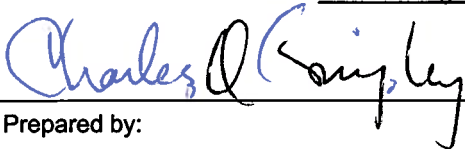
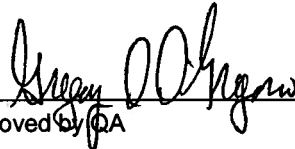
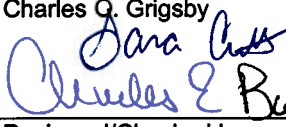
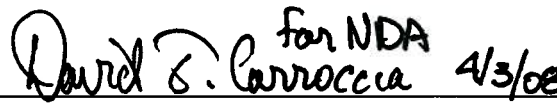


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**Advanced Fuel Cycle Facility
Conceptual Design and NEPA Support Activities**

**NEPA Data Study
AFCF-ST-001, Rev 1**

April 2, 2008

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This report captures the best available information and estimates for construction and operations data for the Advanced Fuel Cycle Facility as of the publication date. Because the AFCF is currently in the initial conceptual design phase, new information (new process designs, changes to or refined estimates for existing process designs, changes to building layouts, etc.) relevant to this data study is generated as the design progresses. Every attempt was made during preparation of this report to provide estimates that are both realistic and bounding – that is, are reasonable and are not likely to be exceeded by on going design development. The design data are based on the conceptual design as of November 2006.

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1. Introduction

This document compiles the best available information about the construction and operation data for the Advanced Fuel Cycle Facility (AFCF), which is one element of the US Department of Energy (DOE) Global Nuclear Energy Partnership (GNEP) initiative. The study was prepared to support the development of a Programmatic Environmental Impact Statement (PEIS) as required by the National Environmental Policy Act (NEPA) of 1969 and in accordance with the Council on Environmental Quality and DOE regulations for implementing NEPA (40 CFR Parts 1500-1508 and 10 CFR Part 1021, respectively).

The DOE's Global Nuclear Energy Partnership (GNEP) is a comprehensive strategy to increase US and global energy security, reduce the risk of nuclear proliferation, encourage clean energy development around the world, and improve the environment. GNEP requires the US to move from a once-through fuel cycle to a new approach that includes recycling of spent nuclear fuel (SNF) by creating uranium and higher actinide product streams without separation of all the individual transuranic components of spent nuclear fuel. This capability would employ advanced technologies to increase proliferation resistance, recover and reuse fuel resources, and reduce the amount of wastes requiring permanent geological disposal. The work builds on the DOE's Advanced Fuel Cycle Initiative.

Spent (used) nuclear fuel contains uranium, transuranic elements (neptunium, plutonium, americium, and curium) and fission products. The fission products are wastes that make up less than 10 percent of the spent fuel. However, these wastes inhibit nuclear reactions, thus, nuclear fuel must be removed from the reactor core as the fission products build up to maintain the overall reactivity in the reactor core.

Under the Global Nuclear Energy Partnership (GNEP), recycling would accomplish:

- Separation of high purity uranium from the spent fuel that would allow recycle for re-enrichment or for other use or disposition
- Separation and immobilization of long-lived fission products, technetium, and iodine for disposal in a geological repository
- Extraction and temporary storage of relatively short-lived fission products (cesium and strontium) to meet the requirements for disposal as low level waste
- Separation of transuranic elements for fabrication into fuel for an Advanced Burner Reactor (ABR). The ABR would consume the transuranic elements and recover their energy, thereby eliminating disposal of transuranic elements in a geological repository and substantially increasing the effective capacity of the repository.

The AFCF will advance the development and testing of all aspects of nuclear fuel cycle processes and equipment for (a) separation and recovery of usable materials from spent nuclear fuels; (b) fabricating advanced, proliferation-resistant, recycle fuels; and (c) securing waste materials in forms suitable for disposition. The AFCF will support the

development of advanced technologies related to safeguards and security, instrumentation, process control and integration. The AFCF will also provide data on reliability and scale-up needed for full-scale separations, and fuel fabrication facilities.

The AFCF will operate fully-integrated separations and fuel fabrication processes at engineering-scale (near full-size equipment, but at lower throughput than a full-scale process) using spent nuclear fuel. Thus, issues such as shielding, remote operations, safeguards and security, material control and accountability, chemical and mechanical processing, fabrication, and waste disposal will be addressed for this facility. The AFCF project is in the early conceptual design stage. As such, best available design information for NEPA impact assessment is presented in this study. Bounding assumptions have been made for the purpose of developing the NEPA analysis data such that the construction requirements and operational characteristics of the AFCF would envelope all anticipated environmental impacts over the planned 50 year operation of the AFCF. The potential construction and operations impacts from the AFCF final design are expected to be less severe than presented in this study.

This study updates and supersedes the previous Preliminary NEPA Data Study dated November 8, 2006. This update is based on the process designs and material balances prepared for the conceptual design of AFCF and incorporates comments from reviewers of the November 8, 2006 version of the NEPA Data Study.

During the conceptual design development, certain equipment sizing and operation issues caused new inventory estimates to exceed the nominally bounding estimates of daily in-process inventory from the November 8, 2006 Data Study. In particular, sizing of centrifugal contactors in the aqueous separations process and sizing of the rotary vacuum drum filter in feed conditioning required operating cycles considerably reduced from the 240 day cycle previously established for the facility. A new approach to estimating the bounding in-process inventory was required to provide flexibility in equipment sizing and operation. This new approach to estimating in-process inventory has been incorporated into this version of the NEPA Data Study.

This study identifies the construction and operations impacts of the AFCF assuming that the entire AFCF facility is constructed at an entirely new site (“greenfield”). A subsequent analysis, presented in Appendix A-1, evaluates the change in environmental impact from this baseline that would result from the use of an existing facility to house all or part of the AFCF processes (“brownfield”). Two sites with existing, clean hot cell facilities were evaluated – the Idaho Nuclear Technology and Engineering Center (INTEC) at Idaho National Laboratory, and the Fuels and Materials Examination Facility at the Hanford site.

The information presented in this NEPA Data Study has been checked and peer-reviewed. Notwithstanding efforts to present the most current and correct information about the AFCF construction and operation data for NEPA impacts assessment, in certain areas the design is less developed than for the processing areas, and the information presented is of a very preliminary nature. In particular, these areas include

the design, construction and operations data for the support facilities of the AFCF. In those cases, sizing of facility systems was based on parametric estimates using the building footprint as the key variable. As the design of these support facilities matures, better information about the construction and operation impacts will become available.

2. AFCF Operations and Requirements

The process, throughput and storage requirements for the AFCF design are defined in the High-Level Functional and Operational Requirements (F&OR)¹. To meet these overall design requirements, conceptual process designs (described in more detail in section 2.2) are used to identify process equipment and to develop material and energy balances for the planned “baseline” processes. The baseline AFCF processes for the conceptual design are shown schematically in Figure 1.

