance under CERCLA. These tanks are exempt from Subtitle I, however. They are located in the reactor building and are situated upon or above the surface of the floor.

B. Waste Classification

1. Is the material a solid waste? Yes
2. Is the solid waste a hazardous waste?
 - a. Is it a listed waste or a mixture of a solid waste and a listed waste? No
 - b. Is it characteristically hazardous?
 - (1) Ignitable? No
 - (2) Corrosive? No
Is it a solid and therefore not corrosive,
 - (3) Reactive? No
 - (4) EP Toxic? No
The only measurable EP toxicity metals are lead (60 mg in 8900 Kg) and silver (1 ug)

III. Conclusions

- A. The fuel and flush salts do not contain listed waste nor are they characteristically hazardous. The material is not a RCRA hazardous waste.
- B. Although the tanks contain hazardous substances as defined by CERCLA and are potentially subject to UST regulations (40 CFR 280), they are exempt from regulation. The applicable exemption is that which exempts tanks located beneath the ground surface but that are inside a building and are situated upon or above the surface of the floor.

Attachment 2

 

DATE 8/7/87 FYI/YOUR FILES _____

ROUTE & DISCARD _____ ROUTE & RETURN _____

XEROX X FILE: MSRE Comps

_____ JWAutrey, 3001, MS 029 (4-4410)	_____ JTKitchings, 4500S, MS 102 (4-7363)
_____ LDBates, 3001, MS 029 (6-4438)	_____ JRLawson, 1000, MS 340 (4-4788)
_____ JSBaldwin, 3047, MS 023 (6-5225)	_____ WNLingle, FOB, 2116 (6-5580)
<u>X</u> TWBurwinkle, 3047, MS 023 (6-0423)	_____ LWLong, 1000, MS 335 (6-5283)
_____ BRClark, 4500S, MS 142 (4-6896)	_____ LEMcNeese, 4500N, MS 186 (4-7456)
_____ KWCook, 3047, MS 023 (6-0311)	_____ ENewman, 3047, MS 021 (4-4846)
_____ NKCutshall, 1505, MS 038 (4-7426)	<u>X</u> CENix, 4500S, MS 102 (4-0845)
_____ SPdumont, 3001, MS 029 (4-1365)	_____ RENorman, 3047, MS 023 (6-1902)
_____ NWDurfee, 1000, MS 338 (4-3945)	<u>X</u> TPAPerry, 1000, MS 335 (6-5587)
_____ KJFoust, 3001, MS 029 (6-1121)	_____ PSRohwer, 4500S, MS 102 (4-6670)
_____ RRRhinton, FOB, G108 (6-8887)	_____ THRow, 4500N, MS 198 (4-5974)
_____ FJHoman, 3047, MS 023 (4-7042)	_____ TFScanlan, 3130, MS 058 (4-4562)
_____ DDHuff, 1505, MS 036 (4-7859)	<u>X</u> FEShardles, 1505, MS 038 (6-0524)
_____ LDHyde, 3047, MS 023 (6-1579)	_____ SHStow, 1505, MS 038 (4-7830)
_____ MRJugan, FOB, 2116 (6-0169)	_____ LEStratton, 3504, MS 317 (6-0504)
_____ RAJung, FOB, 2116 (6-4869)	<u>X</u> JRTrabalka, 1505, MS 036 (4-7382)
_____ LLKaiser, 3001, MS 029 (4-1493)	_____ LDVoorhees, 1505, MS 036 (4-7309)
_____ CMKenrick, 4500N, MS 198 (6-2250)	_____ Other:

This assessment was done by DOE-HQ.Can we refute point (2)? We are
not considering the MSKE fuel as mixedDISTRIBUTED BY: T. E. MYRICK (4-6332)
3001, MS 029, RM 216

Date: July 24, 1987

Refer To: D. Kozlowski, OTS

Subj: Classification of Molten Salt Stored at MSRE

To: W.E. Murphie, NE-23

1. In response to your memo of July 13, 1987, my analysis of the classification of MSRE Molten Salt (Flush, Fuel, and Coolant) is as follows:

(a) The fuel salt (4,650 kg) meets the definition of "special nuclear material" included in 10 CFR 40.4(i). This classification allows for a generic determination of no significant impact for temporary, or 30 year, storage of the spent fuel after cessation of reactor operations (10 CFR 51.23).

