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ENGINEERING CHANGE NOTICE

Page 1 of 2 ~~Page 1 of 2~~ 3

1. ECN 649401

Proj. ECN

2. ECN Category (mark one)	3. Originator's Name, Organization, MSIN, and Telephone No.	4. USQ Required?	5. Date
Supplemental [] Direct Revision [X] Change ECN [] Temporary [] Standby [] Supersedure [] Cancel/Void []	K. L. Pearce, H7-20, 376-3782	[] Yes [X] No	07/31/98
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13a. Description of Change

13b. Design Baseline Document? [X] Yes [] No

1) Added a second volume to describe the design basis feed compositions for the baseline KE Basin and KW Basin sludge process streams expected to be generated during SNF Project activities.

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14a. Justification (mark one)

Criteria Change	[X]	Design Improvement	[]	Environmental	[]	Facility Deactivation	[]
As-Found	[]	Facilitate Const	[]	Const. Error/Omission	[]	Design Error/Omission	[]

14b. Justification Details

Availability of new characterization data for sludge from KE floor and Weasel Pit, KE canisters, KW canisters and KE/KW fuel elements. Characterization data updates for fuel and sludge are not on parallel schedules. Dividing the documents provides both fuel and sludge subprojects the flexibility to revise data independent of one another.

15. Distribution (include name, MSIN, and no. of copies)

See distribution sheet.

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Page 2 of 2

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16. Design Verification Required	17. Cost Impact				18. Schedule Impact (days)	
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19. Change Impact Review: Indicate the related documents (other than the engineering documents identified on Side 1) that will be affected by the change described in Block 13. Enter the affected document number in Block 20.

SDD/DD	[]	Seismic/Stress Analysis	[]	Tank Calibration Manual	[]
Functional Design Criteria	[]	Stress/Design Report	[]	Health Physics Procedure	[]
Operating Specification	[]	Interface Control Drawing	[]	Spares Multiple Unit Listing	[]
Criticality Specification	[]	Calibration Procedure	[]	Test Procedures/Specification	[]
Conceptual Design Report	[]	Installation Procedure	[]	Component Index	[]
Equipment Spec.	[]	Maintenance Procedure	[]	ASME Coded Item	[]
Const. Spec.	[]	Engineering Procedure	[]	Human Factor Consideration	[]
Procurement Spec.	[]	Operating Instruction	[]	Computer Software	[]
Vendor Information	[]	Operating Procedure	[]	Electric Circuit Schedule	[]
OM Manual	[]	Operational Safety Requirement	[]	ICRS Procedure	[]
FSAR/SAR	[]	IEFD Drawing	[]	Process Control Manual/Plan	[]
Safety Equipment List	[]	Cell Arrangement Drawing	[]	Process Flow Chart	[]
Radiation Work Permit	[]	Essential Material Specification	[]	Purchase Requisition	[]
Environmental Impact Statement	[]	Fac. Proc. Samp. Schedule	[]	Tickler File	[]
Environmental Report	[]	Inspection Plan	[]		[]
Environmental Permit	[]	Inventory Adjustment Request	[]		[]

20. Other Affected Documents: (NOTE: Documents listed below will not be revised by this ECN.) Signatures below indicate that the signing organization has been notified of other affected documents listed below.

Document Number/Revision	Document Number/Revision	Document Number Revision
HNF-SD-SNF-TI-053, Rev. 0 K Basins Sludge Inventory Composition		

21. Approvals

	Signature	Date		Signature	Date
Design Authority	A. G. Westra	7/31/98	Design Agent		
Cog. Eng.	T. A. Flament	7/31/98	PE		
Cog. Mgr.	W. W. Rutherford	7/31/98	QA		
QA	D. S. Dutt	7/31/98	Safety		
Safety	R. D. Crowe	7/31/98	Design		
Environ.			Environ.		
Other	K. L. Pearce	7/31/98	Other		
	R. B. Baker	8/3/98			
	D. R. Precechtel	8/3/98			

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Signature or a Control Number that tracks the Approval Signature

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105-K BASIN MATERIAL DESIGN BASIS FEED DESCRIPTION FOR SPENT NUCLEAR FUEL PROJECT FACILITIES, VOLUME 2, SLUDGE

K. L. Pearce, S. C. Klimper, T. A. Flament
Numatec Hanford Corporation, Richland, WA 99352
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Key Words: Sludge, 105-K Basin, SNF Project, Sludge Inventory, Design Basis Feed, Radionuclide Inventory, Chemical Inventory, Shielding Basis, Safety/Regulatory Basis.

Abstract: Volume 2 provides the design feed compositions for the baseline K East and K West Basin sludge process streams expected to be generated during Spent Nuclear Fuel (SNF) Project activities. Four types of feeds are required to support evaluation of specific facility and process considerations during the development of new facilities and processes. These four design feeds provide nominal and bounding conditions for design evaluations.

Volume 2 includes definition of inventories for; 1) KE and KW Basins sludge locations (pit sludges, floor sludge, canister sludge, and wash sludge components), 2) nominal feed for each of five process feed streams, 3) shielding design feed, 4) safety/regulatory assessment feed, and 5) criticality assessment feed.

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105-K BASIN MATERIAL DESIGN BASIS FEED DESCRIPTION FOR SPENT NUCLEAR FUEL PROJECT FACILITIES, VOLUME 2, SLUDGE

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105-K BASIN MATERIAL DESIGN BASIS FEED DESCRIPTION FOR SPENT NUCLEAR FUEL PROJECT FACILITIES, VOLUME 2, SLUDGE

Authors:

K. L. Pearce
S. C. Klimper
T. A. Flament

August 1998

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LIST OF TERMS

AEA	Alpha Energy Analysis
GEA	Gamma Energy Analysis
IWTS	Integrated Water Treatment System
IXC	Ion exchange column
IXM	Ion exchange module
KE	K East
KE Basin	105-KE Basin
KW	K West
KW Basin	105-KW Basin
OIER	Organic ion exchange resin
PCB	Polychlorinated biphenyl
SNF	Spent Nuclear Fuel
XRD	X-ray diffraction

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105-K BASIN MATERIAL DESIGN BASIS FEED DESCRIPTION FOR SPENT NUCLEAR FUEL PROJECT FACILITIES, VOLUME 2, SLUDGE

1.0 INTRODUCTION

1.1 PURPOSE AND SCOPE

The purpose of this document is to describe the design basis feed compositions for the baseline K East (KE) Basin and K West (KW) Basin sludge process streams expected to be generated during Spent Nuclear Fuel (SNF) Project activities. Four types of feeds are required to support evaluation of specific facility and process considerations during the development of new facilities and processes. These four design feeds provide nominal and bounding conditions for design evaluations. The approach is to establish a proposed process flowsheet. The process flowsheet will provide a basis for material compositions and quantities that are used in follow-on calculations (process parameters, etc.). Table 1-1 provides a list of the proposed feeds for sludge and the intended purpose of each feed definition.

The scope of this document includes defining the inventories (1) for KE and KW Basins sludge locations (pit sludges, floor sludge, canister sludge, and wash sludge components) and (2) for the four design feeds defined in Table 1-1.

The feed descriptions defined in this document apply only to the SNF Project facilities that handle K Basin sludge that has not been treated. Definition of those waste streams generated from the treatment process (for example those streams going to the Tank Waste Remediation System and the Environmental Restoration Disposal Facility) are not included in this document. This document utilizes the most current characterization data available to define the various sludge inventories. This document will be revised as new data are acquired and released.

1.2 BACKGROUND

Metallic uranium SNF currently is stored in two water-filled concrete pools, 105-KE Basin (KE Basin) and 105-KW Basin (KW Basin), at the U.S. Department of Energy Hanford Site in southeastern Washington State. These fuel storage pools contain hazardous substances that primarily result from the degradation of the SNF. The hazardous substances consist of the SNF, sludge, debris, and water. In the past, large quantities of contaminated water leaked from the basins into the underlying soil and groundwater. Because of this, the U.S. Department of Energy-Richland Operations Office has determined that the hazardous substances stored in the basins present a potential threat to human health and the environment, and that a non-time-critical removal action conducted under the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* is warranted to reduce this threat.

Table 1-1. Spent Fuel Project Facility Design Feeds for Sludge.

Design Feed	Description/Purpose
Nominal Feed	Average feed to the facility over the plant life. Used to design systems that provide suitable performance over the entire plant life. Among other things, this feed is used to design shielding that will maintain radiation doses to workers as low as reasonably achievable. A nominal feed will be established for each of five process feed streams.
Shielding-Basis Feed	The nominal process feed stream with the highest gamma shielding requirements (^{137}Cs is the dominant gamma contributor). This feed is used to evaluate gamma shielding provided by the plant structure and equipment, to determine if potential peak radiation dose rates are acceptable. This feed represents material that is expected to be in the facility for short campaigns and that would not be used for evaluations of performance over the entire facility life (see nominal feed).
Safety/ Regulatory-Assessment Feed	A feed with bounding ^{241}Am, plutonium isotopes, and ^{90}Sr radionuclides that, if released, dominates the estimate of dose to personnel (both onsite and offsite). This feed is used to analyze design-basis accidents and support definition of safety structures, systems, and components. This feed represents material that is expected to be in the facility for short campaigns and would not be used for evaluations of performance over the entire plant life (see nominal feed).
Criticality-Assessment Feed	A feed with bounding fissile material content, used to define criticality controls (e.g., geometric favorable equipment designs), that may impact the system design. This feed represents an upper bound of the operating envelope for material fissile content that could be introduced into the facility without special operating procedures or additional criticality safety evaluations. The feed represents material that is expected to be in the facility for short campaigns and would not be used for evaluations of performance over the entire plant life (see nominal feed).

Approximately 2,100 metric tons of SNF currently are stored in the K Basins. The KE Basin contains about 1,150 metric tons of the SNF, stored underwater in 3,673 open-top canisters. This SNF has been stored for varying lengths of time ranging from 8 to 24 years. Much of the SNF stored in the KE Basin is damaged; it has been estimated that about 1 percent of the original mass of the fuel has corroded and contributed to the radioactive sludge in that basin (DOE 1996). The remainder of the SNF, approximately 950 metric tons, is stored underwater in the KW Basin in 3,817 closed canisters.

Both the KE and the KW Basins contain contaminated sludge. Sludge on the floor and in the pits of the KE Basin is a mix of fuel corrosion products (including metallic uranium, and fission and activation products), small fuel fragments, iron and aluminum oxide, concrete grit, sand, dirt, and biological debris. The large quantity of fuel corrosion products in the KE Basin floor and pit sludge is a result of the open tops, and in some cases open-screened bottoms, of the fuel storage canisters. Because the SNF stored in the KW Basin was placed in closed containers before storage, corrosion products were retained within the canisters and the sludge buildup in the KW Basin is of much smaller volume than that in KE Basin. The small quantity of sludge on the floor of the KW Basin appears to consist primarily of dust and sediment; the floor sludge is not expected to contain significant amounts of fuel corrosion products because the KW Basin canisters have closed tops and bottoms. Only one of the pits (North Loadout Pit) in the KW Basin contains a significant amount of sludge and is likely to consist of a mix of sand and

fuel corrosion products. Sludge in the KE and KW Basin fuel storage canisters consists primarily of fuel corrosion products.

The sludge in the basins is commingled with SNF and is not considered a waste; however, when the sludge is separated from the SNF and removed from the basins, it will be designated and managed as a waste (Wagoner 1996). For the purposes of differentiating SNF and debris from sludge, any material less than or equal to 0.64 cm (0.25 in.) in diameter is defined as sludge.

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2.0 105-K BASIN SLUDGE

2.1 SLUDGE SOURCES

During the time that the fuel has been stored, approximately 51 m^3 (nominal value) of sludge has accumulated in the fuel canisters and on the bottom of the K Basins. This sludge is being generated from a variety of sources.

- Fuel elements are oxidizing where cladding has been breached, thereby contributing uranium oxide and fission products to the sludge. In KE Basin, some oxidized fuel may have fallen to the floor of the basin through screens in the bottoms of some canisters (the Mark 0 canisters).

- The KE Basin is an unlined concrete pool. As the facility ages, concrete grit comes loose from the walls and falls to the basin floor.

- The basins are enclosed but the structures are not weathertight. High winds cause dust and other pollutants (dirt, insects, bits of tumbleweed, etc.) from the outside environment to enter the facilities and, ultimately, the storage pools.

- Painted carbon steel storage racks sit in the storage pool to hold the fuel canisters in place. As these racks age, they present a source of rust corrosion and paint chips.

- The aluminum canisters in KE Basin were corroded over a two-year period when chlorine was used as a biological control agent.

- The origin of polychlorinated biphenyls (PCB), found sporadically in the sludge solids, is unknown.

- During basin operations, ion exchange column (IXC) screen failure allowed zeolite (Zeolon 900H) to be discharged into the KE Basin. Sludge analyses indicate that mixed resin beads (purolite) also are present in KE Basin; possible pathways into the basins for this resin are via the IXC discharge water and the ion exchange module (IXM) vent system.

- Deterioration and destruction during lid removal of the KW canister lid gaskets has resulted in graphite-based materials being present in the KW canister sludge.

- Particulate matter resulting from back washing the sandfilter, which is part of the skimmer cleaning equipment, contributes to the sludge in the North Loadout Pit (also designated Sandfilter Backwash Pit).

In addition to the existing sludge material, other sludge-like materials will be generated in the processing of fuel elements for dry storage. Before dry storage, the fuel storage canisters will be placed into a primary washing machine that will clean the canisters and elements by a tumbling

action and water process. Based on the physical state of the stored fuel, as observed by underwater video records; the known brittleness of irradiated uranium metal (Swanson et al. 1985); and the fractured state of the uranium within the breached fuel (Swanson 1988), further breakage of the fuel elements is expected that will dislodge corrosion products, corroded uranium metal pieces, zirconium cladding, pieces comprising both uranium and zirconium, and loosely adhered materials (such as coating and internal sludge). The dislodged sludge is referred to as "fuel wash" sludge and is assumed to be made of up three components: coating material, internal sludge, and fuel pieces.

2.2 SLUDGE LOCATIONS

A schematic of the K Basins is shown in Figure 2-1. The six remote pits connected to each basin are the North Loadout Pit [also called the Sandfilter Backwash Pit], the South Loadout Pit, the Dummy Elevator Pit, the Tech View Pit, the Weasel Pit, and the Discharge Chute.

Sludge in the KE Basin is located on the floor of the Basin, in the fuel canisters and in four of the six pits (North Loadout Pit, Dummy Elevator Pit, Tech View Pit and the Weasel Pit). In KE Basin, the sludge in the Discharge Chute and the South Loadout Pit has been pumped into the Weasel Pit. In KW Basin, sludge is located on the floor (in very small quantities compared to KE Basin), in the fuel canisters, and in five of the six pits (the North Loadout pit sludge was pumped into the Tech View pit). The Sandfilter Backwash Pit is the only pit in KW Basin that contains an appreciable amount of sludge.

Both canister sludge and fuel wash sludge currently are located in the fuel canisters. The canister sludge is the sludge that currently resides on the bottom of the canisters. The fuel wash sludge is the sludge in the fuel elements (i.e., internal sludge), on the fuel cladding (i.e., coating material), and part of the element itself (i.e., fuel pieces).

The basin water is recirculated through the pool cooling and cleanup system (WHC 1993) to perform the following:

- Remove the decay heat generated by the irradiated fuel stored in the basin
- Maintain water quality and clarity
- Control the concentration of soluble and particulate radioactive nuclides in the water to minimize personnel radiation exposure.

This recirculation of basin water results in some sludge migration throughout the basin. In addition, there is sufficient decay heat from the fuel canisters in KE Basin to drive convection currents that further promote sludge migration.

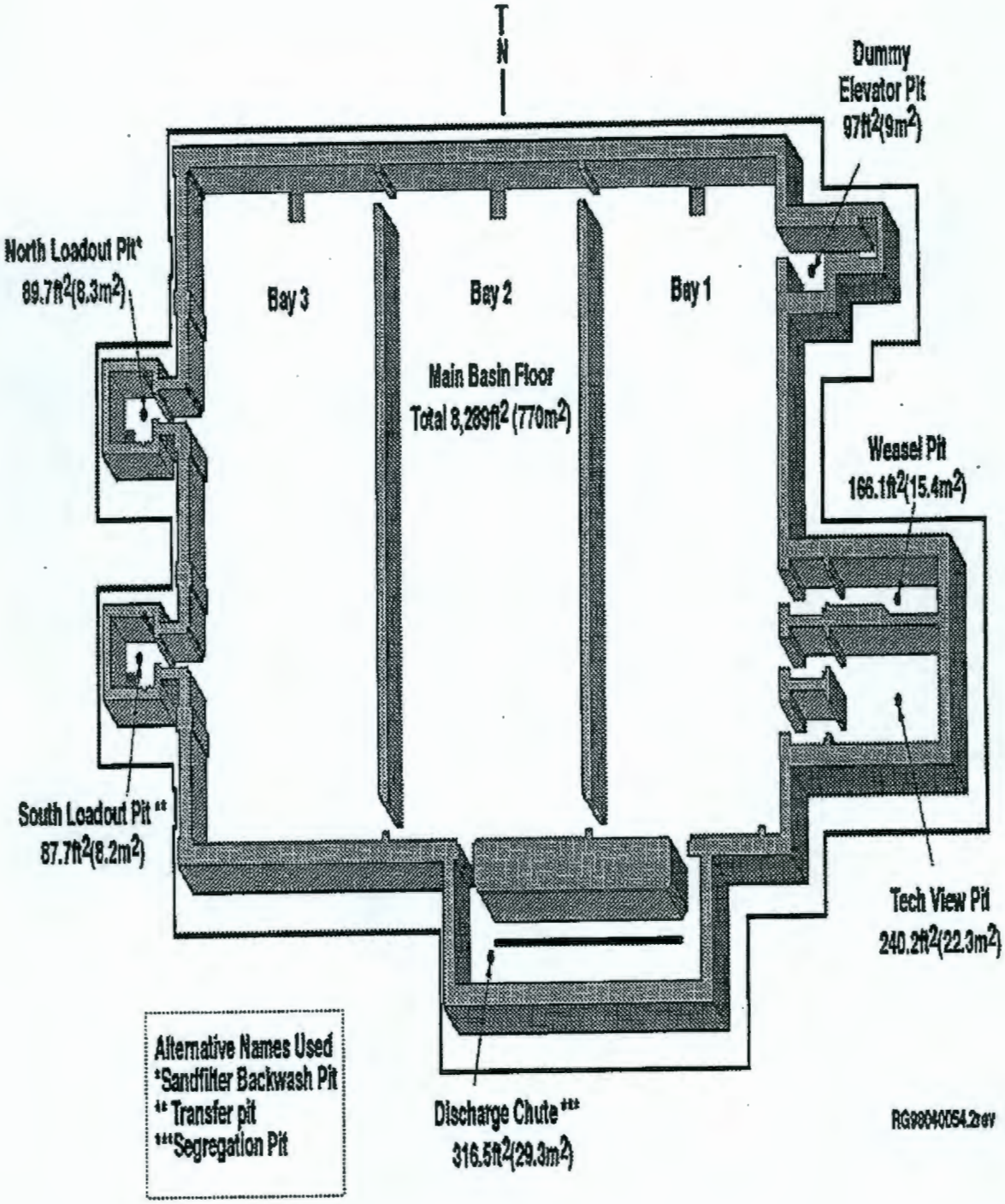

Figure 2-1. Schematic of KE and KW Basin Overview.

The KE Basin Weasel Pit is screened from the main basin by a 37 micron screen so that most of the sludge pumped into the pit is retained until it has had time to settle out (this operation occurs in KE Basin only). However, some fine particulate sludge still escapes back into the main basin, along with all dissolved material. The North Loadout Pit and Discharge Chute are isolated from the main basin.

2.3 SLUDGE VOLUMES

The total as-settled sludge volume in KE Basin, including floor, pits, canister, and fuel wash sludges ranges from a nominal value of approximately 43.8 m^3 to an upper bound of approximately 57.9 m^3. Current estimates for volume of sludge in the KW Basin ranges from a nominal value of approximately 6.75 m^3 to a maximum of approximately 10.1 m^3. Sludge depths, volumes, and locations provided in Baker (1998) are baseline data. The as-settled sludge volumes for each location are shown in Figures 3-1 and 3-2 for KE Basin and KW Basin, respectively.