The AFCF is designed to recycle spent nuclear fuel (SNF) from light water reactors (LWR) and fast reactors (FR). All US commercial nuclear reactors are light water reactors; and there are two basic designs for LWRs – pressurized water reactors (PWRs) where the cooling water is maintained at high pressure to prevent the formation of steam in the reactor, and boiling water reactors (BWRs) where the heat from the nuclear reaction is allowed to boil the primary cooling water. Fast reactors operate with high energy (“fast”) neutrons compared with the neutron energies (“slow” or “thermal”) seen in LWRs. In fast reactors, high-energy neutrons are more readily captured by trans-uranium actinides, causing the actinides to fission. This results in more complete conversion of nuclear fuel to energy, and substantially reduces the extremely-long lived radioactive materials from the SNF. Advanced burner reactors (ABRs) are fast reactors that are specifically designed to “burn” actinides using fast neutrons.

SNF and other nuclear materials are received via truck or rail from a variety of off-site locations. These materials may be stored pending preparation for separations processing. Fuel bundles are prepared for separations processing in the Head End process, where fuel rods are removed from fuel assemblies and chopped into smaller pieces. Depending on the type of SNF (ceramic, metal, dispersed, etc.) and on the separations process to which it will be fed, the chopped fuel may be dissolved, heated, oxidized, or otherwise treated to meet the feed requirements of the separations process.

Separations processes include “wet” processes (termed “aqueous” separations) and “dry” processes (“pyrochemical” separations). Aqueous processes involve dissolution of the fuel materials in solvents followed by separation or purification using solvent extraction, ion exchange, precipitation, or other chemical separations processes. Pyrochemical processes involve dissolving the fuel materials in molten salts (e.g. alkali chlorides) and separation or purification primarily by electrochemical and chemical means. The separations processes are designed to separate waste materials (fission products, rare earth elements, fuel cladding, and other contaminants) from the actinide

¹ High-Level Functional and Operational Requirements for the Advanced Fuel Cycle Facility, Rev 0, GNEP-AFCF-PM-RQ-2006-00012, December 20, 2006.

elements (uranium, neptunium, plutonium, americium, and curium) which are used in the fabrication of new fuels.

A variety of “conditioning” processes may be required to prepare the separated actinide materials into chemical, isotopic, and physical forms required to fabricate fuel. Conditioning primarily includes dissolving separated actinides and depleted uranium (added to adjust the U:TRU ratio²) followed by solidification of the material. The conditioning function includes provision for recovering off-specification material from the fuel fabrication process, as well as provision for making specialized fuel forms (e.g., particle and dispersed compact fuels).

Conditioned fuel materials are transferred to the fuel fabrication process where they are converted to the appropriate form for ceramic (oxide or nitride), metal, or dispersed particle fuels. The conversion to ceramic fuel involves a variety of powder handling, pressing, sintering, and grinding processes to form pellets suitable for loading into fuel cladding. Metal fuels are melted, cast, and machined into rods or slugs that can be loaded into fuel cladding. Dispersed fuels are loaded into fuel cladding as dry powders using vibration or as monolithic compacts. Clad fuel elements are welded and tested before assembly into Lead Test Assemblies (LTAs) that are used to qualify the recycled fuel for use in nuclear power reactors.

Where not limited by processing requirements or physical form, each operation or group of operations within the overall process includes the ability to package material in a reusable “can” for storage or transfer to another operation. Storage operations are designed so downstream processes are not limited by materials availability.

At each stage in the overall process, materials are analyzed for a variety of process parameters such as chemical and isotopic composition, particle size distribution, density, uniformity, physical dimension, etc. These analyses can be for a variety of purposes such as quality assurance and process control, material control and accountability, and criticality safety. Fuel elements and assemblies are inspected and tested to ensure that they meet nuclear fuel specifications for use in a licensed reactor. Evolved gases, and waste liquids and solids are also analyzed and treated to meet established EPA, NRC, DOT or DOE criteria before being released or transported offsite. Some of these analyses are performed in-process, and some involve samples taken for analysis at an on-site analytical laboratory. Waste materials from the process areas are appropriately treated and packaged for storage, shipment and disposal.

² In this study, transuranium elements (specifically, Np, Pu, Am, Cm) are collectively referred to as TRU, which is not to be confused with the DOE waste classification of the same name (TRU waste). See DOE G 435.1-1 (<http://www.directives.doe.gov/pdfs/doe/doetext/neword/435/g4351-1ch3.pdf>) for clarification of the TRU Waste designation.