(b) The flush salt (4,290 kg) stored at MSRE is classified as a radioactive waste because the constituents (excluding radionuclides) are not hazardous waste listed in 40 CFR 261, Subpart D. Concern over beryllium fluoride was dismissed following close review of 40 CFR 261 and confirmation by the RCRA Hotline (382-3000). Flush salt trace-element analysis indicates a chromium concentration which may exceed hazardous waste EP Toxicity characteristic threshold of 5 ppm. If the EP Toxicity characteristic is exceeded, the flush salt would be considered a chromium hazardous waste and, coupled with the presence of radionuclides, the flush salt would be classified as a mixed waste.

(c) The coolant salt (2,610 kg) is classified as a solid waste only. However, this salt may be classified as hazardous waste for the same reason described for flush salt.

2. If the flush and coolant molten salts are respectively classified as mixed and hazardous waste, the existing MSRE facility would require a RCRA storage permit to safely store these materials. However, the present MSRE containers and structures would meet regulatory requirements for hazardous waste storage.

Attachment 3

Internal Correspondence

MARTIN MARIETTA ENERGY SYSTEMS, INC.

June 4, 1992

Memo-to-File

EBASCO Compliance Assessment of the Molten Salt Reactor Experiment Facility

In a recent compliance assessment of the Molten Salt Reactor Experiment (MSRE) facilities, EBASCO claims the beryllium fluoride in the fuel, flush, and coolant tanks is a Resource Conservation and Recovery Act (RCRA) hazardous waste because it exhibits the characteristics of corrosivity and ignitability. This claim is inaccurate for the following reasons:

- 1) In order for a waste to be RCRA hazardous due to corrosivity, it must be in a liquid form (40 CFR 261.22). The beryllium fluoride contained in the MSRE tanks is solidified.
- 2) The fact that fluorine gas could be produced does not indicate the beryllium fluoride is a RCRA hazardous waste. Fluorine is regulated under RCRA as a listed waste (P056) when it is a discarded commercial chemical product, off-specification species, container residue, or spill residue. This is not the case at the MSRE facility. Any fluorine gas present has been generated by radiolysis from the solid lithium, beryllium, zirconium, and uranium fluorides.
- 3) Beryllium fluoride is not a listed waste and does not exhibit the characteristics of ignitability, corrosivity, reactivity or toxicity (see attached material safety data sheet for additional information).

Beryllium fluoride, as a nonhazardous waste, does not need to be stored in RCRA-permitted or interim status facility. Furthermore, the MSRE facility does not require RCRA closure.

If you have any questions, please call.

David D. Skipper, 6026C, MS-6395 (6-5748)

cc/att: N. S. Dailey
C. E. Nix

MARTIN MARIETTA ENERGY SYSTEMS, INC.,
MATERIAL SAFETY DATA SHEETS DATABASE

-----1. IDENTIFICATION-----

RECORD ID NUMBER: 05711

NAME: BERYLLIUM FLUORIDE

SYNONYMS: BERYLLIUM DIFLUORIDE

CHEMICAL FORMULA: BE-F2

HAZARD RATING HEALTH: 4 FIRE: 0 REACTIVITY: 0

GENERAL CLASSIFICATION: 4 = EXTREME HEALTH HAZARD
POTENTIAL CARCINOGEN
IRRITANT
0 = NONFLAMMABLE
0 = NONREACTIVE

SOLID

USE: MANUFACTURE OF BERYLLIUM AND ITS ALLOYS, AND
OF
GLASS. IN NUCLEAR REACTORS.

CAS REGISTRY NUMBER: 007787-49-7 RTECS NUMBER: DS2800000

MANUFACTURER/DISTRIBUTOR: MORTON THIOKOL, INC., ALFA 840800
PRODUCTS, 152 ANDOVER STREET,
DANVERS, MA 01923

MMES PREPARED/REVISED (YYMMDD): 870225

REVIEW STATUS: SCIENTIFIC REVIEW COMMITTEE FOR MSDS

-----2. PHYSICAL DATA-----

PHYSICAL DESCRIPTION: GLASSY HYGROSCOPIC MASS. BECOMES
FREE-FLOWING @ 800 DEG C (SUBLIMES).

MOLECULAR WEIGHT: 47.01

BOILING POINT: 1160 DEG C

SPECIFIC GRAVITY: 1.986 @ 25 DEG C

VAPOR DENSITY: >1 (AIR=1)

VAPOR PRESSURE: NA

MELTING POINT: 555 DEG C

FREEZING POINT: NA

PERCENT VOLATILES: NA

SOLUBILITY IN WATER: EXTREMELY SOLUBLE IN WATER.