2.4 CURRENT INVENTORY BASIS

2.4.1 Characterization Data Background

The majority of the characterization data used for definition of the composition and physical characteristics of the K Basins sludge locations and process feed streams come from characterization campaigns made in the past four years by the Hanford Site SNF Project. Each major characterization campaign was based on a set of data quality objectives and a corresponding sampling and analysis plan that had concurrence from the project stakeholders involved. The sampling and analysis plans were developed to ensure reasonable representativeness of the samples (Welsh et al. 1995, 1996, 1997). The raw data (including quality assurance supporting information) generated from analysis of the sludge samples was summarized in project documents (Makenas et al. 1996, 1997, 1998) to provide integrated databases for the SNF subprojects to use as a basis of design.

2.4.2 Existing Characterization Data

Three sludge sample analysis campaigns have been conducted to date for the KE Basin floor and Weasel Pit, the KE Basin canisters, and the KW Basin canisters (Makenas et al. 1996; Makenas et al. 1997; and Makenas et al. 1998, respectively). These campaigns have developed basic data on (1) sludge volumes in the KE Basin Weasel Pit and canisters (KE Basin floor sludge volumes were reported previously in Baker [1995]) and (2) detailed chemical, radionuclide, and physical properties of the sludges in these locations.

The characterization samples were analyzed by inductively coupled plasma spectrometry for metals concentrations and by radiometric counting techniques to determine total alpha, ^{241}Am, $^{239/240}Pu$, total beta, ^{137}Cs, ^{60}Co, ^{90}Sr, and other radionuclide concentrations of sludge samples on a dry basis. The sludge samples were analyzed for total inorganic carbon (carbonate or bicarbonate) by a wet chemical acidification and for total organic carbon by oxidation in

persulfate. The weight fraction of acid-insoluble residue was determined by gravimetric methods. Numerous other physical and chemical analyses (for example, particle size, X-ray diffraction, and anion concentrations by ion chromatography) also were performed and reported. The results of these sample analyses were used to determine the chemical and radionuclide constituents in the KE Basin floor, Weasel Pit, and canister sludge and in the KW Basin canister sludge.

Limited analyses of samples taken earlier from the KE Basin Sandfilter Backwash Pit also have been reported (Warner 1994). Routine operational sampling of the North Loadout Pit in May 1993 indicated that levels of plutonium had risen above allowable limits as a result of continuing corrosion of irradiated N-Reactor fuel in the basin water. Consequently, an unreviewed safety question was declared regarding continued sand filter backwash operation. A sampling and analysis plan was prepared that outlined a sampling program to obtain sludge samples (Bechtold 1994). The results of this sample analysis were used to determine the chemical and radionuclide constituents in the North Loadout Pit.

The characterization data used to define the fuel wash sludge was taken from the analyses performed on fuel elements taken from the K Basins (Silvers 1998a). Analyses were performed on the coating, on subsurface sludge obtained from the five elements, and on the residue collected from the bottoms of the shipping containers.

2.4.3 Assumed Characterization Data

Analyses of sludge from the KE Basin Tech View Pit and Dummy Elevator Pit and from the KW Basin floor and pits are not currently available. Therefore, the current sludge inventory estimates for the KE Basin Tech View Pit and Dummy Elevator Pit are based on assuming that sludge in these locations will be similar to, or bounded by, the characteristics of the Weasel Pit sludge. It was assumed, however, that the Tech View Pit and the Dummy Elevator Pit do not contain zeolite material, because the only identified spill of zeolite into the KE Basin was pumped into the Weasel Pit.

The characteristics of the KW pits (i.e., Weasel, Tech View, South Loadout, Dummy Elevator, and Discharge Chute Pits) are based on assuming that sludge in these locations will be similar to, or bounded by, the characteristics of the KE Basin Weasel Pit sludge. It is assumed, however, that none of the KW pit sludges contain zeolite or PCBs. The characteristics of the KW floor sludge are based on assuming that this sludge is similar to, or bounded by, the characteristics of the KE Basin floor sludge. It is assumed, however, that the KW floor sludge contains no organic ion exchange resin (OIER) or PCBs. The characteristics of the KW North Loadout Pit sludge are based on assuming that this sludge is similar to, or bounded by, the characteristics of the KE Basin North Loadout Pit.

2.4.4 Mass Balance Determinations

A mass balance was determined using the analytical and residual results for each sludge location described above. The calculations assumed the elemental analyses to represent the likely materials uranium dioxide (UO_2), uranium oxide (U_3O_7), uranium hydrate ($UO_4 \cdot 4H_2O$), uranium hydride (UH_3), aluminum hydroxide ($Al[OH]_3$), aluminum oxide (Al_2O_3), ferric oxyhydroxide ($FeO[OH]$), calcium oxide (CaO), and CO_2 (used to represent carbonate). These compounds

were combined with the remaining trace elements and the residue (assumed to be silicon dioxide [SiO_2]) to determine the mass balance for the dried solids for each sludge location. These calculations are presented in Appendices A through F. It is assumed that the databases (as defined in the Appendices) used for each of the sludge locations (floor, Weasel Pit, North Loadout Pit, canisters, wash machine) are an accurate reflection of the sludges located in the K Basins. These databases were used because they represent the best available current estimates of the sludge compositions for each location.

While it is recognized that a comprehensively defensible mass balance would require more information than is available, an estimate of solids compositions expected in each feed stream is necessary to adequately define those design parameters that will be influenced by the chemical process (for example, differences in dissolution of uranium versus UO_2). To achieve the solids estimate, one or more compounds were chosen to represent each analyte reported in the characterization data. The compounds were chosen based on the likely oxidation products for the analytes and on x-ray diffraction results reported in the characterization reports. While the set of oxidation products identified may be somewhat limited, this approach did simplify the modeling process by minimizing the number of compounds being tracked. The mean concentrations of the compounds were calculated from the mean concentrations of the elements on a dry basis, thereby allowing the calculation of a wt% solids value for each compound without having to account for the water content of as-settled sludge. The total compound concentrations account for approximately one gram of dry sludge, thereby lending credibility to the compounds that were chosen.

The chemical/radionuclide data presented in the KE and KW sludge characterization reports are representative of the constituents found in the sludge locations within the basins. However, numerical averaging of the data may <u>not</u> be representative of homogeneous mixing of all sludges, because the data were taken from basin areas (floor, Weasel Pit, and canisters) having different depths of sludge, and the data in the characterization reports are not volume weighted. Averaging the Weasel Pit and North Loadout Pit sludge constituents was considered representative of a homogeneous sludge because of the fairly uniform depth of sludge within these pits. No attempt was made to "depth weight" the floor and canister sludge samples, which have a great variety of sludge depths. There are other high and low sludge depths that were not sampled. To verify that the application of a depth-weighted averaging approach is indeed more accurate might require much more sampling, especially of all high and low points within the areas of consideration.

A summary of the sludge inventories for each of the sludge locations is presented in Table 2-1 for the KE Basin sludge locations and Table 2-2 for the KW Basin sludge locations.

Table 2-1. Nominal Inventory for KE Basin Sludge Locations (2 sheets).

		Source -- K East						
	Units	Weasel Pit	Main Basin Floor	Tech View	North Loadout Pit	Dummy Elevator Pit	Canisters Full	Canisters Empty
As-settled Sludge **Solid Content** (g dry solids/cm3 as-settled sludge)	g/cm^3	0.931	0.375	0.931	0.370	0.931	0.884	0.884
As-settled Sludge **Density**	g/cm^3	1.56	1.32	1.56	1.27	1.56	1.62	1.62
Volume of Sludge	m^3	10.10	21.50	0.40	6.30	1.40	3.00	0.40
As-settled Sludge Chemical Composition								
U	g/cm^3	0.000554	0.000336	0.000554	0.000133	0.000554	0.023489	0.023489
UO_2	g/cm^3	0.031127	0.018880	0.031127	0.007471	0.031127	0.239820	0.239820
U_3O_7	g/cm^3	0.031741	0.019253	0.031741	0.007619	0.031741	0.244557	0.244557
$UO_4 \cdot 4H_2O$	g/cm^3	0	0	0	0	0	0	0
UH_3	g/cm^3	0	0	0	0	0	0.023785	0.023785
$Al(OH)_3$	g/cm^3	0	0	0	0	0	0.170042	0.170042
Al_2O_3	g/cm^3	0.062895	0.041372	0.062895	0.014103	0.062895	0	0
FeO(OH)	g/cm^3	0.403050	0.128683	0.403050	0.037761	0.403050	0.109399	0.109399
SiO_2	g/cm^3	0.235325	0.073942	0.235325	0.297060	0.235325	0.039261	0.039261
CaO	g/cm^3	0.015968	0.003087	0.015968	0.003699	0.015968	0.001624	0.001624
CO_2	g/cm^3	0.007600	0.004923	0.007600	0	0.007600	0.007565	0.007565
C	g/cm^3	-	0.001107	-	0	-	0.002339	0.002339
Sum of Other Compounds	g/cm^3	0.080532	0.026479	0.080532	0.001955	0.080532	0.010330	0.010330
Miscellaneous solids								
PCB	g/cm^3	0.000225	0.000083	0.000225	0	0.000225	0.0000018	0.0000018
OIER	g/cm^3	0	0.056651	0	0	0	0.010235	0.010235
Zeolite	g/cm^3	0.062079	0	0.062079	0	0.062079	0	0
Zircalloy 2	g/cm^3	0	0	0	0	0	0	0
Grafoil	g/cm^3	0	0	0	0	0	0	0
Dry solid - radionuclide content								
^{238}Pu and $^{239/240}Pu$	g/cm^3	0.000076	0.000102	0.000076	0.000060	0.000076	0.001536	0.001536
^{238}Pu and $^{239/240}Pu$	µCi/g	5.37	19.88	5.37	10.05	5.37	108.70	108.70
^{241}Am	µCi/g	8.17	28.11	8.17	7.27	8.17	138.34	138.34
^{137}Cs	µCi/g	293.54	310.24	293.54	37.84	293.54	806.35	806.35
$^{89/90}Sr$	µCi/g	223.55	302.20	223.55	0	223.55	1053.40	1053.40
Uranium composition								
U	kg	559.83	722.84	22.17	83.87	77.60	1408.97	187.86
^{233}U	mass%	-	-	-	0.00000	-	0.00050	0.00050
^{234}U	mass%	0.00697	0.00587	0.00697	0.00685	0.00697	0.00836	0.00836
^{235}U	mass%	0.69730	0.57976	0.69730	0.70079	0.69730	0.66250	0.66250
^{236}U	mass%	0.07477	0.05735	0.07477	0.07586	0.07477	0.06864	0.06864
^{238}U	mass%	99.22096	99.35702	99.22096	99.21790	99.22096	99.26036	99.26036

Table 2-1. Nominal Inventory for KE Basin Sludge Locations (2 sheets).

	Units	Fuel Wash – Internal Sludge	Fuel Wash – Coating	Fuel Wash – Fuel Pieces		Totals		
As-settled Sludge **Solid Content** (g dry solids/cm3 as-settled sludge)	g/cm^3	2.312	0.969	10.611				
As-settled Sludge **Density**	g/cm^3	3.00	1.50	11.02				
Volume of Sludge	m^3	0.518	0.061	0.149		43.83	m^3	
As-settled Sludge Chemical Composition								
U	g/cm^3	-	-	9.828354		1,558.9	kg	
UO_2	g/cm^3	1.734693	-	-		2,537.3	kg	
U_3O_7	g/cm^3	-	-	-		1;671.1	kg	
$UO_4 \cdot 4H_2O$	g/cm^3	-	0.673135	-		41.1	kg	
UH_3	g/cm^3	0.172178	-	-		170.1	kg	
$Al(OH)_3$	g/cm^3	0.02539	0.213762	-		604.3	kg	
Al_2O_3	g/cm^3	-	-	-		1,726.8	kg	
FeO(OH)	g/cm^3	0.004348	0.028622	-		8,176.8	kg	
SiO_2	g/cm^3	0.348580	-	-		6,575.7	kg	
CaO	g/cm^3	-	0.014884	-		286.1	kg	
CO_2	g/cm^3	-	-	-		222.0	kg	
C	g/cm^3	-	-	-		31.8	kg	
Sum of Other Compounds	g/cm^3	0.017895	0.036809	0.056162		1,595.0	kg	
Miscellaneous solids								
PCB	g/cm^3					4.5	kg	
OIER	g/cm^3					1,252.8	kg	
Zeolite	g/cm^3					738.7	kg	
Zircalloy 2	g/cm^3			0.692665		103.2	kg	
Grafoil	g/cm^3					-		
Dry solid - radionuclide content								
^{238}Pu and $^{239/240}Pu$	g/cm^3	0.008681	0.001794	0.033569		18.3	kg	
^{238}Pu and $^{239/240}Pu$	µCi/g	232.67	114.50	195.91				
^{241}Am	µCi/g	210.50	93.40	168.01				
^{137}Cs	µCi/g	3443.33	1,410.00	5342.20				
$^{89/90}Sr$	µCi/g	3851.61	1,767.75	4045.39				
Uranium composition								
U	kg	880.43	26.14	1464.42		5434.1	kg	
^{233}U	mass%	0.00000	0.00000	0.00000				
^{234}U	mass%	0.00726	0.00694	0.0065				
^{235}U	mass%	0.764	0.682	0.719				
^{236}U	mass%	0.0859	0.086	0.090				
^{238}U	mass%	99.14	99.23	99.19				

Table 2-2. Nominal Inventory for KW Basin Sludge Locations (2 sheets).

		Source -- K-West						
	Units	Weasel Pit	Main Basin Floor	Discharge Chute	Tech View	North Loadout Pit	Dummy Elevator Pit	Canisters Full
As-settled Sludge **Solid Content** (g dry solids/cm3 as-settled sludge)	g/cm^3	0.869	0.318	0.869	0.869	0.370	0.869	2.053
As-settled Sludge **Density**	g/cm^3	1.56	1.32	1.56	1.56	1.27	1.56	2.68
Volume of Sludge	m^3	0.03	0.82	0.06	0.07	3.65	0.04	1.01
As-settled Sludge Chemical Composition								
U	g/cm^3	0.000554	0.000336	0.000554	0.000554	0.000133	0.000554	0.066167
UO_2	g/cm^3	0.031127	0.018880	0.031127	0.031127	0.007471	0.031127	0.675574
U_3O_7	g/cm^3	0.031741	0.019253	0.031741	0.031741	0.007619	0.031741	0.688918
$UO_4 \cdot 4H_2O$	g/cm^3	0	0	0	0	0	0	0
UH_3	g/cm^3	0	0	0	0	0	0	0.067001
$Al(OH)_3$	g/cm^3	0	0	0	0	0	0	0.117661
Al_2O_3	g/cm^3	0.062895	0.041372	0.062895	0.062895	0.014103	0.062895	0
FeO(OH)	g/cm^3	0.403050	0.128683	0.403050	0.403050	0.037761	0.403050	0.209042
SiO_2	g/cm^3	0.235325	0.073942	0.235325	0.235325	0.297060	0.235325	0
CaO	g/cm^3	0.015968	0.003087	0.015968	0.015968	0.003699	0.015968	-
CO_2	g/cm^3	0.007600	0.004923	0.007600	0.007600	0	0.007600	0.002910
C	g/cm^3	-	0.001107	-	-	0	-	0.002934
Sum of Other Compounds	g/cm^3	0.080532	0.026479	0.080532	0.080532	0.001955	0.080532	0.161471
Miscellaneous solids								
PCB	g/cm^3	0	0	0	0	0	0	0.000015
OIER	g/cm^3	0	0	0	0	0	0	0
Zeolite	g/cm^3	0	0	0	0	0	0	0
Zircalloy 2	g/cm^3	0	0	0	0	0	0	0
Grafoil	g/cm^3	0	0	0	0	0	0	0.055248
Dry solid - radionuclide content								
^{238}Pu and $^{239/240}Pu$	g/cm^3	0.000076	0.000102	0.000076	0.000076	0.000060	0.000076	0.005648
^{238}Pu and $^{239/240}Pu$	µCi/g	5.37	19.88	5.37	5.37	10.05	5.37	175.03
^{241}Am	µCi/g	8.17	28.11	8.17	8.17	7.27	8.17	136.66
^{137}Cs	µCi/g	293.54	310.24	293.54	293.54	37.84	293.54	1898.75
$^{89/90}Sr$	µCi/g	223.55	302.20	223.55	223.55	0	223.55	3096.25
Uranium composition								
U	kg	1.66	27.57	3.33	3.88	48.59	2.22	1,329.96
^{233}U	mass%	-	-	-	-	0.00000	-	0.00000
^{234}U	mass%	0.00697	0.00587	0.00697	0.00697	0.00685	0.00697	0.00451
^{235}U	mass%	0.69730	0.57976	0.69730	0.69730	0.70079	0.69730	0.80023
^{236}U	mass%	0.07477	0.05735	0.07477	0.07477	0.07586	0.07477	0.09443
^{238}U	mass%	99.22096	99.35702	99.22096	99.21999	99.21790	99.21999	99.15356

Table 2-2. Nominal Inventory for KW Basin Sludge Locations (2 sheets).

	Units	Fuel Wash – Internal Sludge	Fuel Wash – Coating	Fuel Wash – Fuel Pieces		Totals		
As-settled Sludge **Solid Content** (g dry solids/cm3 as-settled sludge)	g/cm^3	2.310	0.970	10.612				
As-settled Sludge **Density**	g/cm^3	3.00	1.50	11.02				
Volume of Sludge	m^3	0.518	0.405	0.149		6.75	m^3	
As-settled Sludge Chemical Composition								
U	g/cm^3	-	-	9.828354		1,531.8	kg	
UO_2	g/cm^3	1.718239	-	-		1,618.0	kg	
U_3O_7	g/cm^3	-	-	-		742.3	kg	
$UO_4 \cdot 4H_2O$	g/cm^3	-	0.022194	-		9.0	kg	
UH_3	g/cm^3	0.170544	-	-		155.7	kg	
$Al(OH)_3$	g/cm^3	0.129080	0.544151	-		405.5	kg	
Al_2O_3	g/cm^3	-	-	-		98.0	kg	
FeO(OH)	g/cm^3	0.004031	0.306839	-		660.4	kg	
SiO_2	g/cm^3	0.194161	0.028835	-		1,304.2	kg	
CaO	g/cm^3	-	0.004574	-		21.1	kg	
CO_2	g/cm^3	-	-	-		8.5	kg	
C	g/cm^3	-	-	-		3.9	kg	
Sum of Other Compounds	g/cm^3	0.087033	0.063777	0.056162		286.5	kg	
Miscellaneous solids								
PCB	g/cm^3					0.015	kg	
OIER	g/cm^3					-		
Zeolite	g/cm^3					-		
Zircalloy 2	g/cm^3			0.692665		103.2	kg	
Grafoil	g/cm^3					55.5	kg	
Dry solid - radionuclide content								
^{238}Pu and $^{239/240}Pu$	g/cm^3	0.006865	0.000073	0.034805		14.8	kg	
^{238}Pu and $^{239/240}Pu$	µCi/g	184.00	4.62	203.12				
^{241}Am	µCi/g	148.00	4.38	165.58				
^{137}Cs	µCi/g	2210.00	57.70	6505.54				
$^{89/90}Sr$	µCi/g	2116.08	92.90	5065.27				
Uranium composition								
U	kg	872.08	5.72	1464.42		3,759.4	kg	
^{233}U	mass%	0.00000	0.00000	0.00000				
^{234}U	mass%	0.00594	0.00901	0.00690				
^{235}U	mass%	0.67100	0.90860	0.78000				
^{236}U	mass%	0.08870	0.09256	0.09900				
^{238}U	mass%	99.24000	98.98856	99.11000				

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3.0 105-K BASIN PROCESS STREAMS

3.1 PROCESS STREAM BASES

This section provides the bases for the development of the process feed stream characteristics. The characteristics of each of the five process feed streams are based on the data provided in Section 2.4 and Appendices A through F of this document.