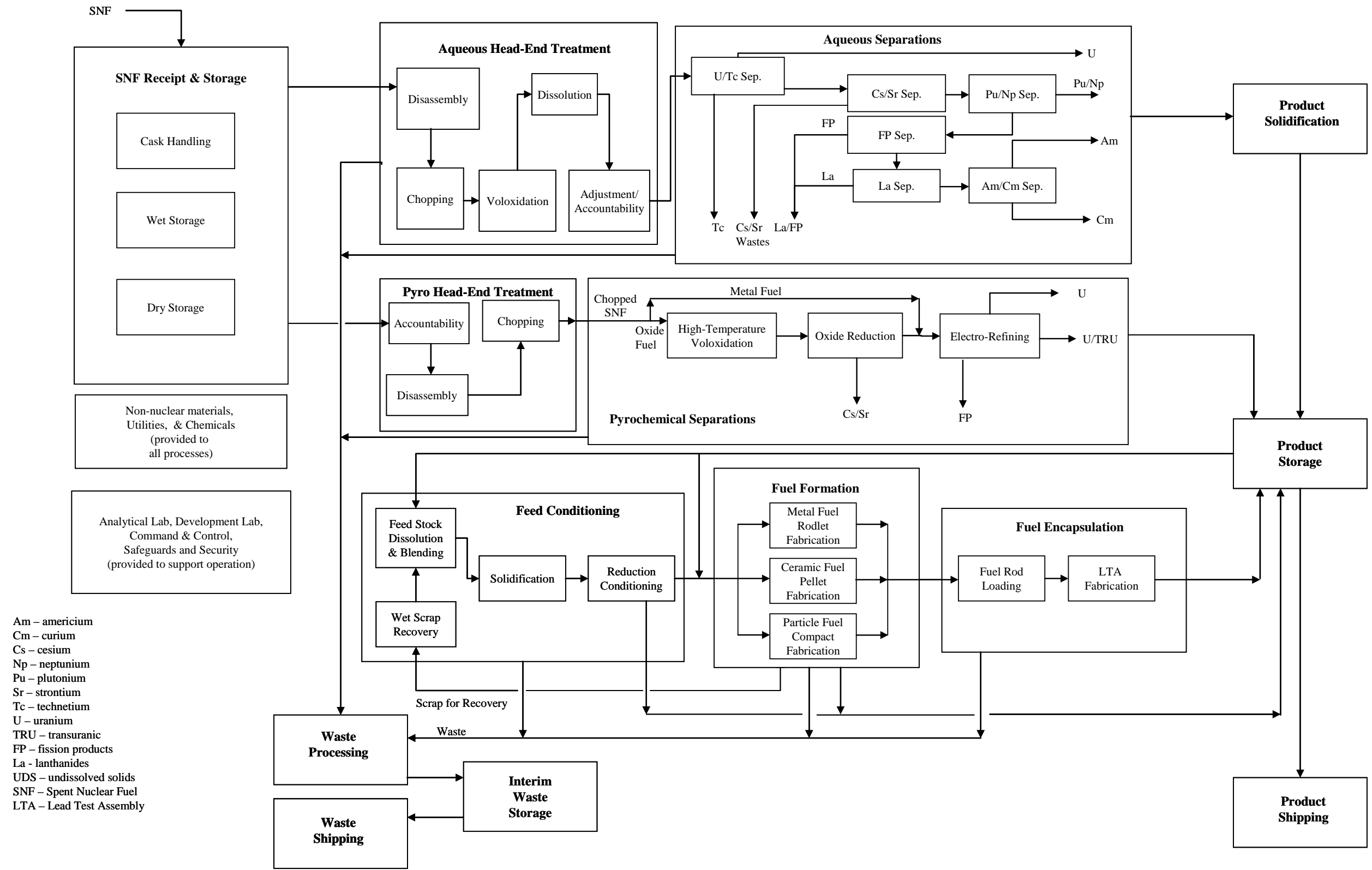


Figure 1 AFCF Block Flow Diagram

2.1 Operations Basis

The design throughput and storage requirements for the AFCF, defined in the F&OR, are summarized in Table 1. Process throughputs are calculated based on conceptual process designs that are used to develop conceptual equipment designs and layouts, which ultimately result in a conceptual design for the entire facility. The design requirements set the minimum capacity of processing equipment needed for the AFCF to perform its mission. In turn, the equipment capacity and operating conditions determine the amount of material (or the “inventory”) that can be contained in the process.

Throughput and inventory are related, but distinct, features of process design and equipment selection. The process throughput is an important parameter in determining process equipment size and capacity, reagent and utility requirements, materials handling requirements, expected annual air emissions storage requirements, transportation requirements, etc. On the other hand, the instantaneous inventory of hazardous or radioactive materials is an important parameter in analyzing the impact of accidents. Equipment sizing and materials handling requirements determine the space and layout requirements for the facility, and ultimately determine the overall facility size. All of these parameters are important in defining and analyzing the expected impacts of construction and operation of the facility.

The mass basis for spent nuclear fuel received and processed by the AFCF is the mass of initial heavy metal (i.e., actinide) content of the fuel before it is irradiated in a nuclear reactor. This is expressed as metric tons of initial heavy metal (MTIHM). Commercial spent nuclear fuel in the current inventory started as low-enriched uranium. The effect of power generation in a reactor is evaluated using nuclear software codes to determine the conversion of fuel to fission products. In addition to fission, capture of neutrons by fuel components sometimes results in transmutation of the original fuel to higher atomic weights (TRU). Finally, irradiation of the stainless steel or zircalloy metal components of a fuel assembly generates (radioactive) activation products. The fission product, actinide and activation product content of SNF depends on the initial fuel elemental and isotopic composition, the burn-up of fuel in the reactor (corresponding to power produced per unit mass of fuel) and on the in-growth of actinides and decay of radioisotopes during cooling. This information is used as the composition of the feed to the separations processes. Calculation of the bounding elemental composition of LWR and ABR SNF is presented in Appendix A-2. Activities of bounding (in terms of burnup and cooling) LWR and ABR SNF (including activation, fission product, and actinide content) that might be received at AFCF are presented in Appendix A-3 and A-4, respectively.

At this conceptual design stage, many design details have not been finalized. To accommodate design or operational changes needed to meet the design requirements defined in the F&OR, this NEPA Data Study employs construction and operations estimates based on assumed bounding values for the maximum annual throughput and the maximum storage capacity for the AFCF. The bounding values, shown in Table 1

as the “NEPA bounding” basis, are selected to provide conservative values that can be used in estimating facility size and impacts from operations and accidents.

In addition to annual throughput and storage space requirements, the NEPA process requires estimates of the inventory that could be involved in an accident. Knowledge of the operating cycles for each component in the overall process and the operation of the materials handling equipment that moves material from one component to another is required to calculate an accurate value for the instantaneous in-process inventory. At the current conceptual design stage, the materials handling equipment has not been designed. However, a bounding estimate of the in-process inventory can be made by assuming that all process equipment and tankage is completely filled with active material at the maximum concentration possible for that equipment or tank. This assumption considerably overestimates the actual amount of material in process. The operational reality is that at least half of the tankage must be empty at any given time because material is transferred from one tank through the process equipment and into another tank where it is stored pending analysis. On the other hand, this method provides the maximum inventory available within the processing area that could be involved in an accident. The calculated equipment and tankage volumes and the corresponding bounding inventory estimates are presented in Table 1.

Materials in process may be present in the vapor phase, in solution (aqueous or organic phase), as a slurry or powder, in a molten salt or metal phase, or as a bulk solid. At the present time, the AFCF has limited information regarding the dispersability or likely particle size distribution of the material in each form. Bounding values for airborne release fractions (ARFs) and respirable fractions (RFs) for a variety of release mechanisms are given in the American National Standard for Airborne Release Fractions at Non-Reactor Nuclear Facilities (ANSI/ANS-5.10-1998).

To estimate the overall facility size, preliminary equipment sizing and layout designs were developed. These layouts included provision for materials handling and facility support equipment, analytical laboratories, and storage areas in addition to process equipment. The bounding flowsheet for each of these processing areas can depend on a variety of factors, including: processing equipment required, footprint required for the processing equipment; volume, mass, or activity of products or wastes; amount of reagents used, in-process storage volumes and times required for sampling and analysis, etc.

In most cases, the process identified in this study as the “bounding” process is that process which requires more equipment, and therefore, a larger footprint. Defining the larger size as the “bounding” flowsheet means that the facility size presented in this data study is a bounding size for the facility, and the environmental impacts from construction and operation of the facility as presented in this data study bound the anticipated impacts. The alternatives considered depend on the feed source and the product form as shown in Table 2.