EVAPORATION RATE: NA

-----3. INGREDIENTS-----

CAS NO.	INGREDIENTS	PERCENT	RTECS NO.
---------	-------------	---------	-----------

PURE CHEMICAL

HAZARD EVALUATION

-----4. FIRE AND EXPLOSION HAZARD DATA-----

FLASH POINT (METHOD): NONFLAMMABLE
AUTOIGNITION TEMPERATURE: NONFLAMMABLE
LOWER FLAMMABILITY LIMIT: NA
UPPER FLAMMABILITY LIMIT: NA

EXTINGUISHING MEDIA: DRY CHEMICAL EXTINGUISHING AGENTS, DRY SAND,
CARBON DIOXIDE, WATER FOG OR SPRAY.

FIREFIGHTING PROCEDURES: WEAR PRESSURE-DEMAND, SELF-CONTAINED
BREATHING APPARATUS AND CHEMICAL PROTECTIVE
SUIT. IF WITHOUT RISK MOVE THIS MATERIAL OUT
OF FIRE AREA.

FIRE AND EXPLOSION HAZARDS: WHEN HEATED TO DECOMPOSITION THIS MATERIAL
EMITS VERY TOXIC FUMES WITH THE RESIDUES
BEING HIGHLY CAUSTIC.

COMBUSTION PRODUCTS: TOXIC DECOMPOSITION PRODUCTS INCLUDE
BERYLLIUM OXIDE AND FLUORIDE.

-----5. REACTIVITY DATA-----

STABILITY: STABLE

SHELF LIFE: NA

CONDITIONS TO AVOID: PROTECT FROM MOISTURE.

INCOMPATIBILITY: MAGNESIUM

HAZARDOUS POLYMERIZATION: WILL NOT OCCUR.

-----6. HEALTH HAZARD DATA-----

OSHA: TWA 0.002 MG (BE)/CU M,
CEILING 0.005, PEAK
0.025/30 MIN/8 HR
(1974), TWA 2.5 MG
(F)/CU M (1974)

ACGIH THRESHOLD LIMIT VALUE: TWA 0.002 MG (BE)/CU M,
TWA 2.5 MG (F)/CU M
(1986-1987)

NIOSH: CEILING NOT TO EXCEED
0.0005 MG (BE)/CU M, FOR
BERYLLIUM

IMMEDIATELY DANGEROUS TO LIFE AND HEALTH: NE

OTHER EXPOSURE LIMITS: NA

ACUTE INHALATION: POISONOUS IF INHALED, CAN BE FATAL. MAY CAUSE
COUGH OR DIFFICULTY IN BREATHING, SYMPTOMS OF
RESPIRATORY TRACT IRRITATION, BRONCHITIS, AND
PNEUMONIA DUE TO INHALATION OF THE COMPOUND.
ACUTE PULMONARY LESIONS HAVE RESULTED FROM A FEW
MINUTES OF INHALATION OF AIR CONTAINING HIGH

CONCENTRATIONS OF THE COMPOUND.

ACUTE SWALLOWING: POISONOUS IF INGESTED, CAN BE FATAL. IRRITATION OF MUCOUS MEMBRANES. MAY CAUSE LOSS OF APPETITE AND WEIGHT LOSS.

ACUTE SKIN ABSORPTION: NA

ACUTE SKIN CONTACT: MAY CAUSE IRRITATION AND CONTACT DERMATITIS. SKIN ULCERS CAN OCCUR IF THE COMPOUND GAINS ENTRANCE INTO SUPERFICIAL CUTS AND ABRASIONS.

ACUTE EYE CONTACT: CAN CAUSE ACUTE IRRITATION OF THE EYES. CAN ALSO CAUSE PERSISTENT BURNING SENSATION AND LIGHT SENSITIVITY.

CHRONIC EFFECTS: CHRONIC EXPOSURE TO VARIOUS BERYLLIUM COMPOUNDS MAY RESULT IN DELAYED FORM OF LUNG DISEASE, CHARACTERIZED BY THE OCCURRENCE OF GRANULOMATOUS AREAS (BERYLLIOSIS) IN THE LUNG TISSUE. SYMPTOMS CAN START DURING EXPOSURE, BUT MAY BE DELAYED UP TO FIVE YEARS AFTER EXPOSURE., SYMPTOMS INCLUDE COUGHING, SHORTNESS OF BREATH, LOSS OF APPETITE, LOSS OF WEIGHT, AND FATIGUE. PROGRESSION OF THE DISEASE CAN RESULT IN DEATH. FLOURIDE POISONING DUE TO CHRONIC EXPOSURE TO THE COMPOUND IS MANIFESTED BY LOSS OF WEIGHT, LOSS OF APPETITE, ANEMIA, WASTING AND MALNUTRITION, AND TOOTH AND BONE DEFECTS. SYMPTOMS OF FLOURIDE INTOXICATION INCLUDE GASTRIC, INTESTINAL, CIRCULATORY, RESPIRATORY AND NERVOUS COMPLAINTS, AND SKIN RASH.