Figures 3-1 and 3-2 show the KE and KW Basins sludge locations with their respective nominal as-settled volumes and interim storage locations. The sludge locations are those areas in the basins where sludge now exists (i.e., main basin floor, pits, and canisters). During the various cleanup activities (i.e., fuel, debris, water, and sludge) within the basins, the sludge will be moved from these locations to interim storage (Segrest 1998). The process feed streams are defined by the interim storage locations.

In KE Basin, an Integrated Water Treatment System (IWTS) will provide the equipment to transfer sludge materials, collected from fuel-cleaning activities, to two interim storage locations, (1) IWTS Knockout Pots for particles greater than 250 μm and less than 0.64 cm and (2) Weasel Pit for particles less than 250 μm. A Sludge Retrieval System will provide the equipment to retrieve the sludge from the basin floor and pits (with the exception of the Weasel Pit), separate out particles larger than 0.64 cm then pump the sludge to the IWTS for interim storage in the Weasel Pit.

In KW Basin, the IWTS will transfer the collected sludge materials from fuel-cleaning activities to two interim storage locations, (1) IWTS Knockout Pots for particles greater than 500 μm and less than 0.64 cm and (2) Settler Tanks for particles less than 500 μm. The sludge in KW Basin that is currently in pits and on the floor will not be consolidated into one interim storage location; these sludges will be pumped directly to the Sludge Loadout System during sludge retrieval activities. On Figure 3-2, it shows an interim storage location for the KW Basin floor and pit sludges; these sludges are combined because it is anticipated that the characteristics of the sludges in these locations will be similar.

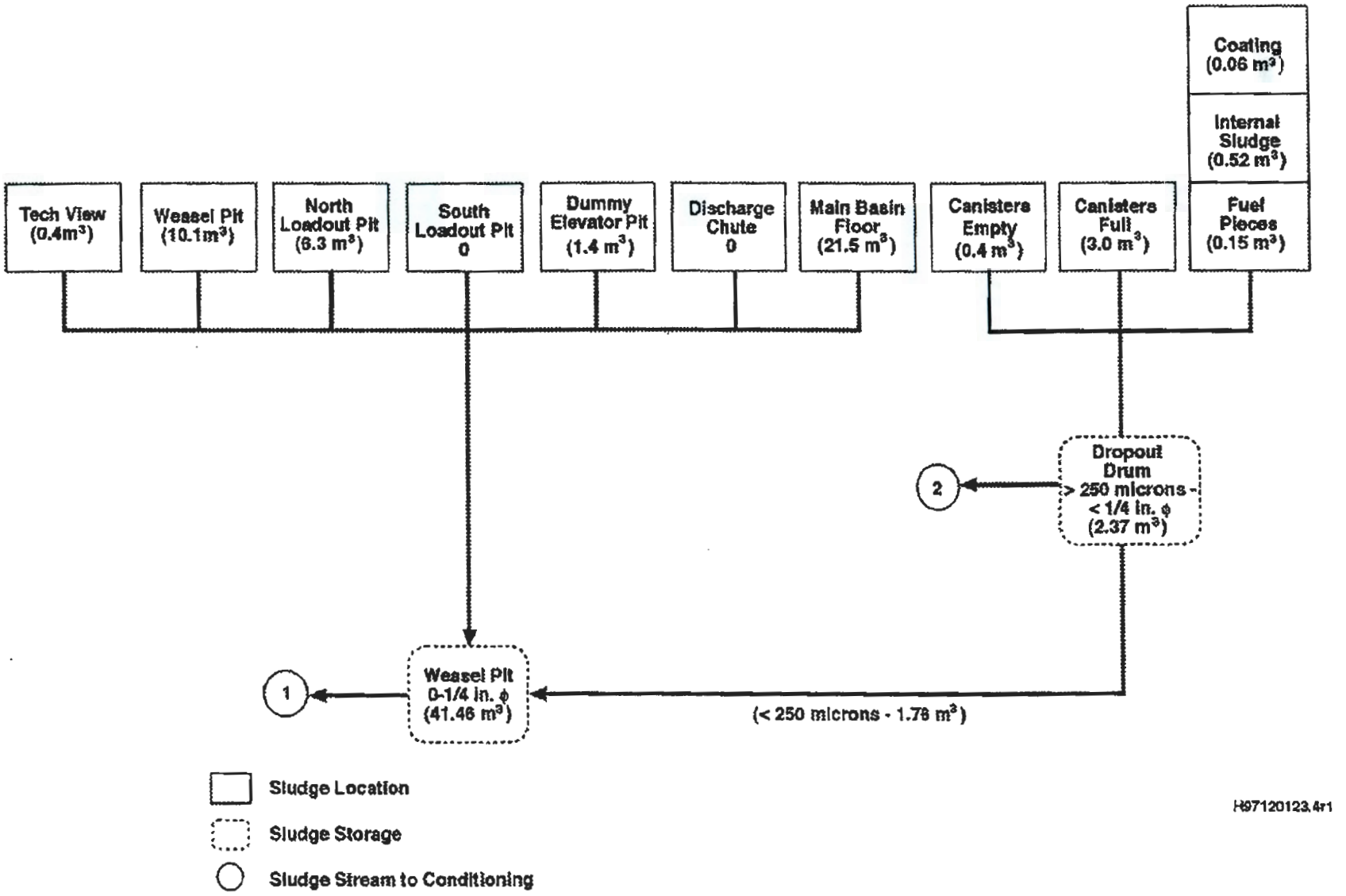

Figure 3-1. K East Basin Sludge Locations, Nominal Volumes, and Feed Streams.

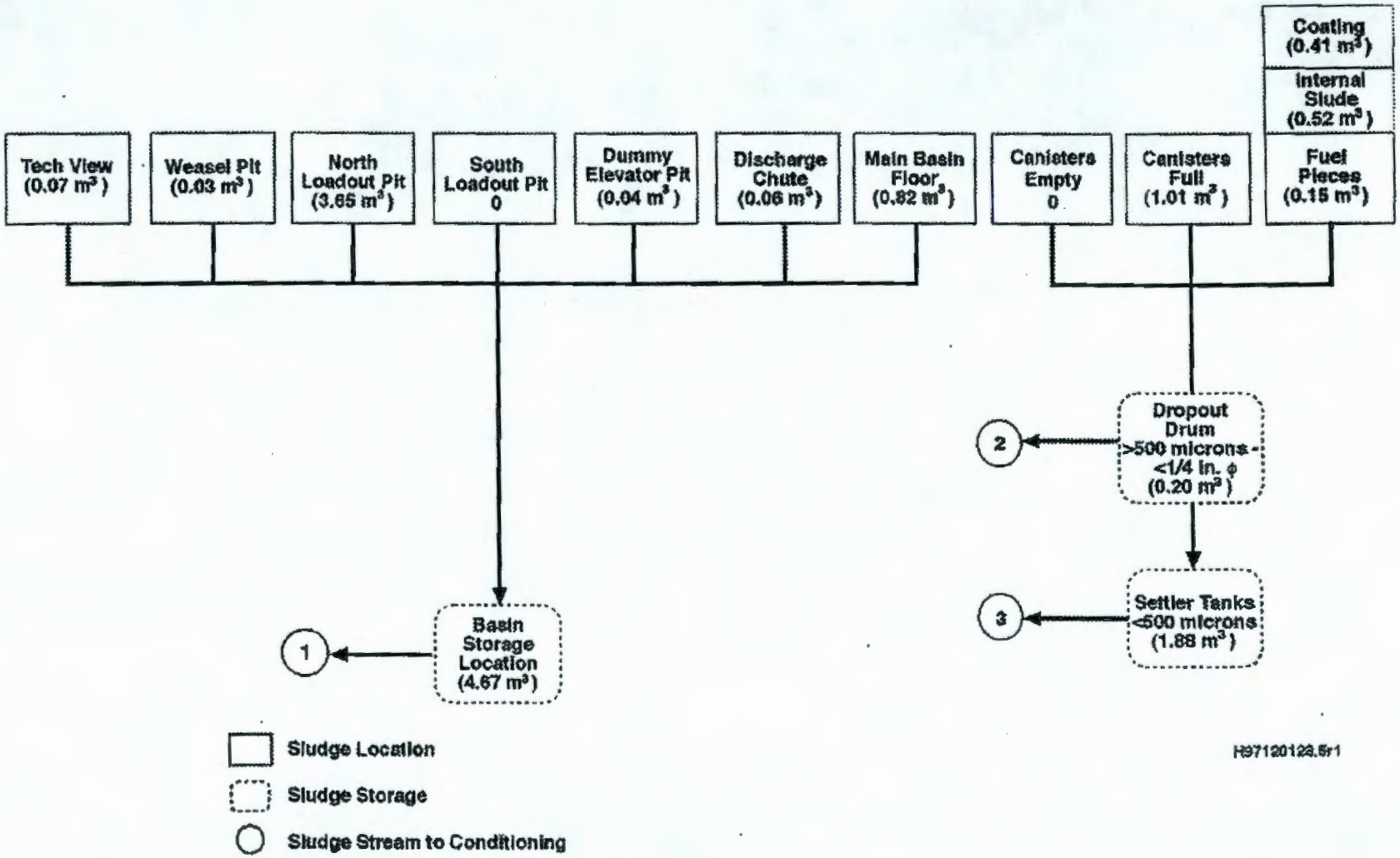

Figure 3-2. K West Basin Sludge Locations, Nominal Volumes and Feed Streams.

3.1.1 Process Stream KE1

Interim storage for process stream KE1 is in the KE Basin Weasel Pit (Figure 3-1). This process stream consists of as-settled sludge (less than or equal to 6350 μm in diameter) retrieved from the various KE Basin pits and floor areas (Bays 1, 2 and 3). This stream also will include canister and fuel wash sludge component particles less than 250 μm in diameter (Segrest 1998; Erickson 1997, Figure 3). The following were used to define process stream KE1 (see Appendices B and C of this document for detailed discussion).

- 42.2 vol% of the canister sludge particles will be less than 250 μm in diameter.
- 100 vol% of the coating particles will be less than 250 μm.
- 51 vol% of the internal sludge particles will be less than 250 μm (the composition of the internal sludge will not change during the IWTS separation process).
- 100 vol% of OIER in the floor sludge will be less than 6350 μm.
- 2 vol% of the OIER from the canister sludge will be less than 250 μm.
- PCB concentration is based on the maximum reported value for Weasel Pit sludge (this conservative value is used to ensure that the sludge treatment system is adequately designed to treat the sludge so that it meets the Tank Waste Remediation System acceptance criteria for PCBs).

3.1.2 Process Stream KE2

Interim storage for process stream KE2 is in IWTS Knockout Pots (Figure 3-1). This process stream consists of as-settled sludge [less than or equal to 6350 μm (0.25 in.) and greater than 250 μm in diameter] collected from the canister removal and fuel wash activities. The following were used in defining process stream KE2 (see Appendices B and C for detailed discussion).

- 57.8 vol% of the canister sludge particles will be greater than 250 μm in diameter.
- 49 vol% of the internal sludge particles will be greater than 250 μm (the composition of the internal sludge will not change during the IWTS separation process).
- 100 vol% of the fuel pieces will be greater than 250 μm.
- 98 vol% of the OIER in the canister sludge will be greater than 250 μm.
- PCB concentration is based on the maximum reported value for canister sludge (this conservative value is used to ensure that the sludge treatment system is adequately designed to treat the sludge so that it meets the Tank Waste Remediation System acceptance criteria for PCBs).

3.1.3 Process Stream KW1

An interim storage location for process stream KW1 currently is not planned, as discussed previously. This process stream consists of the as-settled sludge [less than or equal to 6350 μm (0.25 in.) in diameter] retrieved from the various KW Basin pit and floor areas (Figure 3-2). The assumption that process stream KW1 is bounded by process stream KE1 is likely conservative with respect to the radionuclide inventory; however, the volume of sludge in process stream KW1 is quite low compared to process stream KE1. Therefore, the impact of this assumption on the design of the treatment facility is low.

3.1.4 Process Stream KW2

Interim storage for process stream KW2 is in IWTS Knockout Pots (Figure 3-2). This process stream consists of sludge [less than or equal to 6350 μm (0.25 in.) and greater than 500 μm in diameter] collected from the canister removal and fuel wash activities. The following were used in defining process stream KW2 (see Appendices E and F for detailed discussion).

- 100 vol% of the fuel pieces will be greater than 500 μm.
- 100% of the Grafoil[1] particles from the canister sludge will be greater than 500 μm.

3.1.5 Process Stream KW3

Interim storage for process stream KW3 is in settler tanks (Figure 3-2). This process stream consists of as-settled sludge [less than or equal to 500 μm in diameter] collected from the IWTS Knockout Pot filter system. The following were used in defining process stream KW3 (see Appendices E and F for detailed discussion).

- 100 vol% of the canister sludge (minus the grafoil particles) will be less than or equal to 500 μm.
- 100 vol% of the internal sludge will be less than or equal to 500 μm.
- 100 vol% of the coating will be less than or equal to 500 μm.

[1]Grafoil is a trademark of the Lamons Metal Gasket Company.

3.2 PROCESS STREAM PARTICLE SIZE DISTRIBUTIONS

Figure 3-3 is an ogive that represents the particle distribution expected to be encountered in the K Basin feed streams. The bases for the assumptions are the data reported in the characterization reports (Makenas et al.1996, 1997, 1998; Silvers 1998a, 1998b).

Because the examples were extracted from the K Basins at different times and subjected to different analyses, every attempt was made to compare only those samples that received similar treatment. For example, it was assumed that those samples subjected to sonication at 40W would mimic the sludge that the treatment facility would receive, because of the friability of some of the oxides. Hence, every attempt was made to extract data from those analyses. When that was not possible, particle distribution data were taken from those analyses that were determined to be more robust in the treatment of the sample, thus yielding a shift to the left (smaller) in the particle diameters.

The data that were obtained from wet sieving and Microtrac X-100[2] results were normalized to 100 percent to represent the ogive. This normalization was necessitated because the reported values from both sieving and Microtrac X-100 results are based on 100 percent. The characterization data were weighed against the bases in Section 3.1 and the cumulative percent distribution was determined.

[2]Microtrac is a trademark of Leeds and Northrup.

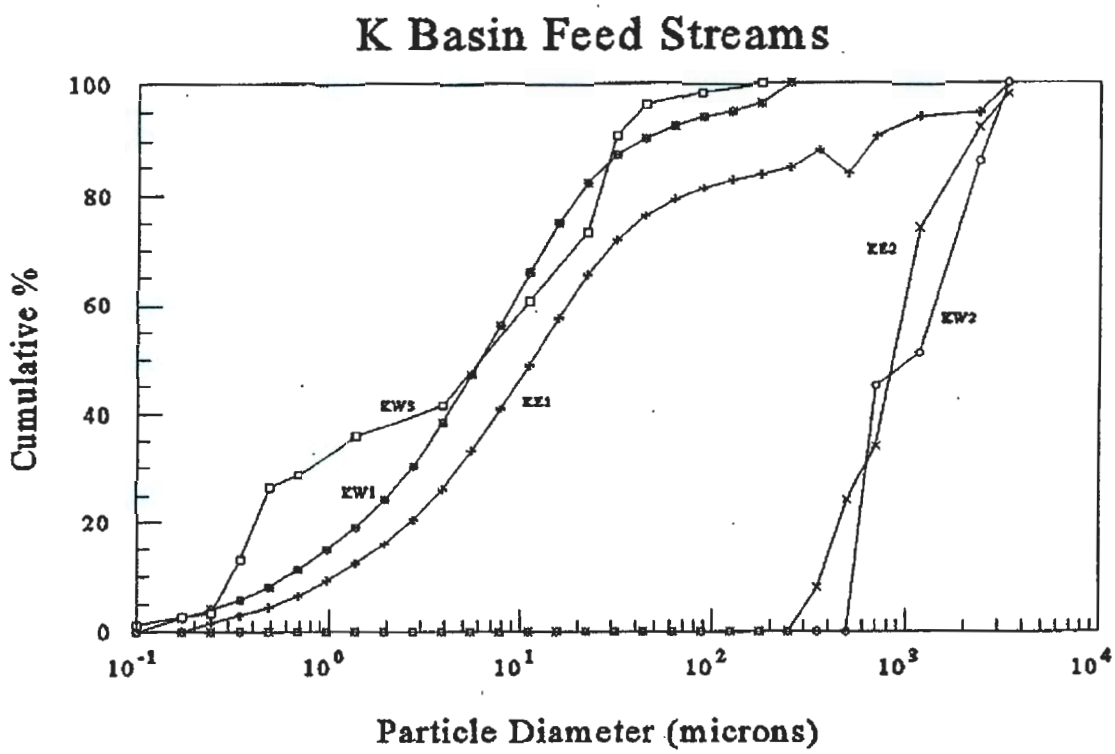

Figure 3-3. Particle Size Distributions for Sludge Feed Streams.

3.3 K BASIN NOMINAL PROCESS STREAM DESIGN BASIS FEED

3.3.1 Process Stream Chemical/Radionuclide Content Methodology

The chemical and radionuclide inventories for each of the five process feed streams were determined by applying the assumptions stated in Section 3.1 to the mass balance determined for each of the various sludge locations as described in Section 2.4.

3.3.2 K Basin Process Stream Chemical/Radionuclide Inventory

Table 3-1 provides an inventory estimate for KE Basin process streams KE1 and KE2. Table 3-2 provides an inventory estimate for KW Basin process streams KW1, KW2, and KW3.

Table 3-1. Nominal Inventory for KE Basin Process Feed Streams.

		Stream KE1			Stream KE2			
	Units		Stream KE1 Composition in total kg			Stream KE2 Composition in total kg		
As-settled Sludge **Solid Content** (g dry solids/cm3 as-settled sludge)	g/cm^3	0.564			1.655			
As-settled Sludge **Density**	g/cm^3	1.403			2.359			
Volume of Sludge	m^3	41.459			2.369			
As-settled Sludge Chemical Composition								
U	g/cm^3	0.001166	48.345		0.637703	1,510.603		
UO_2	g/cm^3	0.039209	1,625.558		0.384911	911.785		
U_3O_7	g/cm^3	0.028711	1,190.347		0.202970	480.799		
$UO_4 \cdot 4H_2O$	g/cm^3	0.000990	41.061		-	-		
UH_3	g/cm^3	0.001920	79.593		0.038189	90.463		
$Al(OH)_3$	g/cm^3	0.006358	263.589		0.143847	340.749		
Al_2O_3	g/cm^3	0.041651	1,726.804		-	-		
FeO(OH)	g/cm^3	0.192012	7,960.648		0.091262	216.182		
SiO_2	g/cm^3	0.154610	6,409.987		0.069935	165.664		
CaO	g/cm^3	0.006824	282.917		0.001348	3.193		
CO_2	g/cm^3	0.004996	207.140		0.006278	14.873		
C	g/cm^3	0.000655	27.163		0.001941	4.599		
Sum of Other Compounds	g/cm^3	0.037669	1,561.739		0.014023	33.218		
Miscellaneous solids								
PCB	g/cm^3	0.000108	4.465		0.000001	0.004		
OIER	g/cm^3	0.029395	1,218.692		0.014397	34.103		
Zeolite	g/cm^3	0.017818	738.740		-	-		
Zircalloy 2	g/cm^3	-	-		0.043569	103.207		
Grafoil	g/cm^3	-	-		-	-		
Dry solid - radionuclide content								
^{238}Pu and $^{239/240}Pu$	g/cm^3	0.000195	8.084		0.004316	10.225		
^{238}Pu and $^{239/240}Pu$	µCi/g	18.79			127.47			
^{241}Am	µCi/g	24.29			147.94			
^{137}Cs	µCi/g	302.79			1,374.21			
$^{89/90}Sr$	µCi/g	284.46			1,541.42			
Uranium composition								
U	kg		2614.96			2,819.18		
^{233}U	mass%	0.0000			0.0004			
^{234}U	mass%	0.0064			0.0081			
^{235}U	mass%	0.6361			0.6769			
^{236}U	mass%	0.0658			0.0718			
^{238}U	mass%	99.29			99.24			

Table 3-2. Nominal Inventory for KW Basin Process Feed Streams.