Table 1. AFCF Design/Operating Basis and the NEPA Bounding Basis		
Process Area	Design/Operating Basis from the High-Level F&OR	NEPA Bounding Basis
Facility Availability	<ul style="list-style-type: none"> At Least 67% (240 days/year) (2.3.1.6) 	<ul style="list-style-type: none"> 100% (365 days/year)
Aqueous Separations Annual Throughput	<ul style="list-style-type: none"> 25 MTIHM of 100 GWD/MT, 5-yr cooled LWR fuel (3.4.2.4), or 1 MTIHM of 250 GWD/MT, 1-yr cooled FR fuel (3.4.1.8 and 3.4.2.7) 	<ul style="list-style-type: none"> 75 MTIHM of 100 GWD/MT, 5-yr cooled LWR fuel, or 2 MTIHM of 250 GWD/MT, 1-yr cooled FR fuel
Aqueous Separations Instantaneous Inventory	<ul style="list-style-type: none"> Expected operating inventory ~ 5 MTIHM 	<ul style="list-style-type: none"> Total equipment/tank volume = 190 m³ (see Notes) Bounding inventory ~ 10 MTIHM
Pyrochemical Separations Annual Throughput	<ul style="list-style-type: none"> 1 MTIHM of 250 GWD/MT, 1-yr cooled FR fuel (3.4.1.8 and 3.4.2.7) 	<ul style="list-style-type: none"> 2 MTIHM of 250 GWD/MT, 1-yr cooled FR fuel
Pyrochemical Separations Instantaneous Inventory	<ul style="list-style-type: none"> Expected operating inventory ~ 0.05 MTIHM 	<ul style="list-style-type: none"> Bounding inventory ~ 0.25 MTIHM
Fuel Fabrication Annual Throughput	<ul style="list-style-type: none"> Up to 10 ABR Lead Test Assemblies (LTAs) – approximately 1 MTHM/year (2.3.2.9 and 3.7.14) 	<ul style="list-style-type: none"> About 50 ABR Lead Test Assemblies (LTAs)
Fuel Fabrication Instantaneous Inventory	<ul style="list-style-type: none"> Expected operating inventory ~ 1 MTHM 	<ul style="list-style-type: none"> Total equipment volume = 1.6 m³ Bounding inventory ~ 5 MTHM
SNF Storage	<ul style="list-style-type: none"> 40 MTIHM of LWR spent fuel (3.2.7), and 1 MTIHM of FR spent fuel (3.2.7) 	<ul style="list-style-type: none"> 75 MTIHM of LWR spent fuel, and 2 MTIHM of FR spent fuel
Product Storage	<ul style="list-style-type: none"> Interim storage for 12 months (3.4.1.9 and 3.5.2) Up to 10 years material accumulation (3.4.1.9) 	<ul style="list-style-type: none"> New (recycled) ABR fuel pellet storage – 4 MT based on 10 yr storage Separated TRU – 10 MT based on 10 yr storage Separated U – 250 MT based on 10 yr storage
LTA Storage	<ul style="list-style-type: none"> AFCF shall provide fuel assembly storage to provide space and controls for staging of fuels in preparation for shipment (3.7.17) 	<ul style="list-style-type: none"> Up to 100 ABR LTAs
Waste Storage	<ul style="list-style-type: none"> Hazardous waste - up to 6 months (2.3.2.11 A) LLW - up to 1 year (2.3.2.11 B) HLW - up to 10 years (2.3.2.11 C) GTCC (≤100 nCi/g TRU) - up to 10 years (2.3.2.11 D) GTCC (>100 nCi/g TRU) - up to 25 years (2.3.2.11 E) Cs/Sr – up to 25 years (2.3.2.11 F) 	<ul style="list-style-type: none"> On-site storage capacity for up to 10 years' production of fission products, activated metals and solidified processing wastes
<p>Notes: Items in parentheses refer to sections of the F&OR Equipment and tank volumes are based on the conceptual design and include surge and lag storage volumes for MC&A. The normal operating volume would be approximately one-half of the installed volume, or 95 m³. The bounding inventory presented in this table takes this normal operating volume into account.</p>		

Process	Feed Material Source		Product Form	
	LWR Fuel	ABR Fuel	Oxide	Metal
Aqueous Separations	Yes	Yes	Yes	No
Pyrochemical Separations	No	Yes	Yes	Yes
Fuel Fabrication	N/A	N/A	Yes	Yes

Alternative processes in each processing area (aqueous separations, pyrochemical separations, fuel fabrication) were compared to identify the largest physical size requirement. For example, aqueous separations is required by the F&OR to be capable of processing LWR fuels and ABR fuels to form an oxide product that can be used in fabrication of new ABR fuel. Thus, aqueous separations processes require consideration of two flowsheets – one for processing LWR fuel to form an oxide product and the other for processing ABR fuel to form an oxide product. The tankage dominates the space required for each of these flowsheets, and many of the tanks will serve both process flowsheets. Between the two alternative flowsheets, processing LWR fuel requires a larger footprint for the contactors. The hot cell layout for aqueous separations tanks and LWR contactors includes sufficient space for the ABR contactors to be installed simultaneously. Thus, the aqueous separations process area is sized to include all required tanks and contactors for both processes.

For pyrochemical separations, the process alternatives are for processing ABR fuel in metal and in oxide forms to produce feed for fabrication of either new ABR metal fuel or new ABR oxide fuel (pyrochemical separations is not required to process LWR fuel). The flowsheet for processing oxide fuel requires more equipment than the flowsheet for processing metal fuel, so the pyrochemical separations footprint is based on the larger (oxide) flowsheet.

In a like manner, the ceramic nitride flowsheet is physically the largest of the fuel fabrication alternatives, and this flowsheet bounds the fuel fabrication space requirements.

Although processing footprint was used as the defining characteristic for the “bounding” flowsheet, a comparison of material balances for the alternative flowsheets shows that other factors may also bound the processes. For example, comparison of flowsheet material balances for the “metal” and “oxide” flowsheets from pyrochemical separations shows that for some reagents, products and wastes, the metal flowsheet is bounding, and for others, the oxide flowsheet is bounding. In this study, the reported “bounding” mass for a given component is the greater of the masses for that component from the alternative flowsheets, regardless of the nominal “bounding” process.

2.2 AFCF Process Descriptions

2.2.1 Shipping and Receiving

Spent nuclear fuel from LWRs or ABRs will be shipped to the AFCF in NRC-approved fuel casks via truck or rail transport. These materials will enter the AFCF protected area through a security inspection station. General cask unloading activities will include rail or truck cask retrieval, receipt inspection, and preparation and removal of SNF into wet- or dry-fuel handling and storage areas. Cold process materials such as reagents, tubing, assembly hardware, and consumable supplies will be received and stored in the warehouse outside the protected area. No more than one year's throughput requirement for hazardous materials will be stored in the warehouse at any time. These types of materials will be transferred to the processing area in quantities appropriate for ensuring that the availability of cold materials never adversely impacts the process throughput, while minimizing the amount of these materials that requires storage inside the processing area.

The AFCF has the capability to ship and receive SNM to/from national laboratories when packaged in approved containers and transported via Safe Secure Transport. The AFCF also has the capability to ship LTAs in approved casks and to package and ship treated waste for disposal at approved facilities/repositories.

2.2.2 Storage

The bounding basis allows a maximum of 75 MTIHM/yr of light water reactor (LWR) fuel and a maximum of 2 MTIHM/yr of ABR fuel to be processed each year. To prevent interruption of processing and fuel fabrication operations due to SNF supply limitations, the AFCF requires storage capacity for up to one year's throughput, with both dry and wet storage capabilities provided within the facility.

The bounding requirement is for AFCF to receive up to 75 MTIHM in LWR assemblies in the first year of operation. On an existing LWR mass inventory basis, approximately two-thirds of this inventory (50 MTIHM) would be PWR fuel containing approximately 0.5 MTIHM per assembly (100 assemblies). The remainder (25 MT) would be BWR fuel with a loading of approximately 0.2 MTIHM per assembly (125 assemblies). This inventory of SNF would require approximately 225 storage locations within a fuel pool.