TARGET ORGANS/SYSTEMS: LUNG

INHALATION EMERGENCY: REMOVE TO FRESH AIR AND GIVE ARTIFICIAL RESPIRATION IF NOT BREATHING. GET MEDICAL AID.

SWALLOWING EMERGENCY: INDUCE VOMITING IF PATIENT IS CONSCIOUS. GET MEDICAL AID.

SKIN CONTACT EMERGENCY: REMOVE CONTAMINATED CLOTHING AND RINSE SKIN WITH RUNNING WATER FOR AT LEAST 15 MINUTES. GET MEDICAL AID.

EYE CONTACT EMERGENCY: FLUSH EYES AT ONCE WITH WATER FOR AT LEAST 15 MINUTES. GET MEDICAL AID.

PHYSICIANS' NOTES: NA

AGGRAVATED CONDITIONS: NA

CARCINOGENICITY: LIMITED EVIDENCE FOR CARCINOGENICITY IN HUMANS, SUFFICIENT EVIDENCE FOR CARCINOGENICITY IN ANIMALS. (IARC 1982)

GENOTOXICITY: NA

REPRODUCTIVE/DEVELOPMENTAL TOXICITY: NA

-----7. SPILL, LEAK, AND DISPOSAL INFORMATION-----

1. SPILL OR LEAK EMERGENCY

SUMMON HELP IMMEDIATELY.

Y-12: SHIFT SUPERINTENDENT, 4-7172 OR 911

X-10: SHIFT SUPERVISOR, 911

K-25: SHIFT SUPERVISOR, 911

PADUCAH: SHIFT SUPERVISOR, BELL-333, PAX-555

MINIMIZE THE SPILL OR RELEASE IF YOU CAN DO SO SAFELY.
EVACUATE THE AREA.

2. DISPOSAL PROCEDURE

Y-12: HEALTH AND SAFETY PROCEDURE 70-903, DISPOSAL OF
HAZARDOUS MATERIALS. FOR MORE INFORMATION, CONTACT THE
WASTE DISPOSAL DEPARTMENT, 6-7897.

X-10: ENVIRONMENTAL PROTECTION MANUAL, EPM-8.0, FORM
UCN-13698. FOR MORE INFORMATION, CONTACT THE DEPARTMENT OF
ENVIRONMENTAL MANAGEMENT.

K-25: SPP-8341, FORM UCN-12463. FOR MORE INFORMATION,
CONTACT THE ENVIRONMENTAL MANAGEMENT DEPARTMENT.

PADUCAH: SPP-68, FORM UCN-12463A. FOR MORE INFORMATION,
CONTACT THE MATERIAL TERMINAL MANAGEMENT DEPARTMENT.

-----8. SPECIAL PROTECTION INFORMATION-----

RESPIRATORS: RESPIRATORS MAY BE REQUIRED WHEN USING THIS
MATERIAL. CONTACT THE INDUSTRIAL HYGIENE
DEPARTMENT FOR MORE INFORMATION.

VENTILATION: CONDITIONS, QUANTITIES, AND OTHER FACTORS
DETERMINE VENTILATION REQUIREMENTS. IF THERE ARE
UNCERTAINTIES, CONTACT THE INDUSTRIAL HYGIENE
DEPARTMENT.

GLOVES: WEAR RUBBER GLOVES.

EYE PROTECTION: WEAR FACE SHIELD AND CHEMICAL SAFETY GOGGLES.

OTHER PROTECTIVE EQUIPMENT: CHEMICAL RESISTANT COVERALLS,
LABORATORY COAT/APRON. DO NOT SMELL!
WASH THOROUGHLY AFTER HANDLING THIS
SUBSTANCE. PROVIDE EYE-WASH IN
IMMEDIATE WORK AREA FOR EMERGENCY USE.

-----9. SPECIAL HANDLING, STORING, PACKAGING-----

PROTECT AGAINST PHYSICAL DAMAGE. STORE IN A DRY, WELL VENTILATED
AREA AWAY FROM MAGNESIUM.

-----10. TRANSPORTATION DATA-----

DOT NAME: BERYLLIUM FLUORIDE
DOT LABEL: POISON

DOT CLASS: POISON B
DOT NUMBER: NA 1566

EPA NUMBER: NA

REPORTABLE QUANTITIES: 5000 LB (2270 KG)

REFERENCES:

IARC MONOGRAPHS ON THE EVALUATION OF THE CARCINOGENIC RISK OF CHEMICALS TO MAN. WORLD HEALTH ORGANIZATION, INTERNATIONAL AGENCY FOR RESEARCH ON CANCER, 1972-PRESENT.