		Stream KW1			Stream KW2			Stream KW3	
	Units		Stream KW1 Composition in total kg			Stream KW2 Composition in total kg			Stream KW3 Composition in total kg
As-settled Sludge **Solid Content** (g dry solids/cm3 as-settled sludge)	g/cm^3	0.382			8.242			1.915	
As-settled Sludge **Density**	g/cm^3	1.292			8.549			2.582	
Volume of Sludge	m^3	4.67			0.199			1.878	
As-settled Sludge Chemical Composition									
U	g/cm^3	0.000187	0.871995		7.374676	1,464.425		0.035401	66.498
UO_2	g/cm^3	0.010487	48.975756		-	-		0.835274	1,569.000
U_3O_7	g/cm^3	0.010695	49.944728		-	-		0.368587	692.363
$UO_4 \cdot 4H_2O$	g/cm^3	0	0		-	-		0.004785	8.988
UH_3	g/cm^3	0	0		-	-		0.082877	155.678
$Al(OH)_3$	g/cm^3	0	0		-	-		0.215869	405.494
Al_2O_3	g/cm^3	0.020981	97.980113		-	-		-	-
FeO(OH)	g/cm^3	0.069370	323.957757		-	-		0.179110	336.445
SiO_2	g/cm^3	0.255239	1191.967215		-	-		0.059759	108.361
CaO	g/cm^3	0.004117	19.226854		-	-		0.000986	1.853
CO_2	g/cm^3	0.001190	5.557143		-	-		0.001557	2.924
C	g/cm^3	0.000194	0.908042		-	-		0.001570	2.949
Sum of Other Compounds	g/cm^3	0.009626	44.955227		0.042141	8.368		0.124142	237.084
cellaneous solids									
}	g/cm^3	0	0		-	-		0.000008	0.015
OIER	g/cm^3	0	0		-	-		-	-
Zeolite	g/cm^3	0	0		-	-		-	-
Zircalloy 2	g/cm^3	0	0		0.519739	103.207		-	-
Grafoil	g/cm^3	0	0		0.279611	55.524		-	-
Dry solid - radionuclide content									
^{238}Pu and $^{239/240}Pu$	g/cm^3	0.000068	0.318071		0.026116	5.186		0.004931	9.262
^{238}Pu and $^{239/240}Pu$	µCi/g	11.57			152.41			145.38	
^{241}Am	µCi/g	10.97			124.25			114.87	
^{137}Cs	µCi/g	96.62			4,881.41			1,637.75	
$^{89/90}Sr$	µCi/g	62.64			3,800.71			2,260.13	
Uranium composition									
U	kg		87.24			1464.42			2,207.77
^{233}U	mass%	-			-			-	
^{234}U	mass%	0.00668			0.00690			0.00584	
^{235}U	mass%	0.6794			0.78000			0.78828	
^{236}U	mass%	0.0726			0.09900			0.09250	
^{238}U	mass%	99.2424			99.11000			99.14212	

3.4 SHIELDING DESIGN BASIS FEED

This section defines the data to be used in developing the shielding calculations associated with K Basin sludge. The shielding design basis feed is based on the overall energy spectrum and the volumetric activity in the sludge. The design basis material feed data provided in Tables 3-1 and 3-2 of this document and the shielding design basis material feed for the fuel provided in Praga and Willis (1998, Table 3.8) were used to develop the energy spectrum and the volumetric activities.

3.4.1 Energy Spectrum

The main shielding constituent for the energy spectrum is ^{137}Cs. A comparison between (Praga and Willis 1998, Table 3.8) and Tables 3-1 and 3-2 of this document shows that the repartition of the main radionuclides, which can impact the shielding analysis, is similar. Therefore, for detailed calculations using computer models, the SNF radionuclide distribution described in Praga and Willis (1998, Table 3.8) would be followed. For conceptual design shielding calculations, only the ^{137}Cs inventory should be considered.

3.4.2 Volumetric Activity

The volumetric activities were calculated for each of the five process streams and are shown in Table 3-3. The values are based on the nominal ^{137}Cs activities and the nominal sludge volumes from Tables 3-1 and 3-2. The "as-settled sludge solids content" is determined by adding the composition of the compounds (note: this excludes concentrations of miscellaneous solids) plus the plutonium concentration. Process stream KW2 possesses the highest volumetric activity and therefore is chosen as the shielding design-basis feed.

Table 3-3. Volumetric Activities for Settled Sludge Process Streams.

	Stream KE1	Stream KE2	Stream KW1	Stream KW2	Stream KW3
$^{137}Cs/^{137m}Ba$ (μCi/g dry)	302.79	1374.21	96.62	4881.41	1637.75
As-settled sludge solids content (g dry/cm^3)	0.517	1.597	0.382	7.443	1.915
Volumetric activity (Ci/m^3)	156.54	2194.61	36.91	36332.33	3136.29

3.5 SAFETY/REGULATORY ASSESSMENT DESIGN BASIS FEED

The methodology for evaluating the radiological and toxicological consequences associated with the SNF safety/regulatory assessment design basis feed material is documented in Rittman (1998). Rittman (1998) used the radioisotopic inventories listed in Praga and Willis (1998) and calculated unit dose factors for the isotopes, based on the isotope activity per gram of uranium and the isotope committed effective-dose equivalent. The unit dose factor indicates the dose to the receptor who inhales one gram of the exposed fuel. This unit dose factor is 4.38 E+03 Sv/g of uranium.

Conservatively, it can be assumed that the uranium concentration is 100% for the sludge (the maximum concentration is 93% for the KE canister sludge). The main isotopes that contribute to the dose are plutonium and ^{241}Am (~99%). Therefore, the dose unit per unit of sludge used for safety/regulatory assessment shall be 4.38 E+03 Sv/g of uranium.

3.6 CRITICALITY DESIGN BASIS FEED

The fissionable materials (U + Pu) in the sludge are a product of the corrosion of fuel with enrichments of 0.95 wt% and 1.25 wt% ^{235}U. The 1.25 wt% ^{235}U unirradiated enriched corrosion products are limiting for all situations involving sludges. This approach is identical to that used in the SNF Projects and shall be used in the preliminary criticality analysis for the sludge project.

The criticality safety criteria require that the fuel be maintained in a configuration with a specific keff under normal and credible single-contingency conditions. The K Basins used a keff < 0.98. New facilities (Cold Vacuum Drying Facility and Canister Storage Building) use a keff < 0.95. To develop the process in either of the K Basins or new facilities, a keff < 0.95 shall be used.

Based on the keff and on the sludge content, the following criticality limits can be used for preliminary criticality analysis (Kessler 1998).

- The combined masses of uranium or fissionable materials allowed in unfavorable containers or equipment shall not exceed 615 kg.
- The safe inner diameter for one vessel is 59.7 cm (23.5 in.). Double parallel vessels shall have either an inner diameter of less than 52.6 cm (20.7 in.) or a separation between outer vessel surfaces of 15.2 cm (6 in.) with an inner diameter of less than 59.7 cm (23.5 in.).
- The safe depth of uncontrolled concentration or masses of fissionable material is 26.7 cm (10.5 in.).

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APPENDIX A

KE BASIN FLOOR AND PIT SLUDGE CHARACTERISTICS

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APPENDIX A

KE BASIN FLOOR AND PIT SLUDGE CHARACTERISTICS

A.1.0 INTRODUCTION

This appendix identifies referenceable characteristics of the sludges located on the K East Basin floor, Weasel Pit, and North Loadout Pit. Thirteen samples from the main basin floor, 5 samples from the Weasel Pit, and 13 samples from the North Loadout Pit have been analyzed. Chemical, radiological, and physical properties for the floor, Weasel Pit, and North Loadout Pit sludges have been determined and are reported in Makenas et al. (1996) for floor and Weasel Pit sludges and Warner (1994) for the North Loadout Pit sludge.

None of the canisters stored in the KE Basin have lids on them, allowing some mixing of sludges from all potential sources. However, the primary sources of sludge for the floor and Weasel Pit remain the degradation of infrastructure (basin walls, storage racks, and the outsides of canisters) and the introduction of particulates from the air. Therefore the sludge consists primarily of iron oxides, aluminum silicates, and silicon oxides with some fuel element and canister component oxidation products.

The North Loadout Pit receives the water and particulate matter resulting from backwashing the sandfilter. The sludge in this pit primarily consists of sand material similar to the floor sludge and small amounts of fissile material.

A.2.0 PHYSICAL PROPERTIES

A summary of the physical properties of the "as-settled" sludge (i.e., the sludge as it sits in the basin) on the basin floor, in the Weasel Pit, and in the North Loadout Pit are presented in Table A-1. The physical properties were determined from the data reported in the characterization documents Makenas et al. (1996) for floor and Weasel Pit and Warner (1994) for the North Loadout Pit.

A.2.1 PARTICLE SIZE

The complete range of particle sizes in the Weasel Pit, North Loadout Pit, and floor sludges is not known. The characterization samples obtained from the floor, Weasel Pit, and North Loadout Pit were limited to particle diameters less than 6350 μm (0.25 in.). However, during sludge retrieval, all retrieved sludge will be pumped to the Sludge Retrieval Knockout Pots where particles < 6350 μm (0.25 in.) will be pumped to the Weasel Pit and particles > 6350 μm (0.25 in.) will be separated out (and disposed of with the debris or fuel). It was assumed that sludge that was in the Weasel Pit before 1994 is < 6350 μm (0.25 in.).

Table A-1. Summary Table for KE Floor, Weasel Pit and North Loadout Pit Physical Properties.

Basin Location	Total Volume (m^3)[1]	Total Mass (Mg)	As-Settled Density (g/cm^3)	Nominal Settling Time	Viscosity[2]	Zeta Potential
Basin Floor	21.5	28.38	1.32[3]	85% @ 2.4 hr[4]	0.4 Pa•s @ 10 s^{-1} to 0.01 Pa•s @ 400 s^{-1}	16 to -24 mV[5] @ pH 7
Weasel Pit	11.9[6]	18.56	1.56[7]	85%@ 2.4 hr	0.2 Pa•s @ 5 s^{-1} to 0.01 Pa•s @ 400 s^{-1}	16 mV[8] @ pH 7
North Loadout Pit	6.3	8.00	1.27[9]	NM	NM	NM

[1] The bases for current estimates of sludge volumes are documented in Baker (1998).
[2] Higher and lower points of the response curves shown in Makenas et al. (1996, Fig. I2, I3, pp. I-13, I-14).
[3] Mean density of 14 floor density measurements listed in Makenas et al. (1996, p. C-11).
[4] Estimation of Makenas et al. (1996, Fig. L1, L2, L3, pp. L7, L8).
[5] Estimation of "mV" range at pH 7 as shown in Makenas et al. (1996, Fig. I8a, p. I-23).
[6] Weasel Pit volume includes volumes from Tech View and Dummy Elevator Pit Locations.
[7] Mean density of 6 Weasel Pit density measurements listed in Makenas et al. (1996, p. C-11).
[8] Estimation of "mV" range at pH 7 as shown in Makenas et al. (1996, Fig. I8b, p. I-23).
[9] Mean density of 13 North Loadout Pit density measurements listed in Warner (1994, p. 27).
NM = Not measured.

A.3.0 KE BASIN FLOOR AND PIT COMPOSITIONS

This section establishes the chemical and radionuclide composition of the KE floor, Weasel Pit, and North Loadout Pit sludge locations. To establish these sludge compositions, the characterization data in Makenas et al. (1996) were used for floor and Weasel Pit sludges and the characterization data in Warner (1994) were used for the North Loadout Pit sludge.

A.3.1 CHEMICAL CONTENT METHODOLOGY

Based on the analyte concentrations (μg of analyte per g dry sludge) for each sample given in Makenas et al. (1996, Appendix D), a mean concentration value was calculated for each analyte in the floor and Weasel Pit sludge (less-than values were excluded from the calculations). Analyte concentrations for each North Loadout Pit sample are given in Warner (1994) (units are in micrograms of analyte per milliliter of as-settled sludge and weight percent of solids). To calculate a mean concentration value for each North Loadout Pit analyte, the units were first converted to micrograms of analyte per gram of dry sludge using the reported data and the weight percent of solid in the as-settled sludge. No attempt was made to use depth weighting to adjust the mean value for the floor, Weasel Pit or North Loadout Pit sludge. The mean analyte concentrations are then assumed to be representative of the whole volume of KE floor, Weasel Pit, and North Loadout Pit sludges.

To account for the total solids found in the floor, Weasel Pit and North Loadout Pit sludges, the mean analyte concentrations were converted to the most probable oxidation product concentrations. This is based on the knowledge that the sludge from the floor and Weasel Pit is almost entirely the result of oxidation, and the North Loadout Pit sludge is a mixture of sand and oxidation products. The following equations demonstrate how this was done, using aluminum as an example.

The primary aluminum compound identified was aluminum oxide (Makenas et al. 1996, Appendix K).

$$Atomic\ Weight\ Al_2O_3 = 101.96\ g/mole \qquad Atomic\ Weight\ Al = 26.98\ g/mole$$

$$Oxide\ Factor = \frac{101.96}{53.96} = 1.89$$

The amount of aluminum compound in the dry floor sludge was determined by multiplying the mean concentration of aluminum (68,876 µg/g of dry floor sludge, see Table A-6) by the oxide factor.

$$68{,}876\ \frac{\mu g\ Al}{g\ dry\ sludge}\ x\ 1.89 = \frac{0.1301\ g\ Al_2O_3}{g\ dry\ sludge}$$

Dividing the mean concentration per cubic centimeter of as-settled sludge by the mean concentration per gram of dry sludge, it was determined that there is 0.318 gram of dry floor sludge per cubic centimeter of as-settled floor sludge. This allows the following calculation.

$$\frac{0.1301\ g\ Al_2O_3}{g\ dry\ sludge}\ x\ \frac{0.318\ g\ dry\ sludge}{cm^3\ as\text{-}settled\ sludge} = \frac{0.0414\ g\ Al_2O_3}{cm^3\ as\text{-}settled\ sludge}$$

A.3.1.1 Chemical Composition of the Uranium Compounds

Multiple uranium compounds have been identified in the floor and Weasel Pit sludges. X-ray diffraction (XRD) analyses for the North Loadout Pit sludge do not exist; therefore, the assumptions for calculating the uranium compounds for floor and Weasel Pit sludge also are assumed for the North Loadout Pit sludge. To make a reasonable assumption for the mass of uranium compounds in the sludge, it has been assumed that the primary sources of uranium are oxidation products and small amounts of uranium metal, as shown in Table A-2. Not knowing the amount of free oxygen in the water, it has been assumed that the oxides will be split about 50-50 between the two listed oxide products and that the amounts of other potential oxides will be negligible. Hydrates and hydrides are expected to be negligible.

Table A-2. Weight Percent of Uranium Compounds in KE Floor and Pit Sludges.

	Wt% Breakdown of Uranium into Compounds				
Location	U	UO_2	U_3O_7	$UO_4 \cdot 4H_2O$	UH_3
Floor, Weasel Pit, and North Loadout Pit Sludges	1.0	49.5	49.5	0.0	0.0

A.3.1.2 Chemical Composition of the Aluminum Compounds

Table A-3 identifies the aluminum compounds that are expected in the floor, Weasel Pit and North Loadout Pit sludges. The choice of aluminum oxide for the floor sludge is meant to be representative of multiple possible compounds (e.g., aluminosilicates) that are found in sand, dirt, and concrete walls. It is not meant to represent pure alumina but instead to allow a reasonable mass balance estimate of the aluminum compounds. Even though aluminum hydroxide is the corrosion product created from the aluminum canisters being in water, none was identified by XRD in the floor and Weasel Pit sludges. Therefore, the floor and Weasel Pit sludges are assumed to contain only aluminum oxide. XRD analyses do not exist for the North Loadout Pit sludge; therefore, the assumptions used in calculating the aluminum compounds for the floor and Weasel Pit sludges also are applied to the North Loadout Pit sludge.

Table A-3. Weight Percent of Aluminum Compounds in KE Floor and Pit Sludges.

	Wt% Breakdown of Compounds With Aluminum				
Location	$Al(OH)_3$	Al_2O_3			
Floor, Weasel Pit, and North Loadout Pit Sludges	0.0	100.0			

A.3.1.3 Chemical Composition of the Iron Compounds

Iron hydroxide was the most common iron compound identified in the XRD results for the floor and Weasel Pit sludges (Makenas et al. 1996, Appendix K). Because iron hydroxide was identified in 11 of 16 samples, while no other iron compounds were identified in more than 2 samples, it has been assumed that all iron will be accounted for as iron hydroxide, as shown in Table A-4. XRD analyses do not exist for the North Loadout Pit sludge; therefore, the assumptions used in calculating the iron compounds for the floor and Weasel Pit sludges also are applied to the North Loadout Pit sludge.

Table A-4. Weight Percent of Iron Compound in KE Floor and Pit Sludges.

	Wt% Breakdown of Compounds With Iron				
Location	FeO(OH)				
Floor, Weasel Pit, and North Loadout Pit Sludges	100.0				

A.3.1.4 Chemical Composition of the Insoluble Solids

The XRD results identified silicon in several of the residue samples after acid digestion (not the same digestion process as the treatment process). It has therefore been assumed that all of the insoluble solids will be accounted for as silicon dioxide. The silicon dioxide values for floor and weasel pit sludge are based on residue concentrations reported in Makenas (1996, Appendix D). The value for the North Loadout Pit sludge is the difference between the total solids concentration (for the reported analytes in Warner 1994) and 100 percent.

A.3.2 RADIONUCLIDE METHODOLOGY

The only radionuclides accounted for in this appendix are uranium, plutonium, americium, cesium, and strontium. These were determined to be the most process-significant radionuclides. Uranium is important to the process from both a mass balance and a safety perspective. See Sections 3.4, 3.5 and 3.6 of this document for a safety-related discussion on the importance of plutonium, americium, cesium, and strontium. Based on the radionuclide inventory for each floor and Weasel Pit sample given in Makenas et al. (1996, Appendix D) (units are microcuries per gram of dry sludge), a mean value for each of these radionuclides in the floor and Weasel Pit sludges was calculated. The radionuclide inventory for the North Loadout Pit sludge is given in Warner (1994) (units are in microcuries per milliliter of as-settled sludge and weight percent of solids). To calculate a mean value for the radionuclides of interest in the North Loadout Pit sludge, the units were first converted to microcuries per gram of dry sludge using the reported data and the weight percent of solids in the as-settled sludge.

The two values for americium documented in Makenas et al. (1996, Appendix D) were averaged; the mean values are recorded in Tables A-6 and A-7 for the floor and Weasel Pit sludges, respectively. The averaged North Loadout Pit americium values are from Warner (1994). No attempt was made to use depth weighting to adjust the mean values. The mean values then are assumed to be representative of the whole volume of KE floor, Weasel Pit and North Loadout Pit sludges. Mean values for the mass percent breakdown of the uranium by its various isotopes for floor, Weasel Pit, and North Loadout Pit sludges were also determined.

A.3.3 MISCELLANEOUS CONSTITUENTS

Two miscellaneous components, important to process considerations, were identified in the KE floor sludge; polychlorinated biphenyls (PCB) and organic ion exchange resins. This section provides the basis for the reported quantities of these two constituents.

Two miscellaneous constituents were identified in the KE Weasel Pit sludge; PCBs and zeolite resins. This section provides the basis for the reported quantities of these two constituents.

No miscellaneous constituents were identified in the KE North Loadout Pit sludge.

A.3.3.1 Polychlorinated Biphenyls

Polychlorinated biphenyls were identified in one of six floor sludge samples subjected to semivolatile organic analyses. The concentration of PCBs, on a settled sludge basis, found in this one sample was 63 ppm (Schmidt 1997). Based on this one sample point, it is assumed that the KE floor sludge has a PCB concentration of about 63 ppm.

Polychlorinated biphenyls were identified in two of three Weasel Pit sludge samples subjected to semivolatile organic analyses. The maximum concentrations of PCBs, on a settled sludge basis, for samples KES-P-16 and KES-R-18 were reported as 40 ppm and 140 ppm, respectively (Schmidt 1997). It is assumed the Weasel Pit sludge has a PCB concentration of about 140 ppm.

A conservative estimate for the PCB concentration is assumed, to ensure that the sludge treatment system can adequately treat the sludge such that it meets the Tank Waste Remediation System (TWRS) acceptance criteria for PCBs.

A.3.3.2 Organic Ion Exchange Resin

A.3.3.2.1 Possible Sources of Resin Beads.