In addition to the LWR fuel, up to 2 MTIHM of FR fuel would be received in the first year. On a FR fuel basis of Fast Flux Test Reactor fuel, each FR assembly contains approximately 0.04 MTIHM. The FR storage requires 50 dry storage tubes. These tubes will be sized to also accept PWR and/or BWR assemblies that could be stored dry.

2.2.3 Head End Processing

Spent nuclear fuel must be mechanically handled, disassembled, and chopped prior to treatment in the aqueous or pyrochemical separations processes. Specialized treatment will be required for some future fuels. The generalized (aqueous) head end processing is illustrated in Figure 2. In the case of LWR fuel, the fuel assembly hardware will be

removed, cleaned, and packaged as wastes. The fuel rods are then chopped into pieces that are suitable for leaching. Typically, the chopped pieces will give off radioactive gases (carbon-14 as CO₂, iodine, krypton, tritium as HT or HTO) and non-radioactive decay product gases (xenon, helium). The gases are treated to remove and sequester radioactive and hazardous components from being released to the atmosphere. For LWR fuel, the disassembly and chopping is conducted in an inert (nitrogen) atmosphere.

Ceramic fast reactor fuel can be treated in a similar way as LWR fuel, as the fuel rods are similarly designed with ceramic oxide fuel charge, helium gas charge, springs and spacers. Fast reactor fuel is ordinarily cooled by liquid sodium metal; however the sodium coolant will have been removed from the exterior fuel bundle surfaces prior to the spent fast reactor fuel being sent to the AFCF. If a fuel assembly contains external, residual sodium coolant on arrival at the AFCF, the cask will not be accepted, and the fuel will be returned to the shipper.

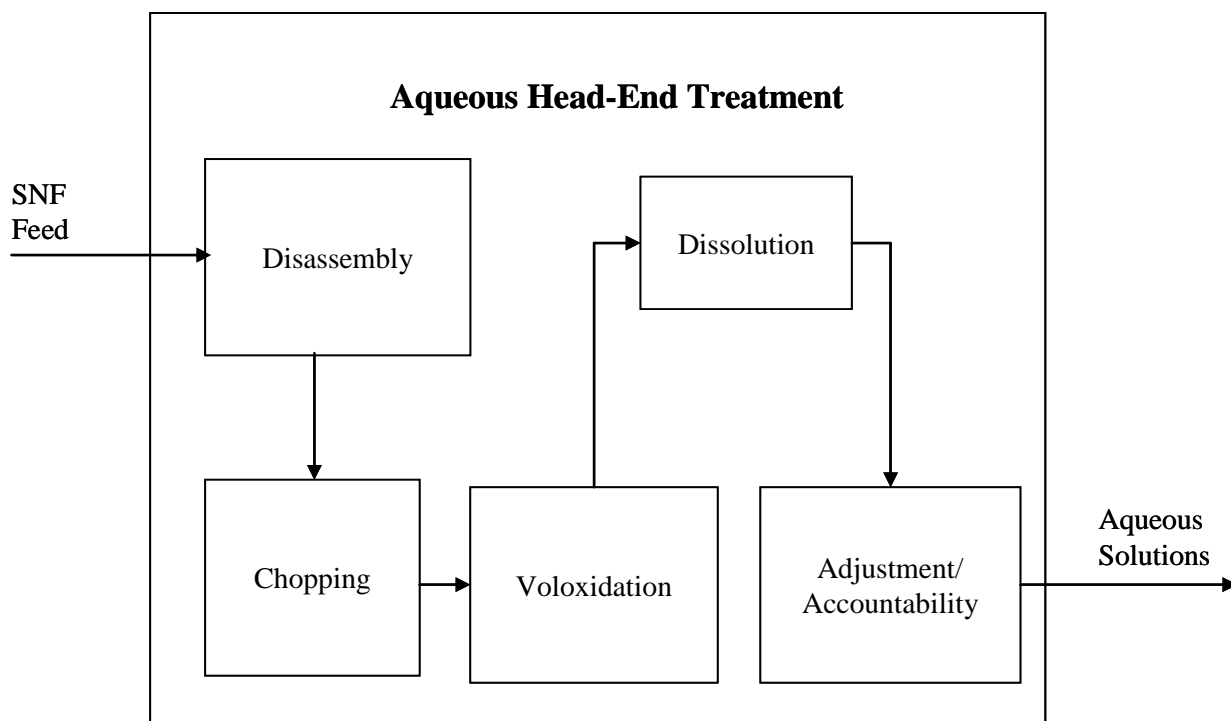


Figure 2. Schematic Block Flow Diagram for Aqueous Head End Processing

Metal fast reactor fuel to be processed in aqueous separations processes must be treated differently from ceramic LWR or ceramic fast reactor fuel. In metal fuels, sodium metal is used inside the fuel element to thermally bond the metal fuel to the cladding, thus preventing excessive temperatures in the fuel. This metal fuel with the sodium bonding must be handled in an inert atmosphere because the sodium metal reacts very rapidly with oxygen or moisture and the reaction generates significant heat. Prior to

aqueous processing, chopped metal fuel containing sodium metal is heated in a sealed pot to melt and drain the sodium metal. Residual sodium metal is reacted with a carefully controlled mixture of superheated steam and argon to form sodium hydroxide, which is charged to the aqueous separations dissolver with the chopped metal fuel. Metal fuel that is to be processed by pyrochemical separations processes does not require separation of the sodium metal.

Ceramic fuel (both LWR and fast reactor) may be processed by voloxidation³ prior to the separations processing. For aqueous processing, moderate temperature (~350°C) voloxidation in 16% ozone at atmospheric pressure converts the ceramic fuel to a powdery form more suitable for dissolution, and fission products such as tritium gas and carbon-14 are oxidized so that they can be sequestered in the head-end off-gas treatment process. The fuel cladding, or hulls, can be separated from the powdered fuel and fission products. The hulls are leached to remove all of the uranium, fission products, and actinides. Leachate solution is adjusted for proper chemistry, clarified of un-dissolved solids, and fed to the solvent extraction process. Spent SNF hulls are further washed to remove contamination. Un-dissolved solids are further leached to recover any residual uranium, fission products, or actinides. Stainless steel and zircalloy hulls are used to form a eutectic alloy for solidifying Tc wastes.

SNF for pyrochemical separations is voloxidized at ~700°C in air or oxygen to drive off fission product gases and other volatile components. After voloxidation, the fuel cladding and SNF are transferred to the pyrochemical separations cell for electrochemical processing.

2.2.4 Aqueous Separations

The simplified aqueous separations block flow diagram is shown schematically in Figure 3. In general, solvent extraction processes are used to separate fission products and other wastes materials from the actinide materials that are to be recycled into new fuel. Separations options will initially be based on the UREX+ suite of aqueous processes for existing inventories of commercial spent fuel. The initial aqueous separations demonstration will be based on the UREX+1a flowsheet, but the facility footprint and support utilities will be sized to provide capability for future demonstration of the UREX+4 flowsheet. The modifications to the flowsheet chemistry and head-end treatment systems are expected to be determined in the course of technology development for the future recycle ABR and GEN IV reactor fuels.