CHEMLINE, CHEMICAL DICTIONARY ONLINE (DATA BASE), NATIONAL LIBRARY OF MEDICINE, BETHESDA MD, 1989.

RTECS, REGISTRY OF TOXIC EFFECTS OF CHEMICAL SUBSTANCES (DATA BASE). NATIONAL LIBRARY OF MEDICINE, BETHESDA MD, 1989.

THE MERCK INDEX. 10TH ED. RAHWAY NJ, 1983.

HAWLEY, G.G. THE CONDENSED CHEMICAL DICTIONARY. 10TH ED. NEW YORK: VAN NOSTRAND REINHOLD CO., 1981.

SAX, N.I. DANGEROUS PROPERTIES OF INDUSTRIAL MATERIALS. 6TH ED. VAN NOSTRAND REINHOLD, NEW YORK NY, 1984.

AMERICAN CONFERENCE OF GOVERNMENTAL INDUSTRIAL HYGIENISTS. TLV THRESHOLD LIMIT VALUES AND BIOLOGICAL EXPOSURE INDICES FOR 1986-1987.

MATERIAL SAFETY DATA SHEETS (MSDS) PROVIDED BY MANUFACTURERS.

HSDB, HAZARDOUS SUBSTANCES DATA BANK (DATA BASE), NATIONAL LIBRARY OF MEDICINE, BETHESDA MD, 1988.

Attachment 4

June 4, 1992

To: C. E. Nix

From: J. M. Wolfe

Compliance Status of Stack 7503-00, MSRE

The MSRE facilities are vented through Stack 7503-00. Regulations which apply to emissions from this facility include the TDEC Air permitting regulations and the Rad NESHAP regulations.

Stack 7503-00 is permitted with the TDEC on permit number 025254P. The permit application indicates I-131 emissions only. Conditions on the permit limit particulate emissions to 0.02 grains per dry standard cubic foot (g/cf), and opacity to 20 percent. Visible emissions have never been observed from this stack, and a stack sample conducted in July 1987 indicates that particulate emissions are well below the 0.02 g/cf limit.

Based on guidance received from the TDEC, this facility could be exempted from permitting requirements. In a letter dated May 17, 1991 (attached) the TDEC indicated that "The exemptions under 1200-3-9-.04 will apply to equipment exhausting radioactive air contaminants if the emissions from this equipment generate an effective body dose less than 0.1 millirem per year (mrem/yr) at the property line of the facility." (see Proposal No. 2 in the attached May 17, 1991 letter) Since this stack emits no hazardous air contaminants other than radionuclides, and radionuclide emissions are below 0.1 mrem/yr, exemption 1200-3-9-.04(kk) would be applicable. This exemption states that "any process emission source emitting only non-hazardous air pollutants that are less than 0.1 pounds per hour" are exempt from permitting requirements. Emission rates of radiolytic fluorine, or any other gaseous emissions must be below the 0.1 lb/hr limit.

The EPA regulates and requires annual reporting of radioactive emissions under 40 CFR 61, National Emission Standards for Hazardous Air Pollutants (NESHAP). Under an FFCA recently developed between EPA and DOE, all ORNL facilities, including the MSRE, are in compliance with the NESHAP requirements.

TENNESSEE DEPARTMENT OF CONSERVATION

Customs House
701 Broadway
Nashville, TN 37247-3530

MAY 17 1991

Mr. Peter J. Gross, Director
Environmental Protection Division
Oak Ridge Operations
Department of Energy
P. O. Box 2001
Oak Ridge, TN 37831

Re: 01-0020-CL; 01-0112-CL; 01-0116-CL

Dear Mr. Gross:

Proposal No. 1, Proposal No. 2, and Proposal No. 3, included as enclosures with your letter dated May 1, 1991, are acceptable as procedures to be followed when dealing with emissions of hazardous air contaminants, radioactive air contaminants, and radionuclides as described in the proposals.

Your assistance in coming to a workable solution to the problem associated with the permitting requirements for very small air emission points is greatly appreciated. If you should have questions concerning these sources in the future, please contact Tupili Reddy or me at (615) 741-3651.

Sincerely,

David G. Carson

David G. Carson
Chief, New Source Permitting Program
Division of Air Pollution Control

DGC/F2241129

Enclosure

cc: Knoxville Field Office

F 2286

8211

MAY 23 1991

PROPOSAL NO. 1ISSUE

Air permitting exemption for laboratory and development ventilation hoods that handle small quantities of hazardous air contaminants as defined by 1200-3-11, other than radionuclides.