The medium used in the ion exchange columns (IXC) and ion exchange modules (IXM) is Purolite NRW-37 mixed-bed resin (an organic ion exchange resin [OIER]). The IXCs were retired from service in 1991; the IXMs are currently used in the KE Basin. No process knowledge indicates resin beads were released into the basins; however, spherical resin beads were observed during wet sieving tests conducted with KE floor, Weasel Pit (Silvers 1998), and canister sludge samples (Makenas et al. 1997).

Potential pathways for the OIER to enter the KE Basin were investigated. One pathway is via the IXC system. Discharge water from the IXCs was directed into a collection tank (i.e., sump) located in the Sandfilter Backwash Pit. The overflow from this sump was drained, via a "6-in." pipe, into the West Bay. The discharge from the pipe was above the canisters. Therefore, it is possible that resin beads from the IXCs were washed into the basin via the discharge from the "6-in." pipe.

The other pathways for the OIER to enter the basin is via the IXM system. When the IXMs were first put into service, the vent system did not have screens installed. During changeout, resin beads were observed coming up through the vent system. Because the vent system discharges into the South Loadout Pit, this would be a possible path for the resin beads to enter the basin. The IXMs were operated from 1984 to 1993 without screens. The physical amount of beads that escaped from the IXMs, however, was very small according to K Basin engineers.

One possible pathway for the OIER to have entered the Weasel Pit is through a "3-in." PVC pipe that was routed from the Sandfilter Backwash Pit to the Discharge Chute. During dose reduction activities this "3-in." PVC pipe was removed. Several hot spots were measured in the pipe, and it was speculated that the dose came from captured resin beads. The contents of the discharge chute were pumped into the Weasel Pit in 1994; therefore, the presence of resin beads in the Weasel Pit could be from the transfer of Discharge Chute material into the Weasel Pit.

A.3.4.2.2 Quantity of Purolite NRW-37 Resin Beads.

Characterization data show resin beads in one of the two sieved KE Basin floor samples (Sample KES-H-08). The sample with beads was obtained from Bay 3 (the West Bay); the sample with no beads was obtained from Bay 1 (the East Bay). None of the floor samples from Bay 2 (the Center Bay) were sieved. From visual observation (Silvers 1998) it was estimated that 75 vol% of the floor sample (H-08) comprised beads.

Characterization data indicated that the bottom layer of sample KES-T-20 had a "significant" fraction of resin beads (Makenas et al. 1997, page I-8). This sample was later subjected to wet sieving. No resin beads were reported in the sieved and presieved fractions. This discrepancy is being investigated but to date has not been resolved. One other sample (KES-S-19 from the Weasel Pit) also was analyzed by wet sieving. Visual observation of the sieved fractions did not show resin beads in this sample either. It is therefore concluded that the Weasel Pit does not contain OIER. If definitive data are provided on the percentage of beads observed in the samples, the value of OIER in the KE Weasel Pit will be adjusted accordingly.

The following assumptions were used to estimate the nominal volume of OIER in the KE Basin floor sludge. (1) Because the pathways for beads to enter the basin are both through Bay 3, and no beads were found in the one sieved sample from Bay 1, it is assumed that only Bay 3 contains OIER. (2) It is assumed that a small quantity (approximately 1 vol%) of beads entered Bay 3 through the IXM vent system before the screen was installed. (3) It is estimated that there is 11.1 m^3 of "floor" sludge in Bay 3. (4) 12.5% of Bay 3 sludge volume contains 75 vol% beads. (5) 12.5% of Bay 3 sludge volume contains 1 vol% beads. The nominal estimate of OIER is then calculated as: $(0.125)(11.1\ m^3)(0.75 + 0.01) = 1.05\ m^3$.

The OIER concentration in the KE Basin floor sludge was calculated assuming an OIER density of 1.16 g/cm^3:

$$\frac{1.05E{+}06\ cm^3\ OIER}{21.5E{+}o6 cm^3\ sludge} \times \frac{1.16\ g\ OIER}{cm^3\ OIER} = \frac{0.056651\ g\ OIER}{cm^3\ sludge}$$

For a bounding value, it is assumed that 25 vol% of the Bay 3 sludge volume contains OIER. The bounding volume of OIER is calculated as: (0.25)(11.1 m^3) = 2.78 m^3.

A.3.4.2.3 Organic Ion Exchange Resin Radionuclide Content.

The radionuclide content for the OIER on a dry solids basis are provided in Table A-5. It is assumed the radionuclide content in the OIER would be equivalent to the values reported for Sample KES-H-08 (Makenas 1996) because this sample contained approximately 75 vol% OIER.

Table A-5. Organic Ion Exchange Resin Radionuclide Content - Dry Solids.

Radioisotope	µCi/g
Pu-238	6.18E-02
Pu-239/240	4.03E-01
Am-241	3.70E-01[1]
Cs-137	1.44E+02
Sr-90	9.66E+01

[1] Mean of Alpha Energy Analysis (AEA) and Gamma Energy Analysis (GEA) results.

A.3.4.3 Zeolite

According to K Basins personnel (Hoefer 1997), four screen failures are known to have occurred in the IXCs during the KE Basin fuel segregation campaign (1983/1984). When the screens failed, the entire contents of the IXCs were flushed to the Discharge Chute. Each failed screen released approximately 0.14 m^3 (5 ft^3) of zeolite (Zeolon 900) for a total of approximately 0.57 m^3 (20 ft^3). The material in the Discharge Chute was pumped into the Weasel Pit in 1994. It is therefore assumed that 0.57 m^3 of zeolite is contained in the Weasel Pit sludge.

The zeolite concentration in the KE Basin Weasel Pit sludge was calculated assuming a density of 1.1 g/cm^3:

$$\frac{0.57E+06\ cm^3\ zeolite}{10.10E+06\ cm^3\ sludge} \times \frac{1.1\ g\ zeolite}{cm^3\ zeolite} = \frac{0.062079\ g\ zeolite}{cm^3\ sludge}$$

A.3.5 KE FLOOR, WEASEL PIT, AND NORTH LOADOUT PIT SLUDGE FINAL COMPOSITIONS

The nominal chemical, radionuclide, and miscellaneous component compositions for the KE floor, Weasel Pit, and North Loadout Pit sludges are presented in Tables A-6, A-7 and A-8, respectively.

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Table A-6. KE Floor Sludge Nominal Composition.

KE Floor Data (Adapted from WHC-SP-1182)						
Measured Element	Mean Concentration of Element	Expected Compounds	Oxide Factor	Mole Fraction of Element in Compound	Mean Concentration of Compound	Mean Concentration of Compound
	µg / g dry sludge				µg / g dry sludge	g / cm³ as-settled sludge
Ag	19.23	Ag_2O	1.074	100%	20.66	0.000007
Al	68,876.86	$Al(OH)_3$	2.889	0%	-	0.000000
		Al_2O_3	1.889	100%	130,100.73	0.041372
B	295.99	B_2O_3	3.222	100%	953.73	0.000303
Ba	311.64	BaO	1.117	100%	348.04	0.000111
Be	58.49	BeO	2.778	100%	162.47	0.000052
Bi	0	BiO	1.077	100%	-	0.000000
Ca	6,932.90	CaO	1.400	100%	9,706.07	0.003087
Cd	166.44	CdO	1.143	100%	190.22	0.000060
Cr	651.83	Cr_2O_3	1.462	100%	952.68	0.000303
Cu	727.08	CuO	1.252	100%	910.28	0.000289
Fe	254,349.62	FeO(OH)	1.591	100%	404,663.69	0.128683
K	0	K_2O	1.205	100%	-	0.000000
Mg	1,984.81	MgO	1.667	100%	3,308.02	0.001052
Mn	596.16	MnO	1.291	100%	769.59	0.000245
Na	3,576.65	Na_2O	1.348	100%	4,820.70	0.001533
Ni	0	NiO	1.273	100%	-	0.000000
P	-	PO_3	2.548	100%	-	0.000000
Pb	533.50	PbO	1.077	100%	574.74	0.000183
Se	198.05	Se	1.000	100%	198.05	0.000063
Sm	198.05	Sm_2O_3	1.160	100%	229.67	0.000073
Sn	0	SnO		100%	-	0.000000
Tl	383.38	Tl_2O_3	1.117	100%	428.39	0.000136
Zn	1,102.20	ZnO	1.245	100%	1,371.86	0.000436
Zr	520.59	ZrO_2	1.351	100%	703.25	0.000224
U	105,724.23	U	1.000	1%	1,057.24	0.000336
		UO_2	1.134	49.5%	59,369.93	0.018880
		U_3O_7	1.157	49.5%	60,542.67	0.019253
		$UO_4 . 4H_2O$	1.571	0%	-	0.000000
		UH_3	1.013	0%	-	0.000000
^{238}Pu and $^{239/240}Pu$					321.99	0.000102
Insoluble Solids	232,521.43	SiO_2	1.000	100%	232,521.43	0.073942
TIC	4,222.42	CO_2	3.667	100%	15,482.21	0.004923
TOC	3,482.29	C	1.000	100%	3,482.29	0.001107
		Miscellaneous solids				
		PCB				0.000083
		OIER				0.056651
		Zeolite				0
		Zircalloy 2				0
		Grafoil				0
CO_2 represents carbonate						
Dry solid - radionuclide content						
^{238}Pu and $^{239/240}Pu$	19.88	µCi/g				
^{241}Am	28.11	µCi/g				
^{137}Cs	310.24	µCi/g				
$^{89/90}Sr$	302.20	µCi/g				
Uranium isotopic composition						
^{233}U	-	mass%				
^{234}U	0.00587	mass%				
^{235}U	0.57976	mass%				
^{236}U	0.05735	mass%				
^{238}U	99.35702	mass%				

Table A-7. KE Weasel Pit Sludge Nominal Composition.

KE Weasel Pit Data (Adapted from WHC-SP-1182)						
Measured Element	Mean Concentration of Element	Expected Compounds	Oxide Factor	Mole Fraction of Element in Compound	Mean Concentration of Compound	Mean Concentration of Compound
	µg / g dry sludge				µg / g dry sludge	g / cm³ as-settled sludge
Ag	17.71	Ag_2O	1.074	100%	19.03	0.000017
Al	38,317.16	$Al(OH)_3$	2.889	0%	-	0.000000
		Al_2O_3	1.889	100%	72,376.85	0.062895
B	144.98	B_2O_3	3.222	100%	467.15	0.000406
Ba	390.54	BaO	1.117	100%	436.15	0.000379
Be	18.53	BeO	2.778	100%	51.47	0.000045
Bi	0	BiO	1.077	100%	-	0.000000
Ca	13,124.90	CaO	1.400	100%	18,374.86	0.015968
Cd	49.92	CdO	1.143	100%	57.05	0.000050
Cr	1,049.64	Cr_2O_3	1.462	100%	1,534.09	0.001333
Cu	397.77	CuO	1.252	100%	498.00	0.000433
Fe	291,525.15	FeO(OH)	1.591	100%	463,808.99	0.403050
K	0	K_2O	1.205	100%	-	0.000000
Mg	1,976.58	MgO	1.667	100%	3,294.30	0.002863
Mn	519.46	MnO	1.291	100%	670.57	0.000583
Na	824.53	Na_2O	1.348	100%	1,111.33	0.000966
Ni	0	NiO	1.273	100%	-	0.000000
P	-	PO_3	2.548	100%	-	0.000000
Pb	507.17	PbO	1.077	100%	546.37	0.000475
Se	199.31	Se	1.000	100%	199.31	0.000173
Sm	199.31	Sm_2O_3	1.160	100%	231.13	0.000201
Sn	0	SnO		100%	-	0.000000
Tl	354.22	Tl_2O_3	1.117	100%	395.82	0.000344
Zn	1,079.72	ZnO	1.245	100%	1,343.87	0.001168
Zr	573.32	ZrO_2	1.351	100%	774.49	0.000673
U	63,765.01	U	1.000	1%	637.85	0.000554
		UO_2	1.134	49.5%	35,818.77	0.031127
		U_3O_7	1.157	49.5%	36,526.30	0.031741
		$UO_4 . 4H_2O$	1.571	0%	-	0.000000
		UH_3	1.013	0%	-	0.000000
^{238}Pu and $^{239/240}Pu$					86.93	0.000076
Insoluble Solids	270,800.00	SiO_2	1.000	100%	270,800.00	0.235325
TIC	2,385.19	CO_2	3.667	100%	8,745.69	0.007600
TOC	-	C	1.000	100%	-	0.000000
		Miscellaneous solids				
		PCB				0.000225
		OIER				0
		Zeolite				0.062079
		Zircalloy 2				0
		Grafoil				0
CO_2 represents carbonate						
Dry solid - radionuclide content						
^{238}Pu and $^{239/240}Pu$	5.37	µCi/g				
^{241}Am	8.17	µCi/g				
^{137}Cs	293.54	µCi/g				
$^{89/90}Sr$	223.55	µCi/g				
Uranium isotopic composition						
^{233}U	0.00000	mass%				
^{234}U	0.00697	mass%				
^{235}U	0.69730	mass%				
^{236}U	0.07477	mass%				
^{238}U	99.22096	mass%				

Table A-8. KE North Loadout Pit Sludge Nominal Composition.

KE North Loadout Pit Data (Adapted from WHC-SD-WM-TA-152)						
Measured Element	Mean Concentration of Element	Expected Compounds	Oxide Factor	Mole Fraction of Element in Compound	Mean Concentration of Compound	Mean Concentration of Compound
	µg / g dry sludge				µg / g dry sludge	g / cm^3 as-settled sludge
Ag	-	Ag_2O	1.074	0%	-	0.000000
Al	20,189.65	$Al(OH)_3$	2.889	0%	-	0.000000
		Al_2O_3	1.889	100%	38,136.00	0.014103
B	-	B_2O_3	3.222	100%	-	0.000000
Ba	157.72	BaO	1.117	100%	176.10	0.000065
Be	15.09	BeO	2.778	100%	41.93	0.000016
Bi	-	BiO	1.077	0%	-	0.000000
Ca	7,143.86	CaO	1.400	100%	10,001.41	0.003699
Cd	119.57	CdO	1.143	100%	136.65	0.000051
Cr	225.65	Cr_2O_3	1.462	100%	329.80	0.000122
Cu	515.85	CuO	1.252	100%	645.83	0.000239
Fe	64,181.81	FeO(OH)	1.591	100%	102,111.60	0.037761
K	-	K_2O	1.205	100%	-	0.000000
Mg	1,009.30	MgO	1.667	100%	1,682.17	0.000622
Mn	677.58	MnO	1.291	100%	874.69	0.000323
Na	-	Na_2O	1.348	0%	-	0.000000
Ni	-	NiO	1.273	0%	-	0.000000
P	-	PO_3	2.548	0%	-	0.000000
Pb	263.71	PbO	1.077	100%	284.09	0.000105
Se	-	Se	1.000	0%	-	0.000000
Sm	97.09	Sm_2O_3	1.160	100%	112.58	0.000042
Sn	-	SnO		0%	-	0.000000
Tl	254.12	Tl_2O_3	1.117	100%	283.96	0.000105
Zn	576.05	ZnO	1.245	100%	716.98	0.000265
Zr	-	ZrO_2	1.351	100%	-	0.000000
U	35,978.34	U	1.000	1%	359.78	0.000133
		UO_2	1.134	49.5%	20,203.80	0.007471
		U_3O_7	1.157	49.5%	20,602.89	0.007619
		$UO_4.4H_2O$	1.571	0%	-	0.000000
		UH_3	1.013	0%	-	0.000000
^{238}Pu and $^{239/240}$Pu					162.76	0.000060
Insoluble Solids	375,373.71	SiO_2	2.140	100%	803,299.74	0.297060
TIC	0	CO_2	3.667	0%	-	0
TOC	0	C	1.000	0%	-	0
		Miscellaneous solids				
		PCB				0
		OIER				0
		Zeolite				0
		Zircalloy 2				0
		Grafoil				0
CO_2 represents carbonate						
Dry solid - radionuclide content						
^{238}Pu and $^{239/240}$Pu	10.05	µCi/g				
^{241}Am	7.27	µCi/g				
^{137}Cs	37.84	µCi/g				
$^{89/90}$Sr	-	µCi/g				
Uranium isotopic composition						
^{233}U	0	mass%				
^{234}U	0.00685	mass%				
^{235}U	0.70079	mass%				
^{236}U	0.07586	mass%				
^{238}U	99.21786	mass%				

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APPENDIX B

KE BASIN CANISTER SLUDGE CHARACTERISTICS

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APPENDIX B

KE BASIN CANISTER SLUDGE CHARACTERISTICS

B.1.0 INTRODUCTION

This appendix provides the characteristics of the sludge located in the K East (KE) Basin fuel storage canisters. Two samples from empty canisters (i.e., canisters that contain no fuel elements) and seven samples from fueled canisters (i.e, canisters that contain fuel elements) have been analyzed. The KE canister sludge consists of sludge from both empty and fueled canisters. Chemical, radiological, and physical properties have been determined and are reported in Makenas et al. (1997). The majority of the sludge from the fueled canisters consisted of uranium oxides and, in some cases, uranium hydrates. Unoxidized uranium metal or uranium hydride were not detectable by X-ray diffraction (XRD) analysis; however, hydrogen generation (plus trace fission gases) was observed in the laboratory. Sludge from empty (nonfueled) canisters consisted primarily of iron oxides and iron hydroxides.

B.2.0 PHYSICAL PROPERTIES

A summary of the physical properties of the "as-settled" sludge (i.e., the sludge as it sits in the basin) in the KE Basin canisters is presented in Table B-1. The physical properties were determined from the data reported in the characterization document, Makenas et al. (1997).

Table B-1. Summary Table for KE Canister Physical Properties.

Basin Location	Volume[1] (m^3)	Mass (Mg)	Density[2] (g/cm^3)	Settling Time[3]	Zeta Potential[4]	Viscosity[5]
Canisters - Fueled and Empty	3.4	5.51	1.62	80% @ 1 hr	0 to -48 mV @ pH 7	20 Pa·s @ 0.1 s^{-1} to 0.01 Pa·s @ 400 s^{-1}

[1] The basis for current sludge volume estimates are documented in Baker (1998).

[2] Mean density of samples listed on Table D-3, page D-18 (Makenas et al. 1997); excludes samples 96-01 and 96-06 due to incomplete data. An average of the two layers from samples 96-04 and 96-11 was used in overall mean value.

[3] Estimation of Figure I.5-1 and I.5.-2 on pages I-37 and I-38 (Makenas et al. 1997).

[4] Estimation of "mV" range at pH 7 as shown on Figure I.10-1 on page I-83 (Makenas et al. 1997).

[5] Values are viscosity (Pa•s) versus shear rate (s^{-1}) at the higher and lower points of the response curve.

B.2.1 PARTICLE SIZE

This section establishes a particle size distribution for the canister sludge to calculate the composition of the streams after the sludge passes through the Integrated Water Treatment System Knockout Pot (cut at 250 μm). The following estimation is based on the data reported in Makenas et al. (1997). A limited set of samples (designated research samples) were subjected to

particle size analyses. As such, the sample analysis is considered limited and may or may not be fully representative.

Research layer samples labeled 96-04 U/L, 96-06 M (both from full canisters), and 96-11 L (from an empty canister) were analyzed for particle size distributions using two separate methods. A Microtrac[1] X-100 Particle Size Analyzer was used to measure particle sizes from 0.12 to 704 m., and a wet sieving technique was used to fractionate particles as coarse, medium, and fine. Sample 96-04 U/L was taken from the interfacial layer that formed between the upper and lower settled sludge, 96-06 M was taken from the middle layer of settled sludge, and 96-11 L was taken from the lower layer of the settled sludge.

The reported sieve cutoff diameters were 0 to 706 minus, 706 plus to 1191 minus, 1191 plus to 2380 minus, 2380 plus to 3353 minus, and 3353 plus to 6350 minus in microns. Because lower particle size diameters were not discretely defined from 0 to 706 minus, the volume particle size distribution (as received) was used to determine the 250 to 706 minus percentage. This percentage was then subtracted from the total appearing in the range of 0 to 706. The difference was an estimate of that percentage less than 250 μm. Likewise, the particle sizes for the other sieve sizes were estimated from the bar graph. Samples 96-06 and 96-04 were averaged to obtain estimated percentages. The total percentages are the result of weighting factors of percent particle size distribution and associated stream volumes. Table B-2 shows the particle size split for the canister sludge going to the two process feed streams.