The individual product streams from the separations processes are concentrated via evaporation and converted to oxides via thermal/mechanical denitration. These separated oxide products are packaged for storage pending transfer to the fuel fabrication process. Fission product and irradiated metal wastes are solidified and packaged for storage and ultimate disposal. Separated Cs/Sr fission products will be solidified and packaged for on-site storage up to 25 years, followed by long-term (> 300

³ Oxidation of chopped fuel in a fixed or rotating kiln so that tritium trapped in the fuel is released into an oxidizing environment where it is converted to tritiated water. The tritiated water is separated from the off-gas and sequestered in the appropriate waste form.

years) decay storage off-site pending development of regulatory bases and disposal pathways.

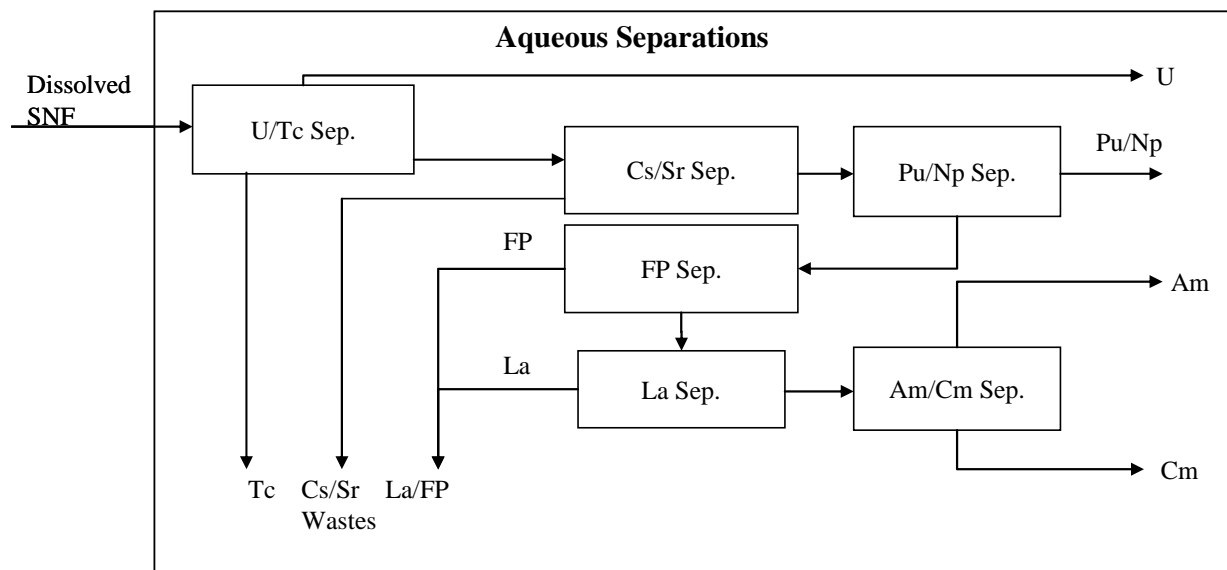


Figure 3. Schematic Block Flow Diagram for Aqueous Separations

2.2.5 Pyrochemical Separations

The pyrochemical separations block flow diagram is shown schematically in Figure 4. Pyrochemical separations can be used to process either ceramic or metal fast reactor fuel. For processing ceramic FR fuel, the chopped fuel is voloxidized at higher temperatures (~700°-1200°C) and lower pressures (~1 torr) than the fuel processed in aqueous separations in order to remove more of the volatile fission product components from the chopped fuel. The hulls are mechanically separated from the voloxidized, powdered fuel and transferred to metal waste processing.

The powdered fuel is placed in the electrochemical reduction furnace where the actinide and lanthanide elements are electrochemically reduced to metal. Cesium and strontium form chlorides that are removed from the salt via ion exchange, converted into sodalite (ceramic) waste forms, and packaged for long-term decay storage.

The separation and recovery of actinides from spent FR fuel is completed in the electrorefining step. The metal product from the electroreduction process and/or chopped metal fuel are transferred to a molten salt electrorefiner where a pure uranium metal product is collected on steel electrodes, and a combination of uranium and transuranic elements are removed from the salt using a liquid cadmium electrode. These electrodes are removed from the salt bath and purified metal products are recovered from the electrodes.

Fission products in the electrorefining step are either lanthanides (from oxide fuels) or lanthanides with Cs/Sr (from metal fuels). These fission products remain in the

electroreduction salt as chlorides. Molten salt from the electrorefiner is contacted with zeolites which act as an ion exchange medium for removing fission products from the salt. The fission-product-loaded zeolite is fed into the ceramic waste process with additional dry zeolite and glass frit for conversion to a glass-bonded sodalite (ceramic) waste form⁴. Noble metals, zirconium from the spent fuel matrix and cladding hulls from metal fuel assemblies are removed from the electrorefiner and sent, along with additional zirconium, to a vacuum melter that produces a metal waste form⁴.

Metal ABR fuel processing is essentially the same as above except that voloxidation and electroreduction are not required. In addition, Cs and Sr are not separated and ultimately end up in the same ceramic waste as the lanthanide fission products.

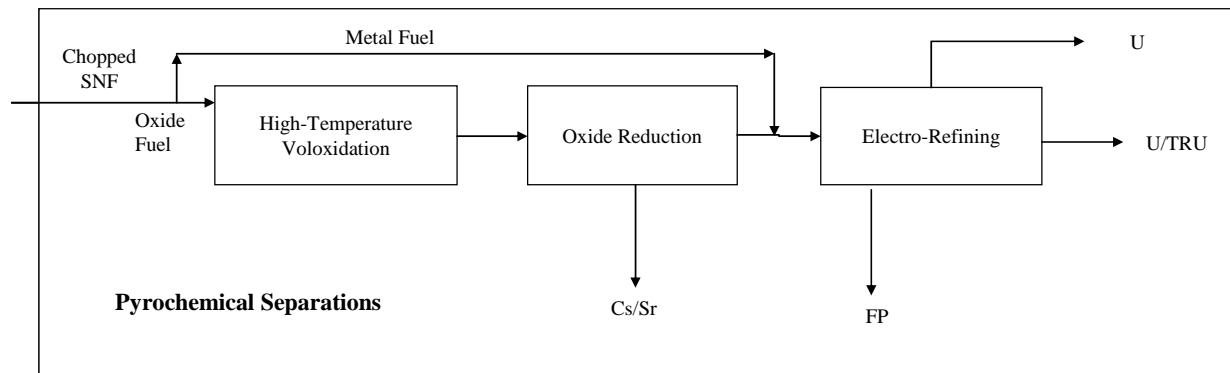


Figure 4. Schematic Block Flow Diagram for Pyrochemical Separations

2.2.6 Feed Conditioning

A variety of wet chemical processes that can be conducted in an air environment (as opposed to requiring nitrogen or argon blanketing) have been consolidated into a “fuel feed conditioning” hot cell (see Figure 5). Actinide oxide materials from the aqueous or pyrochemical separations processes or from recycle of off-specification material from the fuel fabrication process are dissolved along with depleted uranium to adjust the chemical and isotopic composition of the fuel. This material is then precipitated using oxalic acid and calcining the actinide oxalate precipitate to form actinide oxide powder suitable for use in the fuel fabrication process. Other wet chemical processes such as gel precipitation used to form particles for dispersion fuels are also located in the “conditioning” cell. The products of the conditioning cell are feedstock to the ceramic and dispersion fuel fabrication processes.