PROPOSAL

The exemption identified in 1200-3-9-.04-(4)-(i) shall apply to laboratory equipment which handle compounds regulated as hazardous air contaminants under 1200-3-11-.01 - Asbestos, Beryllium, Mercury, Vinyl Chloride, Benzene, and Inorganic Arsenic - if the ambient concentration of the contaminant emitted from the laboratory hood does not exceed 0.1 percent of the Threshold Limit Value - Time Weighted Average (TLV-TWA), as established by the American Conference of Government Industrial Hygienists (ACGIH) at the nearest property line of the facility. TLVs as listed in the ACGIH handbook, "TLVs and Biological Exposure Indices," shall be used for this evaluation. Any air quality modeling used to demonstrate that ambient limits will be met shall follow recognized EPA modeling guidance.

RATIONALE FOR PROPOSAL

The U.S. Department of Energy (DOE) operates a large number of laboratory and development hoods which handle small quantities of compounds other than radionuclides which are listed in 1200-3-11-.01 as hazardous air contaminants. Examples of these laboratory operations include areas where analyses are performed on air sample filter papers that contain trace quantities of beryllium, analyses performed with the use of small amounts of mercury compounds, etc. Since the current air permitting exemptions do not normally apply to equipment that processes hazardous air contaminants, it could be interpreted that these laboratory hoods would not be exempt from permitting requirements even though the emissions from these sources are extremely small.

In order to minimize the paperwork burden for laboratory hoods that emit very small quantities of carcinogenic air contaminants, TDHE has established a policy for determining permitting needs for laboratory hoods that emit small quantities of carcinogenic compounds.

Since each of the hazardous air contaminants regulated in 1200-3-11-.01 (other than radionuclides) has been designated as carcinogenic by ACGIH and have an established TLV, DOE proposes that the TDHE October 9, 1990, carcinogenic policy be extended to include these hazardous air pollutants. Under this interpretation, only those laboratory hoods that cause the ambient concentration at the nearest DOE property line to exceed 0.1 percent of the established TLV for that compound would be required to obtain an air permit.

DOE believes this will reduce unnecessary paperwork associated with permitting these very small air emission points, while at the same time providing a technically defensible program for the protection of the environment and ambient air quality.

PROPOSAL NO. 2

ISSUE

Air permitting exemption for sources other than laboratory hoods which are listed under air permitting exemptions of 1200-3-9-.04 and emit trace quantities of radioactive air contaminants.

PROPOSAL

The exemptions under 1200-3-9-.04 will apply to equipment exhausting radioactive air contaminants if the emissions from this equipment generate an effective body dose less than 0.1 millirem per year (mrem/yr) at the property line of the facility.

RATIONALE

DOE operates a large number of sources which are listed as being exempt from air permitting requirements under 1200-3-9-.04 and also emit very small quantities of radionuclides. Since radionuclides are listed as a hazardous air contaminant under 1200-3-11-.01, and since the listed air permit exemptions do not normally apply if hazardous air contaminants are emitted, it could be interpreted that these very small emission points are not exempt from permitting requirements.

In order to reduce the paperwork burden associated with the permitting of these small sources, TDHE has developed a policy that defines normally-exempt laboratory hoods that emit radionuclides causing less than 0.1 mrem/yr effective dose equivalent at the property line as being exempt from air permitting requirements.

DOE proposes that this policy be extended to all sources which would normally be exempt from air permitting requirements under 1200-3-9-.04 and emit radionuclides causing less than 0.1 mrem/yr effective dose equivalent at the property line.

DOE believes this policy will significantly reduce the paperwork burden associated with permitting these very small sources emitting only trace quantities of radionuclides.

PROPOSAL NO. 3ISSUE

Clarification of the Tennessee Division of Air Pollution Control (TN DAPC) permitting requirements for airborne radionuclides emitted from U.S. Department of Energy (DOE) sources.

PROPOSAL

Since the emission of airborne radionuclides from DOE facilities is currently regulated by the U.S. Environmental Protection Agency (EPA) under 40 CFR Part 61, National Emission Standards for Hazardous Air Pollutants (NESHAPs), Subpart H, National Emission Standard for Radionuclide (Rad) Emissions from DOE Facilities, TN DAPC permit applications and permits obtained for these sources are not required to contain process and/or emission data for radiological parameters.

RATIONALE

EPA currently regulates the airborne emissions of radionuclides from DOE facilities under the Rad NESHAPs. These regulations limit radionuclide emissions from the Oak Ridge Reservation to quantities that contribute no more than 10 millirem per year effective dose equivalent to any member of the public. The Rad NESHAPs regulations also stipulate detailed stack monitoring requirements and annual emission reporting requirements for all potential sources of radionuclide emissions to the atmosphere. This program enforces a stringent level of control for the affected sources.