Table B-2. K East Canister Sludge Stream Estimates.

Basin / Source	Particle Size Split	
K East	Stream KE2, 250 μm < x ≤ 6350 μm	Stream KE1 < 250 μm
Empty Canisters (0.4 m^3)	4.0%	96.0%
Full Canisters (3.0 m^3)	65.0%	35.0%
Total	57.8%	42.2%

The manufacturer's specifications for Purolite NRW-37 indicate that the beads are between 16 and 40 mesh (U.S. Standard); less than 5% are greater than 1.2 mm and under 2% are less than 0.4 mm. Laboratory examinations of a limited number of samples have shown that approximately 98% of the beads are larger than 250 μm; therefore, it is assumed that canister beads will be split between streams KE1 and KE2, with 2% going to KE1 and 98% going to KE2.

[1]Microtrac is a trademark of Leeds and Northrup.

B.3.0 KE CANISTER SLUDGE COMPOSITION

This section establishes the chemical composition of the K East canister sludge. The characterization data in Makenas et al. (1997) were adapted for this activity.

B.3.1 CHEMICAL CONTENT METHODOLOGY

Based on the samples' analyte concentrations given in Makenas et al. (1997, Appendix E) (units of characterization data were milligrams of analyte per gram of dry sludge), a mean concentration value for each analyte was calculated (less than values were not included in the calculations). No attempt was made to use depth weighting to adjust the mean value. The overall mean value does not include sample 96-01, because this sample yielded very different chemistry results when compared to other samples. The assumption was made that there was an inhomogeneity or dilution problem. The overall mean value also does not include sample 96-06. This sample was excluded because it did not have complete data for each layer. Data from these samples were not used to calculate other values in this document. For samples 96-04 and 96-11, where values are given for each layer, a mean of the two values was used. The mean analyte concentrations are thus assumed to be representative of the whole volume of K East canister sludge.

The canister sludge is almost entirely the result of oxidation; therefore, to account for the total solids found in the sludge, the mean analyte concentrations were converted to the most probable oxidation product concentrations. The following equations demonstrate how this was done, using aluminum as an example:

The primary aluminum compound expected is aluminum hydroxide

$$Atomic\ Weight\ Al(OH)_3 = 77.99\ g/mole \qquad Atomic\ Weight\ Al = 26.98\ g/mole$$

$$Oxide\ Factor = \frac{77.99}{26.98} = 2.89$$

The amount of aluminum compound in the dry canister sludge was determined by multiplying the mean concentration for aluminum (67,484 µg/g of dry sludge, Table B-6), by the oxide factor.

$$\frac{67{,}484\ \mu g\ Al}{g\ dry\ sludge}\ x\ 2.89 = \frac{0.1949\ g\ Al(OH)_3}{g\ dry\ sludge}$$

Dividing the mean concentration per cubic centimeter of as-settled sludge by the mean concentration per gram of dry sludge, it was determined that there are 0.872 grams of dry canister sludge per cubic centimeter of as-settled canister sludge. This allows the following calculation:

$$\frac{0.1949\ g\ Al(OH)_3}{g\ dry\ sludge} \times \frac{0.872\ g\ dry\ sludge}{cm^3\ as\text{-}settled\ sludge} = \frac{0.170\ g\ Al(OH)_3}{cm^3\ as\text{-}settled\ sludge}$$

B.3.1.1 Chemical Composition of the Uranium Compounds

Multiple uranium compounds have been identified. To make a reasonable assumption for the mass of uranium compounds in the sludge, it has been assumed that the primary sources of uranium in the canister sludge will be oxidation products and small amounts of uranium metal and uranium hydride, as shown in Table B-3. Not knowing the amount of free oxygen in the water, it has been assumed that the oxides will be split about 50-50 between the two listed oxide products, and that the amounts of other potential oxides will be negligible. The metal and hydride are being included to account for the hydrogen bubbles that have been seen in the sludge. Hydrates are expected to be negligible.

Table B-3. Weight Percent of Uranium Compounds in KE Canister Sludge.

	Wt% Breakdown of Compounds With Uranium				
Location	U	UO_2	U_3O_7	$UO_4{\cdot}4H_2O$	UH_3
Canister Sludge	5.0	45.0	45.0	0.0	5.0

B.3.1.2 Chemical Composition of the Aluminum Compounds

Table B-4 identifies the aluminum compound that is expected in the canister sludge. The choice of aluminum hydroxide for the canister sludge is meant to be representative of multiple possible sources (sand, dirt, concrete walls) of sludge in the canisters; it is not meant to represent a pure aluminum compound but rather to allow a reasonable mass balance estimate of the aluminum compounds. Aluminum hydroxide was the most common aluminum compound identified in the XRD results for the K West (KW) canister sludge (Makenas et al. 1998, Appendix G). It is assumed that the primary aluminum compound in the K East canister sludge will, therefore, also be aluminum hydroxide.

Table B-4. Weight Percent of Aluminum Compounds in KE Canister Sludge.

	Wt% Breakdown of Compounds With Aluminum				
Location	$Al(OH)_3$	Al_2O_3			
KE Canister Sludge	100.0	0.0			

B.3.1.3 Chemical Composition of the Iron Compounds

Iron hydroxide was the most common iron compound identified in the XRD results or the canister sludge (Makenas et al. 1997, Appendix J). It was assumed that all iron will be accounted for as iron hydroxide, as shown in Table B-5.

Table B-5. Weight Percent Iron Compounds in KE Canister Sludge.

	Wt% Breakdown of Compounds With Iron				
Location	FeO(OH)				
Canister Sludge	100.0				

B.3.2 RADIONUCLIDE METHODOLOGY

The only radionuclides accounted for in this appendix are uranium, plutonium, americium, cesium, and strontium. These were determined to be the most process-significant radionuclides. Uranium is important to the process from both a mass balance and a safety perspective. See Sections 3.4, 3.5, and 3.6 of this document for a safety-related discussion on the importance of plutonium, americium, cesium, and strontium. Based on the radionuclide inventory for each sample given in Makenas et al. (1997, Appendix E) (units of characterization data are microcuries per gram of dry sludge), a mean value for each of these radionuclides was calculated. The characterization data reported two values for americium. These two values were averaged; the mean value is recorded in Table B-6. No attempt was made to use depth weighting to adjust the mean values. The mean values are assumed to be representative of the whole volume of K East canister sludge.

B.3.3 KE CANISTER MISCELLANEOUS CONSTITUENTS

Two miscellaneous constituents were identified in the KE canister sludge; polychlorinated biphenyls (PCB) and organic ion exchange resins. This section provides the basis for the reported quantities of these two constituents.

B.3.3.1 Polychlorinated Biphenyl Concentration

Polychlorinated biphenyls have been found in KE canister sludge ranging from approximately 0.6 ppm to 1.1 ppm, (by weight in settled sludge). For the KE canister composition, it is assumed that the PCB concentration in the sludge is 1.1 ppm.

A conservative estimate for the PCB concentration is assumed, to ensure that the sludge treatment system can adequately treat the sludge to meet the Tank Waste Remediation System acceptance criteria for PCBs.

B.3.3.2 Organic Ion Exchange Resin

The pathway for OIER to enter the KE canister sludge is also via the ion exchange column system as described in Appendix A. The IXC discharge water drains into the basin through a "6-in." pipe. Because the pipe outlet is located above the canisters, it is possible that the beads dropped into the canisters when the sump overflow was drained into the basin via the "6-in." pipe.

Characterization data show resin beads in one of three sieved canister samples. Two of the canister samples (96-11 and 96-06) were obtained from Bay 3 (the West Bay); the other sample (96-04) was obtained from Bay 2 (the Center Bay). Sample 96-11 had resin beads. From visual observation it is estimated that 10% of sample 96-11 comprises beads. Spherical beads also were noted lodged on top of spent fuel in KE near where beads were found on the KE Basin floor (Pitner 1995).

The following assumptions were used to estimate the nominal volume of organic resin beads in KE Basin canister sludge. (1) Because the pathways for beads to enter the basin are both through Bay 3 and no beads were found in the one sieved sample from Bay 2, it is assumed that only Bay 3 contains organic resin beads. (2) 25% of the Bay 3 canister sludge volume contains 10% beads. (3) There are approximately 1.13 m^3 of canister sludge in Bay 3. The nominal estimate of OIER is calculated as $(0.25)(1.13\ m^3)(0.10) = 0.03\ m^3$.

The OIER concentration in the KE Basin canister sludge was calculated assuming an OIER density of 1.16 g/cm^3:

$$\frac{0.03E{+}06\ cm^3\ OIER}{3.4E{+}06 cm^3\ sludge} \times \frac{1.16\ g\ OIER}{cm^3\ OIER} = \frac{0.010235 g\ OIER}{cm^3\ sludge}$$

For a bounding value, it is assumed that 25% of the Bay 3 canister sludge volume contains OIER. The bounding volume of OIER in the canister sludge equals 0.28 m^3.

B.3.4 FINAL KE CANISTER SLUDGE COMPOSITION

The nominal chemical, radionuclide and miscellaneous compositions for the KE canister sludge are presented in Table B-6.

Table B-6. KE Canister Sludge Nominal Composition.

KE Canister Data (Adapted from HNF-SP-1201)						
Measured Element	Mean Concentration of Element	Expected Compounds	Oxide Factor	Mole Fraction of Element in Compound	Mean Concentration of Compound	Mean Concentration of Compound
	µg / g dry sludge				µg / g dry sludge	g / cm³ as-settled sludge
Ag	100.73	Ag_2O	1.074	100%	108.20	0.000094
Al	67,484.61	$Al(OH)_3$	2.889	100%	194,955.55	0.170042
		Al_2O_3	1.889	0%	-	0.000000
B	334.28	B_2O_3	3.222	100%	1,077.13	0.000939
Ba	166.61	BaO	1.117	100%	186.07	0.000162
Be	81.92	BeO	2.778	100%	227.56	0.000198
Bi	440.34	BiO	1.077	100%	474.05	0.000413
Ca	1,330.77	CaO	1.399	100%	1,862.01	0.001624
Cd	83.94	CdO	1.143	100%	95.93	0.000084
Cr	452.40	Cr_2O_3	1.462	100%	661.20	0.000577
Cu	440.15	CuO	1.252	100%	551.06	0.000481
Fe	78,836.86	FeO(OH)	1.591	100%	125,427.41	0.109399
K	-	K_2O	1.205	100%	-	0.000000
Mg	1,616.51	MgO	1.667	100%	2,694.18	0.002350
Mn	404.60	MnO	1.291	100%	522.30	0.000456
Na	685.92	Na_2O	1.348	100%	924.50	0.000806
Ni	227.62	NiO	1.273	100%	289.66	0.000253
P	907.43	PO_5	2.548	100%	2,312.48	0.002017
Pb	439.59	PbO	1.077	100%	473.56	0.000413
Se	-	Se	1.000	100%	-	0.000000
Sm	-	Sm_2O_3	1.160	100%	-	0.000000
Sn		SnO	1.135		-	0.000000
Tl	-	Tl_2O_3	1.117	100%	-	0.000000
Zn	543.42	ZnO	1.245	100%	676.36	0.000590
Zr	421.34	ZrO_2	1.351	100%	569.18	0.000496
U	538,597.55	U	1.000	5%	26,929.88	0.023489
		UO_2	1.134	45.0%	274,956.31	0.239820
		U_3O_7	1.157	45.0%	280,387.55	0.244557
		$UO_4.4H_2O$	1.571	0%	-	0.000000
		UH_3	1.013	5%	27,269.33	0.023785
^{238}Pu and $^{239/240}Pu$					1,760.92	0.001536
Insoluble Solids	45,013.35	SiO_2	1.000	100%	45,013.35	0.039261
TIC	2,365.42	CO_2	3.667	100%	8,673.21	0.007565
TOC	2,681.99	C	1.000	100%	2,681.99	0.002339
		Miscellaneous solids				
		PCB				0.0000018
		OIER				0.010235
		Zeolite				0
		Zircalloy 2				0
		Grafoil				0
CO_2 represents carbonate						
Dry solid - radionuclide content						
^{238}Pu and $^{239/240}Pu$	108.70	µCi/g				
^{241}Am	138.34	µCi/g				
^{137}Cs	806.35	µCi/g				
$^{89/90}Sr$	1,053.40	µCi/g				
Uranium isotopic composition						
^{233}U	0.0005	mass%				
^{234}U	0.0084	mass%				
^{235}U	0.6625	mass%				
^{236}U	0.0686	mass%				
^{238}U	99.2604	mass%				

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APPENDIX C

KE BASIN FUEL WASH SLUDGE CHARACTERISTICS

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APPENDIX C

KE BASIN FUEL WASH SLUDGE CHARACTERISTICS

C.1.0 INTRODUCTION

This appendix provides the characteristics of the K East Basin (KE Basin) fuel wash sludge components expected to be generated in the processing of fuel elements for dry storage. Before being sent to dry storage, the fuel storage canisters will be dumped into a primary washing machine that cleans the canisters and elements by a tumbling action and water flushing process. Because of the physical state of the stored fuel, it is expected that the washing process will cause further breakage of the fuel elements and will dislodge corroded uranium pieces, zirconium cladding, pieces comprising both uranium and zirconium, and loosely adhered materials (such as coatings and internal sludge). This dislodged material is referred to as the "fuel wash" sludge components: fuel pieces, coating, and internal sludge. A screen inside the washing machine separates particles less than 6350 μm (canister sludge and wash sludge components) from the fuel elements and fragments. The IWTS system then pumps the fuel wash sludge components to Integrated Water Treatment System (IWTS) Knockout Pots, which separate these components into two streams based on particle size (in KE Basin the cut is at 250 μm and in K West Basin [KW Basin] the cut is at 500 μm).

Experimental tests on the cleaning process have not been done; therefore, no samples of actual KE Basin fuel wash sludge exist. However, examinations were made of the surface and/or subsurface of a KE Basin fuel element. The examinations included collection of coating pieces from the fuel cladding and particles recovered from cracks in the fuel and from beneath the cladding material. Often the particulate material was accompanied by large (0.64 to 1.27 cm [0.25- to 0.5-in.]) pieces of fuel. In general, no great quantities of sludge or particulate fuel were found beneath the cladding breaches. However, substantial residue sample was obtained by straining the water from the spent fuel element container (SFEC) (shipping container used to transport the fuel element to the 300 Area hot cells), suggesting that loose fuel material escaped from breached areas during shipping and handling activities (Pitner 1997). The subsurface particles from the fuel elements and the residue from the SFECs make up the internal sludge. During the examinations, fuel pieces were also obtained; analyses were not performed on the fuel pieces. Characterization data from the subsurface fuel examinations (Silvers 1998) and KE Basin fuel elements (Praga and Willis 1998) form the basis of the fuel wash sludge inventory.

C.2.0 KE WASH SLUDGE PHYSICAL PROPERTIES

The physical properties were determined from the subsurface fuel examination data (Silvers 1998); the volume calculations are documented in Pearce and Pitner (1998). A summary of the physical properties for the "as-settled" fuel wash sludge components is presented in Table C-1.

Table C-1. Summary Table for KE Fuel Wash Component Physical Properties.

Fuel Wash Component	Volume (m^3)	Mass (Mg)	Density (g/cm^3)
Coating	0.061	0.092	1.50
Internal Sludge	0.518	1.55	3.0
Fuel Pieces	0.149	1.64	11.0

C.2.1 WASH SLUDGE COMPONENTS PARTICLE SIZE

This section provides the basis for particle size distributions for the three components of the wash sludge (coating, internal sludge, and fuel pieces). These distributions are estimated to calculate the composition of the process feed streams following particle separation in the IWTS knockout pot (cut at 250 μm).

C.2.1.1 Coating Material Particle Size

Data do not exist that delineate particle size measurements for the coating particles after the fuel washing operation and the subsequent transfer to the IWTS knockout pot. However, scanning electron microscopy images of the coating indicate that these materials are primarily flocculent agglomerates of submicron particles (Abrefah et al.1998). It is likely that the particle sizes of the materials removed from the cladding will be below 250 μm after the tumbling operation and the transfer to the IWTS knockout pot.

C.2.1.2 Internal Sludge Particle Size

A particle size analysis was performed on one residue sample (Sample R1) by wet sieving (Silvers 1998). Sample R1 was obtained from the bottom of the SFEC that was used to transport the KE Basin fuel element. Table C-2 lists the weight percent of wet solids separated by sieve size during the sieving analysis.

Table C-2. K East Internal Sludge Sieve Results.

Sieve Size (μm)	3350	2360	1180	710	250	<250
Wt % Trapped on Sieve	30	5	4	3	6	51

These results show that the IWTS knockout pot will stop 49 vol% (particle larger than 250 μm) of the internal sludge. Data are not available for the composition of the different sieved fractions; therefore, it is assumed that the chemical composition of the particles stopped by the IWTS knockout pot have the same composition as the particles leaving the IWTS knockout pot.

C.2.1.3 Fuel Pieces Particle Size

Currently no data exist on the fuel pieces, but it seems reasonable (based on visual examination of the pieces removed from the fuel element during the subsurface examinations) to consider that 100 vol% of the fuel pieces will be above 250 μm.

C.3 KE BASIN WASH SLUDGE COMPOSITION

This section provides the basis for determining the chemical and radionuclide compositions for each of the wash sludge components (coating, internal sludge and fuel pieces). The elemental data are essential to identify solid phases in the fuel wash sludge components. These compositions are then used in defining the mean wash sludge component inventories.

C.3.1 KE WASH SLUDGE CHEMICAL CONTENT METHODOLOGY

C.3.1.1 Coating Elemental Composition

Three KE outer fuel elements (removed from KE canisters 2350E, 2540E, and 5427E) were brushed to remove the gray coating from the surface of the elements. A portion of the coatings were analyzed using X-ray diffraction to identify the crystallographic phases present. The predominant species identified in samples from elements 2540E and 5427E were peroxide hydrate, $UO_4 \cdot 4H_2O$, and dihydrate, $UO_4 \cdot 2H_2O$ (Abrefah et al. 1998). In the coating sample from 5427E, the predominant species was U_4O_9 (Silvers 1998).

Elemental data are available only on the coating sample from KE fuel element 5427E. This coating sample was subjected to inductively coupled plasma analyses (Silvers 1998); the results are summarized in Table C-3.

Table C-3. Elemental Analyses of Coating.

Elements	CS1 (μg/g dry coating)	Elements	CS1 (μg/g dry coating)
Al	76500	Fe	18600
B	1000	Mn	1370
Ba	543	Na	8700
Bi	-	Si	-
Ca	11000	U	443000
Cr	510	Zn	-
Cu	12300	Zr	4480

C.3.1.2 Internal Sludge Elemental Composition

The cladding around breached and cracked areas on one KE Basin fuel element was removed and subsurface particulate material was recovered from the top end, hanger, and lower end of the fuel element (Pitner 1997). The elemental compositions of these three internal sludge samples (SSL1, SSL2, and SSL3) were determined by inductively coupled plasma analyses (Silvers 1998). The analyses are presented in Table C-4.

Table C-4. Elemental Analyses of Internal Sludge.

	Sample SSL1	Sample SSL2	Sample SSL2d[1]	Sample SSL3	SSLmean
Element	µg/g dry sludge	µg/g dry sludge	µg/g dry sludge	µg/g dry sludge	µg/g dry sludge
Al	4300	3200	3100	4000	3,817
B					
Ba	160	56	45	207	139
Bi					
Ca					
Cr	180	160	160	180	173
Cu	690				
Fe	1800	1000	1400	560	1,187
Mn	650	410	340	790	605
Na	3000	3100	3100	3600	3,233
Si					
U	736000	709000	703000	772000	738000
Zn	550				
Zr	1300	600	630	1100	1005
[1]Duplicate of Sample SSL2					

C.3.1.3 Wash Sludge Component Chemical Compounds

To determine the total solids found in the coating and internal sludge components, the oxide and hydroxide percentages were calculated using the likely oxidation state for each element (e.g. aluminum (III)). The very low level of other anions such as chloride, nitrate, and phosphate justifies this approach. The choice between oxide or hydroxide (which may sometimes appear arbitrary) was based on the following observations for the coating and internal sludge components.