Metal fuels do not require conditioning via wet chemical processes, and any metal blending that is required is performed in the fuel casting furnace. To obtain metal feed from the oxide separations product, electrochemical reduction is required, and this reduction may be accomplished in the pyrochemical processing area and/or in a

⁴ This waste is high-level waste.

separate electrochemical reduction furnace located within the fuel fabrication process area.

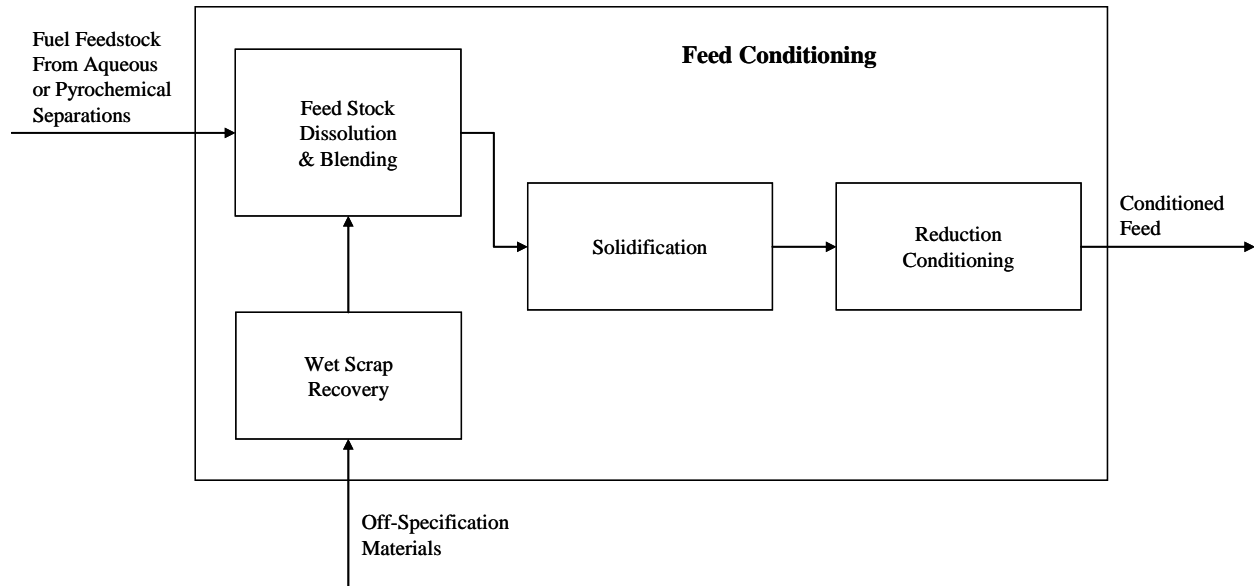


Figure 5. Schematic Block Flow Diagram for Feed Conditioning

2.2.7 Fuel Formation and Encapsulation

The AFCF fuel fabrication process is being designed to accommodate a variety of ABR fuel forms, including ceramic (oxide or nitride), metal, or dispersion fuels and sphere-pac targets. The fabrication process flow paths are shown schematically in Figure 6. The fabrication cell is designed to accommodate the largest process line (ceramic nitride fuel), and any of the fabrication processes used for making slugs, pellets, compacts, or particles required for the fabrication routes defined above.

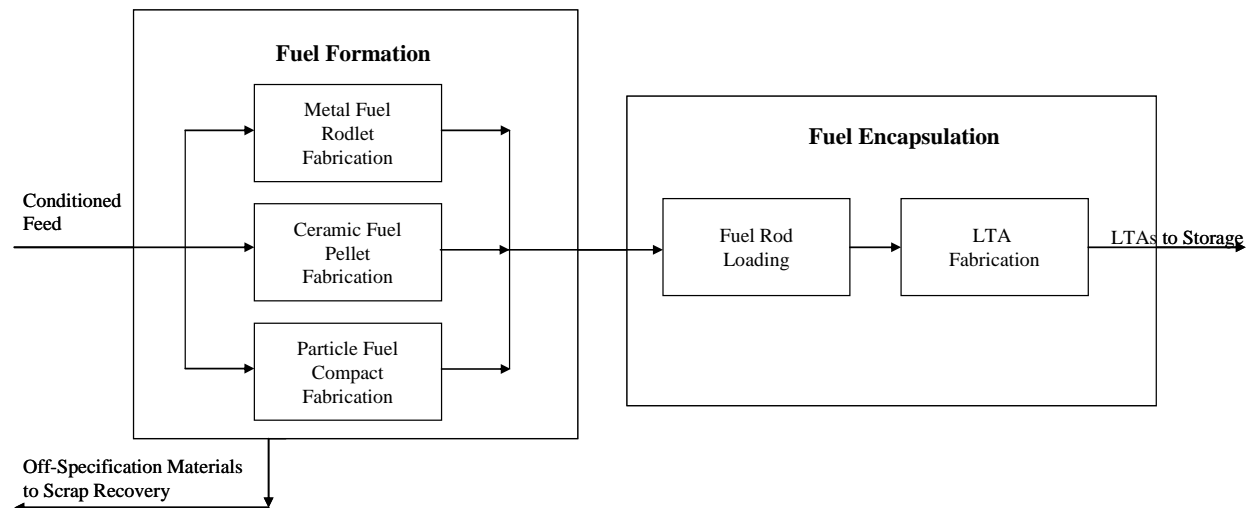


Figure 6. Schematic Block Flow Diagram for Fuel Fabrication

Feed material from the conditioning process is adjusted to the correct oxygen-to-metal stoichiometry. This material is blended with binder, lubricant, and recycled sintered materials before being pressed and granulated. The blending, pressing and granulation steps are required to achieve physical properties (grain size, particle morphology, density, etc.) necessary for forming stable compacted pellets. After pelletizing, the material is sintered at high (~1650°C) temperature in a reducing atmosphere, and the sintered pellets are ground to final size prepared for loading into fuel clads. Any required spacers, springs, or other hardware is placed in the fuel cladding, the cladding is backfilled with the appropriate atmosphere, the end cap is welded, and the welded fuel element is checked for leakage. Fuel elements that pass inspection are fitted with a wire wrap and assembled into LTAs.