The TN DAPC has promulgated air pollution permitting regulations under Rule 1200-3-9 in order to ensure protection of the ambient air quality in Tennessee. Since the Rad NESHAPs regulations limit radionuclide emissions by means of a public dose standard, the regulation of radiological emissions under the TN DAPC permitting program would appear to offer little added regulatory control over these sources. In addition, since the Rad NESHAPs dose standard applies to the sum of all sources at the exposure point, it would be impractical to relate emission criteria to individual sources.

DOE Oak Ridge Operations (DOE-ORO) believes that acceptance of this proposal will significantly reduce the administrative burden associated with listing radiological parameters on applicable permit applications and permits, while at the same time maintaining a high level of regulatory control for radiological sources. DOE-ORO also believe this proposal will prevent potential conflict between the established Federal Rad NESHAPs program which utilizes a public effective dose equivalent from all combined radiological sources located on the Oak Ridge Reservation and the TN DAPC permitting program which regulates individual air contaminant sources with specific permit conditions.

Appendix K

Preliminary Report of the Leachability of Selected Unirradiated Metals

Introduction

All types of metal when discarded are considered to be RCRA solid waste. If the material is considered to be scrap metal as defined by RCRA and is recycled, then the scrap metal is exempt from regulation. If it is not recycled, then the metal must be characterized to determine if it is hazardous or non-hazardous as defined by RCRA.

An investigation was initiated to determine which types of metal used at ICPP would exceed regulatory levels, for various hazardous constituents, using the Toxicity Chemical Leaching Procedures (TCLP). The information will be used in developing the appropriate procedures for disposing of materials constructed of these metals.

Materials and Methods

Attachment A list the types of metals used in this study. The list represents those metals which are most commonly used at ICPP for the construction of process systems. It does not represent a comprehensive list. Other types of metals will be tested with the results being added to the data provided in this report. None of the samples had been exposed to radiation.

Metal samples were prepared in a variety of forms i.e. metal shavings, rod-like sections, quarter-inch square sections. Each sample type met the TCLP size requirement. The samples were extracted as described in the TCLP.

Based upon the analytical results of Phase I, additional analyses were performed in Phase II on metals which failed or could potentially the TCLP.

Results

Attachment B lists the results from Phase I only. Two metals had hazardous constituents greater than the regulatory level. Carpenter 20 and T-304 exceeded the regulatory level for chromium. Three other metals Hastelloy C-4, Hastelloy C-22 and 304L, had a chromium concentration of greater than 4 ppm. None of the 5 metals listed above failed the TCLP in Phase II. (Results from Phase II are in notebook).

Discussion

During Phase I a majority of the samples were metal filings. This provided the greatest surface area. If samples prepared in this manner passed the TCLP, then the possibility of metals existing in other forms failing would be minimal.

Two metals failed the TCLP for chromium and the other metals had a chromium concentration of greater than 4 ppm. Based upon these analytical results, additional samples of these metals were prepared. The samples consisted of metal shavings as well as samples prepared in other forms i.e. rod-like. None of the samples in Phase II failed the TCLP. The metal shavings were prepared in the same manner as during Phase I. The reason for different results, for samples of the same form, is not readily apparent and will require additional evaluation.

Heat sheats, which describe the primary constituents of the metals, were obtained for the various metal types when available. Based upon evaluation of the analytical results and the percent composition of the constituents of concern, there is no apparent correlation between the amount leached and percent composition of the constituent.

The effect of exposure to acids and/or radiation were not evaluated in this study. These variables should be evaluated to determine if there is a change in the leachability of hazardous constituents from metals.

Conclusion

Based upon this preliminary investigation, the disposal of any metal with dimensions less than or equal to 1/4 inch, such as metal filings, shavings, turnings, grindings, etc. should be evaluated to determine if TCLP analysis is required before disposal. This action is necessary based upon results of the characterization activities performed at ICPP and from information obtained by EPA which suggest that RCRA hazardous constituents may be more readily leached when metals are in these forms.

The results of this study apply only to the types of metals listed in Attachment A. All other types of metals regardless of size must be characterized prior to disposal.