- $Al(OH)_3$ has been observed in KW canisters and seems to result from the corrosion of the aluminum canister.
- FeO(OH) often has been identified in KE canister and floor sludge.

- UO_2 + 10% UH_3: when uranium is corroding in water, the resulting corrosion product is a mixture of uranium oxide and uranium hydride. It has been shown that the UH_3 percentage can vary between 2 and 9 wt% (Baker et al. 1966). As the presence of uranium hydride may impact the safety assessment of the facility, a bounding value of 10% for the uranium hydride content was chosen for the internal sludge.

- $UO_4 \cdot 4H_2O$ and U_4O_9 have been identified in the coating; the best mass balance for the coating is obtained when using $UO_4 \cdot 4H_2O$.

The following equations demonstrate how the elemental data was used to convert to oxidation product concentrations (in weight percent) for the coating and internal sludge components. Aluminum is used as an example:

Atomic Weight $Al(OH)_3$ = 77.99 *g/mole* *Atomic Weight Al* 26.98 *g/mole*

$$\textit{Oxide Factor} = \frac{77.99}{26.98} = 2.89$$

The mean concentration of aluminum is 11,030 µg/g of dry sludge for the internal sludge component (an average of SSL2 and SSL2duplicate (SSL2d) was first determined; then the average of the three samples was calculated to give the mean elemental concentration of each analyte). The weight percent of aluminum compound in the dry internal sludge was determined by multiplying the oxide factor by the mean analyte concentration (SSLmean on Table C-4) and multiplying by 100.

$$\frac{3{,}817\ \mu g\ Al}{g\ dry\ sludge} \times 2.89 = \frac{0.01103\ g\ Al(OH)_3}{g\ dry\ sludge} \times 100 = 1.103\ wt\%$$

The weight percent of aluminum compounds in the dry coating is determined by multiplying the oxide factor by the elemental concentration for aluminum, given in Table C-3, and multiplying by 100.

The composition of the fuel pieces generated in the primary washing machine are assumed to have the same composition as the KE Basin fuel elements (in particular, the U/Zr ratio will be identical). The composition of the fuel pieces is determined from the N Reactor fuel element data reported in Praga and Willis (1998, Table 2.1, page 5). The composition of the fuel pieces is calculated as follows:

Uranium	= 2.10/2.26 x 100	= 92.92 wt%
Zirconium	= 0.148/2.26 x 100	= 6.55 wt%
Miscellaneous	= 92.92 - 6.55	= 0.53 wt %.

C.3.2 KE WASH SLUDGE COMPONENT CHEMICAL COMPOSITION

Applying the assumptions and performing the calculations from Section C.3.1 for all identified elements and their associated oxide factor, the chemical composition for the coating, internal sludge, and fuel pieces was determined. The results are presented in Table C-5.

Table C-5. Weight Percent of Wash Sludge Component Chemical Composition.

Compound	Oxide Factor	Internal Sludge (%)	Coating (%)	Fuel Pieces (%)
AlH_3	2.889	1.103	22.101	
Al_20_3	1.889			
CaO	1.399		1.539	
FeO(OH)	1.591	0.189	2.959	
U	1.000			92.92
UO_2	1.134	75.320		
U_30_7	1.157			
$UO_4.4H_2O$	1.571		69.595	
UH_3	1.013	7.476		
SiO_2	1.000	15.135		
Zircalloy2				6.55
Misc.		0.777	3.806	0.53

C.3.3 KE WASH SLUDGE RADIONUCLIDE METHODOLOGY

The only radionuclides accounted for in this appendix are uranium, plutonium, americium, cesium, and strontium. These were determined to be the most process-significant radionuclides. Uranium is important to the process from both a mass balance and a safety perspective. See Sections 3.4, 3.5, and 3.6 of this document for a safety-related discussion on the importance of plutonium, americium, cesium, and strontium.

The radionuclide inventory for the coating and internal sludge components was determined from the radiochemistry results reported in Silvers (1998). Analysis for ^{90}Sr was not performed for these samples. Therefore, the following equation was used to determine the ^{90}Sr content in the coating and internal sludge samples:

$$^{90}Sr_{measured} = (Pu_{measured})(^{90}Sr_{origen}) / (Pu_{origen})$$

where: $Pu_{measured}$ = total measured plutonium reported in Silvers (1998).
Pu_{origen} = total plutonium from ORIGEN data reported in Praga and Willis (1998)
$^{90}Sr_{origen}$ = ^{90}Sr from ORIGEN data reported in Praga and Willis (1998).

A mean for the three internal sludge samples was determined by first averaging the results for samples SSL2 and SSL2d, then determining a mean for the three samples (SSL1, (SSL2+SSL2d)/2, SSL3).

For the fuel pieces, the radionuclide inventory reported in Praga and Willis (1998, Table 3.6) presents ORIGEN results for KE Basin) has been used to derive a mean radionuclide inventory expressed in curies per gram of uranium.

C.3.4 KE WASH SLUDGE RADIONUCLIDE CONTENT

Table C-6 presents the radionuclide inventory for each of the three fuel wash sludge components.

Table C-6. KE Wash Sludge Radionuclide Inventory.

Isotope	Sample CS1	Sample SSL1	Sample SSL2	Sample SSL2dup	Sample SSL3	Sample SSLmean	Fuel Pieces
	uCi/g	uCi/g	uCi/g	uCi/g	uCi/g	uCi/g	uCi/g
Pu238	16.5	27.7	26.0	25.3	36.6	29.98	49.34
Pu239	61.7	128.0	102.0	101.0	150.0	126.50	94.61
Pu240	36.3	76.6	59.0	58.7	93.1	76.18	51.95
Am241	93	218	147	150	265	210.50	168.01
Cs137	1,410	4,340	1,740	1,020	4,610	3,443	5,342.20
Sr90	1,768	3,824	2,828	2,825	4,904	3,852	4,045.39
	%	%	%	%	%	%	%
U234	0.00694	0.00715	0.00692	0.00671	0.00782	0.00726	0.00655
U235	0.682	0.677	0.685	0.683	0.93	0.76	0.719
U236	0.086	0.0859	0.0874	0.0863	0.0848	0.0859	0.0895
U238	99.23	99.23	99.22	99.22	98.98	99.14	99.19

C.3.5 KE WASH SLUDGE MISCELLANEOUS COMPOSITIONS

Organic ion exchange resins have been observed sitting on top of fuel elements in one canister (6753). These beads have been included in the KE canister sludge composition; therefore, it is assumed there are no organic ion exchange resins in any of the KE wash sludge components.

The only component from the wash sludge that has been analyzed for PCBs is a coating sample from the surface of a KE fuel element (5427E); PCBs were nondetectable (Silvers 1998). Therefore, it is assumed that the fuel wash sludge components do not contain PCBs.

C.3.6 K EAST WASH SLUDGE FINAL COMPOSITION

Table C-7 lists the nominal chemical and radionuclide compositions of the KE wash sludge components (internal sludge, coating, and fuel pieces). The table also presents physical properties (mass, density, and volume) on dry and as-settled basis for each of the components.

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Table C-7. KE Fuel Wash Sludge Component Nominal Compositions.

KE Fuel Wash Sludge		Internal Sludge	Coating	Fuel pieces	Mass of dry sludge total		Concentration of Compound for Internal Sludge	Concentration of Compound for Coating	Concentration of Compound for Fuel Pieces
					kg		grams per cm^3	grams per cm^3	grams per cm^3
					2828.00		as-settled	as-settled	as-settled
Dry mass	kg	1,193.00	59.00	1,576.00			sludge	sludge	sludge
Dry density	g/cm^3	7.56	2.06	19.00					
Dry volume	m^3	0.158	0.029	0.083					
Volume of as-settled sludge	m^3	0.518	0.061	0.149					
As-settled sludge density	g/cm^3	3.00	1.50	11.02					
							g/cm^3	g/cm^3	g/cm^3
Dry solid chemical composition									
U	%	0	0	92.92			-	-	9.828354
UO2	%	75.32	0	0			1.734693	-	-
U3O7	%	0	0	0			-	-	-
UO4.4H2O	%	0	69.60	0			-	0.673135	-
UH3	%	7.48	0	0			0.172178	-	-
Al2O3	%	0	0	0			-	-	-
AlOH3	%	1.103	22.10	0			0.025395	0.213762	-
FeOOH	%	0.189	2.96	0			0.004348	0.028622	-
SiO2	%	15.14	0	0			0.348580	-	-
CaO	%	0	1.54	0			-	0.014884	-
C	%	0	0	0			-	-	-
CO2	%	0	0				-	-	-
Miscel.	%	0.777	3.81	0.53			0.017895	0.036809	0.056162
Dry solid - radionuclide content									
^{238}Pu and $^{239/240}Pu$	µCi/g	232.67	114.50	195.91			0.008681	0.001794	0.033569
^{241}Am	µCi/g	210.50	93.40	168.01					
^{137}Cs	µCi/g	3443.33	1410.00	5342.20					
$^{89/90}Sr$	µCi/g	3851.61	1767.75	4045.39					
Uranium isotopic composition									
U 233	mass%	0	0	0					
U 234	mass%	0.0073	0.00694	0.0065					
U 235	mass%	0.764	0.682	0.719					
U 236	mass%	0.086	0.086	0.090					
U 238	mass%	99.14	99.23	99.19					
Miscellaneous solids									
PCB									
OIER									
Zeolite									
Zircalloy2	%	0	0	6.55					0.692665
Grafoil									
CO_2 represents carbonate									

APPENDIX D

KW BASIN FLOOR AND PIT SLUDGE CHARACTERISTICS

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APPENDIX D

KW BASIN FLOOR AND PIT SLUDGE CHARACTERISTICS

D.1.0 INTRODUCTION

Characterization currently does not exist for the K West Basin floor and pit areas; therefore, characteristics are not provided in this revision. A sampling campaign is scheduled for early fiscal year 1999. This campaign will obtain sludge samples from the K West Basin floor and pits and will perform various analytical tests on the samples. This appendix will be revised following receipt of the analytical data.

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APPENDIX E

KW BASIN CANISTER SLUDGE CHARACTERISTICS

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APPENDIX E

KW BASIN CANISTER SLUDGE CHARACTERISTICS

E.1.0 INTRODUCTION

This appendix provides the characteristics of the K West Basin (KW Basin) canister sludge contained in the fuel storage canisters. Eight sludge samples from the KW Basin canisters have been analyzed. Chemical, radiological, and physical properties have been determined and are reported in Makenas et al. (1998). The majority of the sludge from the fueled canisters consisted of uranium oxides and, in some cases, uranium hydrates, iron hydroxides, and aluminum hydroxide. The canister sludge also contained some uranium hydride as detected by X-ray diffraction (XRD) analyses. Discrete flakes of graphite (from lid seals) also were seen in various subsamples.

E.2.0 PHYSICAL PROPERTIES

A summary of the physical properties of the "as-settled" sludge (i.e., the sludge as it sits in the canisters) in the KW Basin canisters is presented in Table E-1. The physical properties were determined from the data reported in the characterization document, Makenas et al. (1998).

Table E-1. Summary Table for KW Canister Physical Properties.

	Volume [1] (m^3)	Mass (Mg)	Density[2] (g/cm^3)	Settling Time[3]	Zeta Potential[4]	Viscosity[5]
Canisters	1.01	2.71	2.68	80% @ 29 hr	-28 to -34 mV @ pH 7	100 Pa•s @ 0.1 s^{-1} to 0.5 Pa•s @ 300 s^{-1}

[1] The bases for current sludge volume estimates are documented in Baker (1998).
[2] Mean density of samples listed in Makenas et al. (1998, Table 4.5, page 49); excludes sample 96-23 because of the presence of transient gas bubbles..
[3] Estimation for slower settling samples shown in Makenas et al. (1998, Figure F.9-2, page F-49).
[4] Estimation of "mV" range at pH 7 as shown in Makenas et al. (1998, Figure F.7-2, page F-47).
[5] Values are viscosity (Pa•s) versus shear rate (s^{-1}) at the higher and lower points of the response curve.

E.2.1 PARTICLE SIZE

This section establishes a particle size distribution for the canister sludge to calculate the composition of the streams after the sludge passes through the Integrated Water Treatment System Knockout Pots (cut at 500 μm).

The following estimation is based on the data reported in Makenas et al. (1998). A limited set of samples (designated research samples) were subjected to particle size analyses. As such, the sample analysis is considered limited and may or may not be fully representative.

Particle size distribution measurements were performed on Samples 96-21, 96-23, and 96-24 using two separate methods. A Microtrac[1] X-100 particle size analyzer was used to measure particle sizes from 0.12 μm to 704 μm, and a wet sieving technique was used to fractionate particles as coarse, medium, and fine. Sieving results showed that between 80 vol% and 97 vol% of the material was less than 710 μm in diameter (Makenas et al. 1998). Sieving also showed, in conjunction with XRD, that the material above 710 μm (between 6350 μm and 710 μm) was primarily Grafoil®[2] generated when the canisters were opened. Also, the particle size distribution results for those particles smaller than 710 μm indicate that, unlike the K East canister sludges, the majority of particles in the KW canister sludges are less than 1.0 μm.

Table E-2 gives the response of particle size distribution measurements of sludge subsamples under 40 mL/s (0.64 gal/min) circulation (final, sonicated) and 70 mL/s (1.11 gal/min) circulation (as received).

Table E-2. K West Canister Sludge, Per Cent Distribution.

Sample	40 mL/s; 40 W Sonication, Final	70 mL/s, As Received, no Sonication
96-21		
< 500 μm	100%	84%
> 500 μm		16%
96-23		
< 500 μm	100%	100%
> 500 μm		
96-24		
< 500 μm	100%	100%
> 500 μm		

[1]Microtrac is a trademark of Leeds and Northrup.

[2]Grafoil is a trademark of Lamons Metal Gasket Co.

The subsamples analyzed at 40 mL/s, 40 W sonication best represent the conditions expected during process implementation. Based on this information, the estimation in Table E-3 below shows all the K West canister sludge being smaller than 500 μm.

Table E-3. K West Canister Sludge Stream Estimates.

Basin / Source	Particle Size Split	
K West	IWTS Knockout Pots, m^3 500 μm < x ≤ 6350 μm	Settler Tanks, m^3 < 500 μm
Full Canisters	13%[1]	87%

[1] Consists of Grafoil® particles only.

E.3.0 KW BASIN CANISTER SLUDGE COMPOSITION

This section establishes the chemical composition of the KW canister sludge. The characterization data in Makenas et al. (1998) were used for this activity.

E.3.1 CHEMICAL CONTENT METHODOLOGY

Based on the analyte concentrations for each sample given in Makenas et al. (1998, Appendix C) (units of characterization data are micrograms of analyte per gram of dry sludge), a mean concentration value for each analyte was calculated (less than values were excluded from the calculations). No attempt was made to use depth weighting to adjust the mean value. The mean analyte concentrations are then assumed to be representative of the whole volume of KW canister sludge.

To account for the total solids found in the sludge, and knowing that the sludge in the closed KW canisters are almost entirely the result of oxidation, the mean analyte concentrations were converted to the most probable oxidation product concentrations. The following equations demonstrate how this was done, using aluminum as an example.

The only aluminum compound identified was aluminum hydroxide (Makenas et al. 1998, Appendix G).

$$\textit{Atomic Weight } Al(OH)_3 = 77.99 \textit{ g/mole} \qquad \textit{Atomic Weight } Al = 26.98 \textit{ g/mole}$$

$$\textit{Oxide Factor} = \frac{77.99}{26.98} = 2.89$$

The amount of aluminum compound in the dry sludge was determined by multiplying the oxide factor by the mean analyte concentration for aluminum (20,446 μg/g of dry sludge, Table E-7).

$$20{,}446 \ \frac{\mu g\ Al}{g\ dry\ sludge} \ x\ 2.89 = \frac{0.0591\ g\ Al(OH)_3}{g\ dry\ sludge}$$

Dividing the mean concentration per cubic centimeter of as-settled sludge by the mean concentration per gram of dry sludge, it was determined that there are 1.992 grams of dry sludge per cubic centimeter of as-settled sludge. This allows the following calculation.

$$\frac{0.0591\ g\ Al(OH)_3}{g\ dry\ sludge} \ x\ \frac{1.992\ g\ dry\ sludge}{cm^3\ as\text{-}settled\ sludge} = \frac{0.1177\ g\ Al(OH)_3}{cm^3\ as\text{-}settled\ sludge}$$

The same calculation is performed for all identified elements and their associated compounds.

E.3.1.1 Chemical Composition of the Uranium Compounds

Multiple uranium compounds have been identified. To make a reasonable assumption for the mass of uranium compounds in the sludge, the following text was developed to document the basis for the assumed breakdown.

It has been assumed that the primary source of uranium in the canister sludge will be oxidation products, with small amounts of uranium hydride as shown in Table E-4. Not knowing the amount of free oxygen in the water, it has been assumed that the oxides will be split about 50-50 between the two listed oxide products and that this will provide an acceptable representation of the mass of uranium oxide compounds in the canister sludge. The presence of sludge generated bubbles, assumed to be hydrogen plus fission gases, which indicates the presence of uranium metal in the sludge. Uranium hydride was found by XRD in one sample. Given the limited data, 5% of the uranium compounds will be attributed to uranium hydride and 5% will be attributed to uranium metal. It is assumed that any hydrates present in the canister sludge will be negligible.

Table E-4. Weight Percent of Uranium Compounds in KW Canister Sludge.

	Wt% Breakdown of Uranium into Compounds				
Location	U	UO_2	U_3O_7	$UO_4{\cdot}4H_2O$	UH_3
Canister Sludge	5.0	45.0	45.0	0.0	5.0

E.3.1.2 Chemical Composition of the Aluminum Compounds

Aluminum hydroxide was the only aluminum compound identified in the XRD results for the KW canister sludge (See Makenas et al. 1998, Appendix G). Therefore, it has been assumed that all aluminum will be accounted for as aluminum hydroxide, as shown in Table E-5.

Table E-5. Weight Percent of Aluminum Compounds in KW Canister Sludge.

	Wt% Breakdown of Compounds With Aluminum				
Location	$Al(OH)_3$	Al_2O_3			
KW Canister Sludge	100.0	0.0			

E.3.1.3 Chemical Composition of the Iron Compounds

Iron hydroxide was the most common iron compound identified in the XRD results for the KW canister sludge (See Makenas et al. 1998, Appendix G). It has been assumed that all iron will be accounted for as iron hydroxide, as shown in Table E-6.

Table E-6. Weight Percent of Iron Compounds in KW Canister Sludge.

	Wt% Breakdown of Compounds With Iron				
Location	FeO(OH)				
KW Canister Sludge	100.0				

E.3.2 RADIONUCLIDE METHODOLOGY

The only radionuclides accounted for in this appendix are uranium, plutonium, americium, cesium, and strontium. These were determined to be the most process-significant radionuclides. Uranium is important to the process from both a mass balance and a safety perspective. See Sections 3.4, 3.5, and 3.6 of this document for a safety-related discussion on the importance of plutonium, americium, cesium, and strontium. Based on the radionuclide inventory for each sample given in Makenas et al. (1998, Appendix C) (units of characterization data are microcuries per gram of dry sludge), a mean value for each of these radionuclide was calculated. The characterization data recorded two values for americium. The mean for americium shown on Table E-7 is an average of the two reported values. No attempt was made to use depth weighting to adjust the mean values. The mean values are then assumed to be representative of the whole volume of KW canister sludge.

E.3.3 KW CANISTER MISCELLANEOUS CONSTITUENTS

Two miscellaneous components were identified in the KW canister sludge; polychlorinated Biphenyls (PCB) and Grafoil®. This section provides the basis for the reported quantities of these two constituents.

E.3.3.1 Polychlorinated Biphenyls

Polychlorinated biphenyls have been found in KW canister sludge ranging from approximately 0.056 ppm to 5.73 ppm, (by weight in settled sludge). For the KW canister composition, it is assumed that the PCB concentration in the sludge is 5.7 ppm.

A conservative estimate for the PCB concentration is assumed, to ensure that the sludge treatment system can adequately treat the sludge such that it meets the Tank Waste Remediation System acceptance criteria for PCBs.