Attachment A

List of Metals Analyzed During Phase I

304L

T-304

T-316

T-347

Hastelloy Alloy G-30

Hastelloy Alloy C-22

Hastelloy Alloy C-4

Inconel 625

Nitronic 33

Incoloy-825

Hastelloy Alloy C-276

Nitronic 50

Carpenter 20 CB-3

Monel 400

Carpenter 20

308L

PRELIMINARY

HAZARDOUS CONSTITUENTS (mg/L) IN DIFFERENT METALS

	MITRONIC 33	INCONEL 625	CAMPNTR 20	CAMPNTR 20- CBE	HASTELLOY C-4	HASTELLOY C-22	HASTELLOY C-30	304L	T-316	T-304	T-347	MONEL 400	MITRONIC 50	INCOLY 825	HASTELLOY 276	309L	REG. LEVEL
NICKEL	♦.640	♦11.7	♦9.41	♦10.8	♦25.5	♦16.1	♦6.19	♦1.88 ♦.943*	♦2.09	♦2.59	♦1.80	♦460.0	♦2.75	♦5.03	♦16.7	**	100
CHROMIUM	♦2.35	♦1.06	♦.75	♦2.82	♦1.30	♦.68	♦1.47	♦4.08 ♦2.49*	♦1.92	♦.35	♦1.91	♦2.27	♦2.39	♦.947	♦1.45	♦1.08*	5.0
ARSENIC	<.277	<.277	<.277	<.277	<.277	<.277	<.277	<.277 <.183*	<.277	<.277	<.277	♦.788	<.277	<.277	<.277	<.120*	5.0
SELENIUM	<.264	<.264	<.264	<.264	<.264	<.264	<.264	<.264 ♦.788*	<.264	<.264	<.264	<.264	<.264	<.264	<.264	<.122*	1.0
SILVER	<.0288	<.0288	<.0288	<.0288	<.0288	<.0288	<.0288	<.0288 ♦.0189*	<.0288	<.0288	<.0288	<.0288	<.0288	<.0288	<.0288	<.0021*	5.0
CADMIUM	<.0111	<.0111	<.0111	<.0111	<.0111	<.0111	<.0111	<.0111 ♦.0054*	<.0111	<.0111	<.0111	<.0111	<.0111	<.0111	<.0111	<.0321*	1.0
BARIUM	<.0345	<.0345	<.0345	♦.285	<.0345	<.0345	<.0345	♦.251 ♦.273*	♦.310	♦.230	♦.240	♦.0952	♦.0349	<.0345	<.0345	♦.0431*	100
MERCURY	NA	NA	NA	<.0005	NA	NA	NA	<.0005 ♦.0005*	<.0005	<.0005	<.0005	<.0005	<.0005	<.0005	<.0005	<.0005*	0.2
LEAD	<.126	<.126	<.126	<.126	<.126	<.126	<.126	<.126 ♦.102*	<.126	<.126	<.126	♦.211	<.126	<.126	<.126	<.121*	5.0

Sample size of one unless except where noted.

Less than values represent detection limits.

NA = Data not available at this time, awaiting final analysis

* = These data from a separate analysis, log #92-021210. Preparation of the sample for this analysis was different than the sample preparation for other metals listed above.

** = Analysis for this constituent not performed. No reason given for not performing analysis.

♦ = Constituents greater than detection limits

= Exceeded regulatory limits

ZZZZ = Further evaluation may be necessary

Appendix L

Ag-In-Cd Control ROD Analytical Results

FINAL report for AG-CD-IN
(Customer copy)

ROD

** EPA Log **

Report for : J E SAILER
Address : MS-3202

Log Number : 94-033121
Phone number : 6-5832

Date received : 03/31/94
Time received : 13:17

Date completed: 04/25/94
Time completed: 11:46

GWA charged : 36150-400-100

Reviewed by D.A. PAVLICA

MSR mR/hr : COLD

Signature *D.A. Pavlica*

Hazard Index : CD

Lab QC/QA reviewed by

Quality Level : IV

Signature *Cindy A Whitmer*

COMMENTS: (sorted by Analysis)

THE BARIUM AND CHROMIUM CONCENTRATIONS ARE AT THE BLANK
LEVEL OF THE ANALYTICAL METHOD.
SAMPLE IS A SILVER-CADMIUM-INDIUM CONTROL ROD 3/8 INCH

Analysis	Sample	Method	Analyst	Result(s) for log 033121
ARSENIC	CONTROLROD	2339	LBZ	Not Detected:DL= 0.05 mg/l
BARIUM	CONTROLROD	2569	LBZ	0.0359 MG/L
CADMIUM	CONTROLROD	2489	LBZ	0.251 MG/L
CHROMIUM	CONTROLROD	2249	LBZ	0.0359 MG/L
LEAD	CONTROLROD	2829	LBZ	Not Detected:DL= 0.06 mg/l
SILVER	CONTROLROD	2479	LBZ	0.0393 MG/L
TCLP	CONTROLROD	8998	GMH	100.95 G / pH 4.90 / 4-5-94