E.3.4.2 Grafoil®

The mass of Grafoil® in KW canister sludge is 55.8 kg (Pearce and Pitner 1998).

E.3.5 KW CANISTER SLUDGE INVENTORY

The nominal chemical, radionuclide and miscellaneous compositions for the KW canister sludge are presented in Table E-7.

E.4.0 REFERENCES

Baker, R. B., 1998, (DESH Internal Letter to K. L. Pearce, [NHC] "Revised Estimates of Sludge Volumes In K East and K West Basins,"), DE&S Hanford, Inc., Richland, Washington.

Makenas, B. J., T. L. Welsh, R. B. Baker, G. R. Golcar, P. R. Bredt, A. J. Schmidt, and J. M. Tingey, 1998, *Analysis of Sludge from Hanford K West Basin Canisters*, HNF-1728, Rev. 0, prepared by DE&S Hanford, Inc., for Fluor Daniel Hanford, Inc., Richland, Washington.

Pearce, K. L., and A. L. Pitner, 1998, *K West Basin Sludge Volume Estimates for Integrated Water Treatment System*, HNF-3165, Rev. 1, prepared by DE&S Hanford, Inc., for Fluor Daniel Hanford, Inc., Richland, Washington.

Table E-7. KW Canister Sludge Composition.

KW Canister Data (From HNF-1728, Rev. 0)						
Measured Element	Mean Concentration of Element	Expected Compounds	Oxide Factor	Mole Fraction of Element in Compound	Mean Concentration of Compound	Mean Concentration of Compound
	µg / g dry sludge				µg / g dry sludge	g / cm^3 as-settled sludge
Ag	-	Ag_2O	1.074	100%	-	0.000000
Al	20,446.25	$Al(OH)_3$	2.889	100%	59,066.94	0.117661
B	-	B_2O_3	3.222	100%	-	0.000000
Ba	254.00	BaO	1.117	100%	283.60	0.000565
Be	49.50	BeO	2.778	100%	137.50	0.000274
Bi	-	BiO	1.077	100%	-	0.000000
Ca	-	CaO	1.399	100%	-	0.000000
Cd	-	CdO	1.142	100%	-	0.000000
Cr	321.17	Cr_2O_3	1.462	100%	469.40	0.000935
Cu	-	CuO	1.252	100%	-	0.000000
Fe	65,942.50	FeO(OH)	1.591	100%	104,940.75	0.209042
K	-	K_2O	1.205	100%	-	0.000000
Mg	-	MgO	1.658	100%	-	0.000000
Mn	285.00	MnO	1.291	100%	368.06	0.000733
Na	-	Na_2O	1.348	100%	-	0.000000
Ni	260.00	NiO	1.273	100%	330.87	0.000659
P	-	PO_3	2.548	100%	-	0.000000
Pb	-	PbO	1.077	100%	-	0.000000
Se	-	Se	1.000	100%	-	0.000000
Sn	-	SnO	1.135	100%	-	0.000000
Tl	-	Tl_2O_3	1.117	100%	-	0.000000
Zn	620.00	ZnO	1.245	100%	771.68	0.001537
Zr	440.67	ZrO_2	1.351	100%	595.29	0.001186
U	664,330.36	U	1.000	5%	33,216.52	0.066167
		UO_2	1.134	45%	339,143.44	0.675574
		U_3O_7	1.157	45%	345,842.57	0.688918
		$UO_4 . 4H_2O$	1.571	0%	-	0
		UH_3	1.013	5%	33,635.21	0.067001
^{238}Pu and $^{239/240}$Pu					2,835.41	0.005648
Insoluble Solids	NA	SiO_2				0.000000
TIC	398.38	CO_2	3.667	100%	1,460.71	0.002910
TOC	1,473.00	C	1.000	100%	1,473.00	0.002934
		Miscellaneous solids				
		PCB				0.000015
		OIER				0
		Zeolite				0
		Zircalloy 2				
		Grafoil				0.055248
CO_2 represents carbonate						
Dry solid - radionuclide content						
$^{239/240}$Pu and ^{238}Pu	175.03	µCi/g				
^{241}Am	136.66	µCi/g				
^{137}Cs	1898.75	µCi/g				
$^{89/90}$Sr	3096.25	µCi/g				
Uranium isotopic composition						
^{233}U	0.000000	%				
^{234}U	0.004506	%				
^{235}U	0.800234	%				
^{236}U	0.094425	%				
^{238}U	99.153555	%				

APPENDIX F

KW BASIN FUEL WASH SLUDGE CHARACTERISTICS

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APPENDIX F

KW BASIN FUEL WASH SLUDGE CHARACTERISTICS

F.1.0 INTRODUCTION

This appendix provides the characteristics of the K West Basin (KW Basin) fuel wash sludge components expected to be generated in the processing of fuel elements for dry storage. Before being sent to dry storage, the fuel storage canisters will be dumped into a primary washing machine that cleans the canisters and elements by a tumbling action and water flushing process. Because of the physical state of the stored fuel, it is expected that the washing process will cause further breakage of the fuel elements and will dislodge corroded uranium pieces, zirconium cladding, pieces comprising both uranium and zirconium, and loosely adhered materials (such as coatings and internal sludge). This dislodged material is referred to as the "fuel wash" sludge components; fuel pieces, coating, and internal sludge. A screen inside the washing machine separates particles less than 6350 μm (canister sludge and wash sludge components) from the fuel elements and fragments. The IWTS system then pumps the canister and wash sludge components to Integrated Water Treatment System (IWTS) Knockout Pots, which separate these sludges into two streams based on particle size.

Experimental tests on the cleaning process have not been done; therefore, no samples of actual KW Basin fuel wash sludge exist. However, examinations were made of the surface and/or subsurface of four KW Basin fuel elements. The examinations included collection of coating pieces from the fuel cladding and particles recovered from cracks in the fuel and from beneath the cladding material. Often the particulate material was accompanied by large (0.64 to 1.27 cm [0.25- to 0.5-in.]) pieces of fuel. In general, no great quantities of sludge or particulate fuel were found beneath the cladding breaches. However, substantial residue sample was obtained by straining the water from the spent fuel element container (SFEC) (shipping container used to transport the fuel elements to the 300 Area hot cells), suggesting that loose fuel material escaped from breached areas during shipping and handling activities (Pitner 1997). The subsurface particles from the fuel elements and the residue from the SFECs make up the internal sludge. Characterization data from the subsurface fuel examinations (Silvers 1998) and KW Basin fuel elements (Praga and Willis 1998) form the basis of the fuel wash sludge inventory.

F.2.0 KW WASH SLUDGE PHYSICAL PROPERTIES

The physical properties were determined from the subsurface fuel examination data (Silvers 1998); the volume calculations are documented in Pearce and Pitner (1998). A summary of the physical properties for the "as-settled" fuel wash sludge components is presented in Table F-1.

Table F-1. Summary Table for KW Fuel Wash Component Physical Properties.

Fuel Wash Component	Volume (m^3)	Mass (Mg)	Density (g/cm^3)
Coating	0.406	0.609	1.50
Internal Sludge	0.518	1.55	3.0
Fuel Pieces	0.149	1.64	11.0

F.2.1 WASH SLUDGE COMPONENT PARTICLE SIZES

This subsection provides the basis for particle size distributions for each of the three components of the wash sludge (coating, internal sludge, and fuel pieces). These distributions are determined to calculate the composition of the process feedstreams following particle separation in the IWTS Knockout Pot (cut at 500 μm).

F.2.1.1 Coating Material Particle Size

No data currently exist that delineate particle size measurements for the coating particles after the fuel washing operation and the subsequent transfer to the IWTS Knockout Pot. Visual observations indicated that the coating flakes off in approximately 1-in. pieces. It is anticipated that the coating will further break apart into pieces that are below 500 μm during the fuel cleaning operation and subsequent transfer to the IWTS.

F.2.1.2 Internal Sludge Particle Size

A particle size analysis was performed on one residue sample (Sample R5) by wet sieving (Silvers 1998). Sample R5 was obtained from the bottom of the shipping container (SFEC) that was used to transport the KW Basin fuel elements. All of the material in Sample R5 passed through the sieves. The smallest sieve used was a Type 32 (500 μm); therefore, all particles in R5 were below 0.500 mm. It is assumed that all of the KW Basin internal sludge will reside in the IWTS settler tanks.

F.2.1.3 Fuel Pieces Particle Size

Particle size data for the fuel pieces do not exist; however, it seems reasonable (based on visual examination of the pieces removed from the fuel element during subsurface examinations) to consider that 100 vol% of these pieces will be above 500 μm.

F.3.0 KW BASIN WASH SLUDGE COMPOSITION

This section provides the basis for determining the chemical and radionuclide compositions for each of the wash sludge components (coating, internal sludge, and fuel pieces). The elemental data are essential to identify solid phases in the fuel wash sludge components. These compositions are then used in defining the mean wash sludge component inventories.

F.3.1 WASH SLUDGE CHEMICAL CONTENT METHODOLOGY

F.3.1.1 Coating Elemental Composition

Elemental analytical data are available for coating samples (CS2, CS3, CS4, and CS7) obtained from four KW Basin fuel elements. The elemental compositions of the coating samples have been determined by inductively coupled plasma analyses (Silvers 1998). The results are summarized in Table F-2.

Table F-2. Coating Elemental Composition.

	Sample CS2[1]	Sample CS3[1]	Sample CS7[1]	Sample CS4[1]	Sample CS4 dup[1]	CS Mean
Element	µg/g dry coating	µg/g dry coating	µg/g dry coating	µg/g dry coating	µg/g dry coating	µg/g dry coating
Al	44000	53300	39700	304000	310000	194104
B	5500					2376
Ba	814	296	313			205
Bi		280	230			110
Ca	8500	9400	5500			3370
Cr	390	400	2930			536
Fe	397000	476000	450000	27800	1200	198748
Mn	2330	978	1670	680	250	981
Na	15000	4600	3400	3600	3700	5385
P		940	720			359
Si	57000		7200			13867
U	16000	20000	65100			14558
Zn	900	790	420			304
Zr	860	3010	900	910	480	1082

[1] Iron Rich Coating
[2] Aluminum Rich Coating

The mean analyte value for the coating samples is calculated using the following equation.

Csmean = 0.432 x (CS2+CS3+CS7)/# of samples+ 0.568 x (CS4+CS4dup)/# of samples

where: 0.432 is correction factor for thickness of iron-rich coating layer
0.568 is correction factor for thickness of aluminum rich coating layer

F.3.1.2 Internal Sludge Elemental Composition

The cladding around breached and cracked areas on KW Basin fuel element 7913U was removed and subsurface particulate material was recovered from the bottom and center (samples SSL7 and SSL8) of the fuel element (Pitner 1998). The elemental composition of the particulate material recovered from the center breach (Sample SSL8) was determined by inductively coupled plasma analyses (Silvers 1998). The elemental data are summarized in Table F-3.

Table F-3. Internal Sludge Elemental Composition.

Sample SSL8		Sample SSL8	
Element	µg/g dry sludge	Element	µg/g dry sludge
Al	19400	Fe	1100
B		Mn	210
Ba	120	Na	4700
Bi		Si	14000
Ca		U	731000
Cr	200	Zn	
Cu		Zr	560

F.3.1.3 Wash Sludge Component Chemical Compounds

To determine the total solids found in the coating and internal sludge components, the oxide and hydroxide percentages were calculated using the likely oxidation state for each element (e.g., aluminum (III)). The very low level of other anions such as chloride, nitrate, and phosphate justifies this approach. The choice between oxide or hydroxide (which may sometimes appear arbitrary) was based on the following observations for the coating and internal sludge components.

- $Al(OH)_3$ has been observed in K West canisters and identified by X-ray diffraction in coating sample CS4.
- FeO(OH) has often been identified in K East canister and floor sludge.

- UO_2 + 10% UH_3: when uranium is corroding in water, the resulting corrosion product is a mixture of uranium oxide and uranium hydride. It has been shown that the UH_3 percentage can vary between 2 and 9 wt% (Baker et al. 1966). Because the presence of uranium hydride may impact the safety assessment of the facility, a bounding value of 10% for the uranium hydride content was chosen.

- $UO_4 \cdot 4H_2O$ has been identified by X-ray diffraction on KE fuel elements.

The following equations demonstrate how the elemental data in Tables F-2 and F-3 were used to convert to the oxidation product concentrations (in weight percent) for the coating and internal sludge components:

Atomic Weight $Al(OH)_3$ = 77.99 *g/mole* *Atomic Weight Al* 26.98 *g/mole*

$$\textit{Oxide Factor} = \frac{77.99}{26.98} = 2.89$$

The mean concentration of aluminum is 194,104 µg/g of dry material for the coating component The weight percent of aluminum compound in the dry coating was determined by multiplying the oxide factor by the mean analyte concentration, then multiplying by 100.

$$\frac{194{,}104\ \mu g\ Al}{g\ dry\ coating} \times 2.89 = \frac{0.5610\ g\ Al(OH)_3}{g\ dry\ coating} \times 100 = 56.10\ wt\%$$

The weight percent of aluminum compounds in the dry internal sludge were determined by multiplying the oxide factor by the elemental concentration for aluminum given in Table F-3, then multiplying by 100.

The composition of the fuel pieces generated in the primary washing machine are assumed to have the same composition as the fuel elements (in particular, the U/Zr ratio will be identical). The composition of the fuel pieces then is determined from the N Reactor fuel element data reported in Praga and Willis (1998, Table 2.1, page 5). The composition of the fuel pieces is therefore calculated as:

Uranium = 2.10/2.26 x 100 = 92.92 wt%
Zirconium = 0.148/2.26 x 100 = 6.55 wt%
Miscellaneous = 92.92 - 6.55 = 0.53 wt %.

F.3.2 KW Wash Sludge Chemical Inventory

Applying the assumptions and performing the calculations, from section F.3.1, for all identified elements and their associated oxide factor, the chemical inventory for the coating, internal sludge, and fuel pieces was determined. The results are presented in Table F-4.

Table F-4. Weight Percent Component Chemical Composition.

Compounds	Oxide Factor	Internal Sludge (%)	Coating (%)	Fuel Pieces (%)
AlOH3	2.89	5.605	56.077	
Al2O3	1.89			
CaO	1.40		0.471	
FeO(OH)	1.59	0.175	31.621	
U	1.00			92.92
UO2	1.13	74.606		
U3O7	1.16			
UO4·4H2	1.57		2.287	
UH3	1.01	7.405		
SiO2	2.14	8.430	2.972	
Zircalloy2				6.55
Miscellaneous		3.779	6.572	0.53

F.3.3 KW WASH SLUDGE RADIONUCLIDE METHODOLOGY

The only radionuclides accounted for in this appendix are uranium, plutonium, americium, cesium, and strontium. These were determined to be the most process-significant radionuclides. Uranium is important to the process from both a mass balance and a safety perspective. See Sections 3.4, 3.5, and 3.6 of this document for a safety-related discussion on the importance of plutonium, americium, cesium, and strontium.

The radionuclide inventory for the coating and internal sludge components were determined from the radiochemistry results reported in Silvers (1998). Analysis for ^{90}Sr was not

performed for these samples. Therefore, the following equation was used to determine the ^{90}Sr content in the coating and internal sludge samples:

$$^{90}Sr_{measured} = (Pu_{measured})(^{90}Sr_{origen}) / (Pu_{origen})$$

where: $Pu_{measured}$ = total measured Pu reported in Silvers (1998)
Pu_{origen} = total Pu from origen data reported in Praga and Willis (1998)
$^{90}Sr_{origen}$ = ^{90}Sr from origen data reported in Praga and Willis (1998).

For the fuel pieces, the radionuclide inventory reported in Praga and Willis (1998, Table 3.7 provides ORIGEN results for KW Basin) has been used to derive a mean radionuclide inventory expressed in curies per gram of uranium.

F.3.4 KW Wash Sludge Radionuclide Inventory

Table F-5 presents the radionuclide inventory for the three fuel wash sludge components.

F-5. KW Wash Sludge Radionuclide Content.

Isotope	Sample CS2	Sample CS3	Sample CS7	Sample CS4	Sample CS4dup	CS mean	Sample SSL8	Fuel Pieces
	µCi/g	µCi/g	µCi/g	µCi/g	µCi/g	µCi/g	µCi/g	µCi/g
Pu238	0.776	0.897	2.87	0.0876	0.0848	0.70	20.7	49.97
Pu239	3.19	3.41	9.96	0.281	0.267	2.54	107	98.95
Pu240	1.72	1.79	5.44	0.166	0.154	1.38	56.3	54.18
Am241	7.7	7.31	13.4	0.483	0.533	4.38	148	165.58
Cs137	33.7	238	102	7.65	6.02	57.70	2210	6505.54
Sr90	97.95	93.50	417.95	9.42	8.70	92.90	2116	5065.30
	%	%	%	%	%	%	%	%
U234	0.00727	0.0085	0.00796	0.0111	0.00858	0.009006	0.00594	0.00689
U235	0.885	0.945	0.912	0.904	0.905	0.908604	0.671	0.780
U236	0.0869	0.0905	0.0962	0.0936	0.0936	0.092563	0.0887	0.0995
U238	99.02	98.96	98.98	98.99	98.99	98.99	99.24	99.11

F.3.5 KW WASH SLUDGE MISCELLANEOUS COMPOSITIONS

The only component from the wash sludge that has been analyzed for polychlorinated biphenyls (PCB) is coating samples from the surfaces of four KW fuel elements (6743U, 7913U, 0161M, and 2667U). One coating sample reported a maximum PCB concentration of 0.081 ppm; PCBs were nondetectable for the other three samples (Silvers 1998). Because of the low values reported for the coating materials and lack of data for the fuel pieces or internal sludge, it is assumed that the fuel wash sludge components do not contain PCBs.

F.3.6 KW WASH SLUDGE COMPONENT INVENTORY

The nominal chemical, radionuclide, and miscellaneous component inventories for the KW wash sludge components are presented in Table F-6.

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Table F-6. KW Fuel Wash Sludge Component Composition.

KW Fuel Wash Sludge		Internal Sludge	Coating	Fuel	Mass of dry sludge		Concentration of Compound for Internal Sludge	Concentration of Compound for Coating	Concentration of Compound for Fuel Pieces
					kg		grams per cm^3	grams per cm^3	grams per cm^3
					3162.00		as-settled	as-settled	as-settled
Dry mass	kg	1,193.00	393.00	1,576.00			sludge	sludge	sludge
Dry density	g/cm^3	7.56	2.06	19.00					
Dry volume	m^3	0.158	0.191	0.083					
Volume of as-settled sludge	m^3	0.518	0.405	0.149					
As-settled sludge density	g/cm^3	3.00	1.50	11.02					
							g/cm^3	g/cm^3	g/cm^3
Dry solid chemical composition									
U	%	0	0	92.92			-	-	9.828354
UO2	%	74.61	0	0			1.718239	-	-
U3O7	%	0	0	0			-	-	-
UO4.4H2O	%	0	2.29	0			-	0.022194	-
UH3	%	7.41		0			0.170544	-	-
Al2O3	%	0	0	0			-	-	-
AlOH3	%	5.60	56.08	0			0.129080	0.544151	-
FeOOH	%	0.18	31.62	0			0.004031	0.306839	-
SiO2	%	8.43	2.97	0			0.194161	0.028835	-
CaO	%	0	0.47	0			-	0.004574	-
C	%	0	0	0			-	-	-
CO2	%	0	0				-	-	-
Miscel.	%	3.78	6.57	0.531			0.087033	0.063777	0.056162
								-	-
Dry solid - radionuclide content								-	-
^{238}Pu and $^{239/240}Pu$	µCi/g	184	4.62	203.12			0.006865	0.000073	0.034805
^{241}Am	µCi/g	148	4.38	165.58					
^{137}Cs	µCi/g	2210	57.70	6505.54					
$^{89/90}Sr$	µCi/g	2116	92.90	5065.27					
Uranium isotopic composition									
U 233	mass%	0		0					
U 234	mass%	0.0059	0.0090	0.0069					
U 235	mass%	0.67	0.91	0.78					
U 236	mass%	0.089	0.093	0.099					
U 238	mass%	99.24	98.99	99.11					
Miscellaneous solids									
PCB									
OIER									
Zeolite									
Zircalloy2	%	0	0	6.55					0.692665
Grafoil									
CO2 represents carbonate									

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