Metal fuel slugs are cast from the casting furnace into molds. The slugs are removed from the molds and sheared to the proper length for loading into fuel cladding. The cladding is pre-loaded with sodium metal that is required to thermally couple the metal fuel to the cladding. When the metal slugs have been loaded into the cladding, it is externally heated to melt the sodium and the slugs are pushed into the molten sodium to form the thermal couple. Any required internal hardware is added to the fuel cladding, the cladding is backfilled with the appropriate atmosphere, the end cap is welded, and the welded fuel element is checked for leakage. Fuel elements that pass inspection are fitted with a wire wrap and assembled into LTAs.

Off-specification materials that cannot be fed back into the fuel fabrication process are transferred to the feed conditioning cell for recovery.

2.2.8 Waste Management

Waste products may be generated at every step of the AFCF process operations. Generated wastes will be managed in accordance with applicable Federal, state and local laws, regulations and requirements as well as DOE's waste management orders and pollution prevention and waste minimization policy. The AFCF processes are designed to minimize waste generation to the extent possible and to appropriately capture and treat radioactive wastes for interim storage or disposal. A variety of radioactive waste processing technologies are planned and waste disposal pathways identified as shown schematically in Figure 7.

Liquid waste streams containing radioactive materials will be solidified as part of the AFCF process, and classified according to the appropriate DOE or NRC waste regulations. The solidified waste forms would meet applicable waste acceptance criteria for the waste disposal facility prior to leaving the AFCF. The primary wastes include activated metals (primarily fuel rod cladding and fuel assembly hardware), gaseous fission products, solidified fission products, solidified processing liquids, and salts. The ultimate waste forms generated by the AFCF include high-level radioactive wastes (HLW) that require disposal in a geologic repository⁵, low-level radioactive

⁵ HLW is defined in 10 CFR 60.2

wastes (LLW) (classified as class A, B, or C)⁶ that can be disposed in shallow land burial, or “greater-than-class-C” low-level wastes⁷ for which the DOE is currently developing a disposal strategy⁸.

Hazardous and mixed wastes will be treated to destroy hazardous (organic) components and the residue from waste treatment processes will be appropriately immobilized, characterized, and packaged for interim storage or disposal in accordance with applicable regulations.

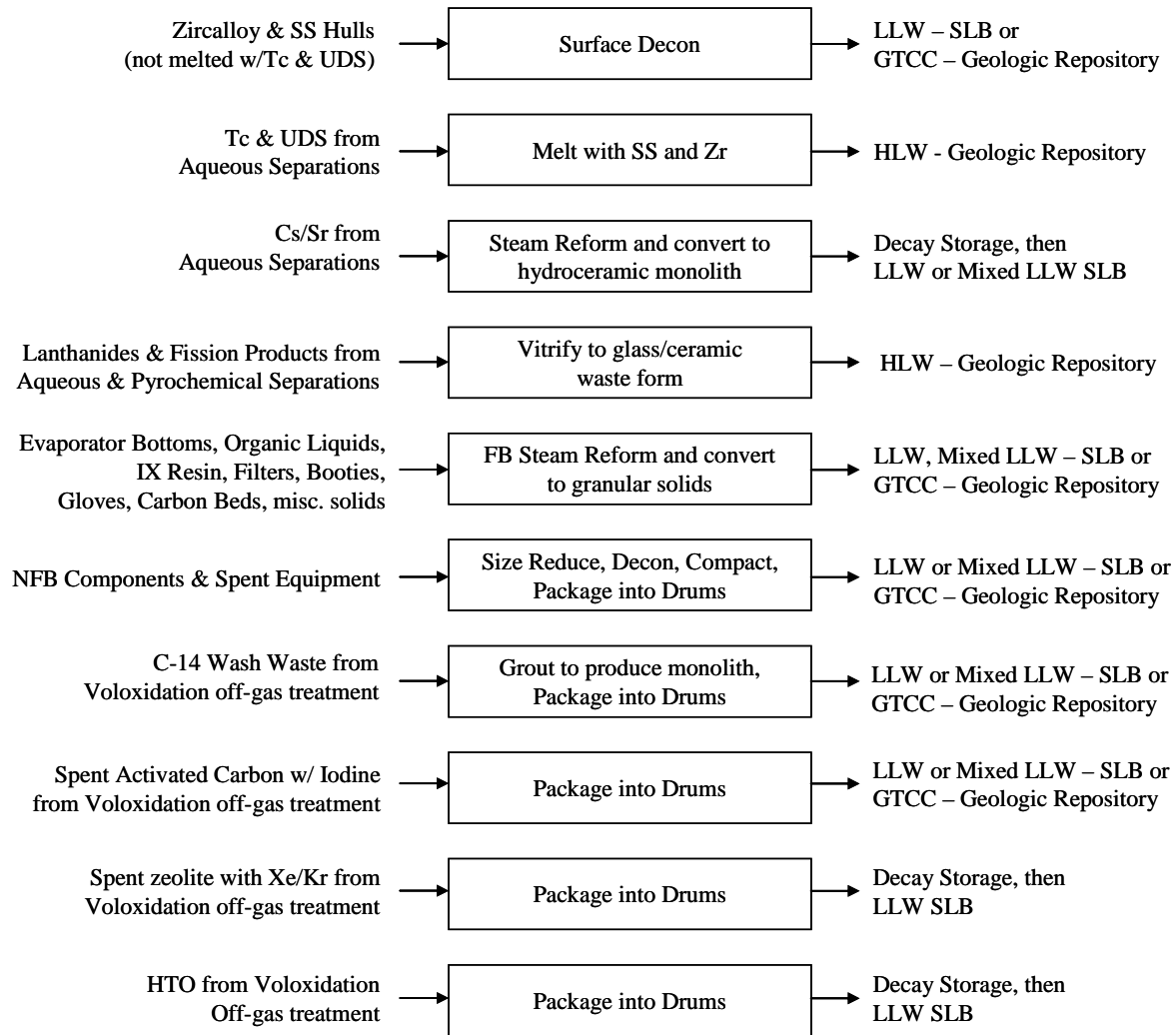


Figure 7. Schematic Block Flow Diagram for Radioactive Waste Processing

⁶ See 10 CFR 61.7(b)(2)-(b)(4)

⁷ See 10 CFR 61.7(b)(5)

⁸ Advance Notice of Intent to Prepare an Environmental Impact Statement for the Disposal of Greater-Than-Class-C Low-Level Radioactive Waste, Federal Register 70(90), May 11, 2005, pp 24775-24778.

The AFCF is designed with sufficient waste storage capacity (see Table 1) to allow for AFCF processing operations to proceed in advance of the opening of disposal pathways for HLW and GTCC wastes. Proven technologies are used as a baseline for all waste stabilization processes. No credit is taken for emerging technology improvements. The design goal of the AFCF includes consideration of waste minimization and pollution prevention to minimize facility and equipment contamination, and to make future decontamination and decommissioning as simple and inexpensive as possible.

2.2.9 Analytical Laboratory

Fully-equipped analytical laboratories are provided to enable rapid chemical, isotopic, and physical property analyses required to support process control, accountability, criticality safety, and waste management needs. In addition, the analytical laboratories will support development of new processes. Wastes from analytical laboratories will be appropriately segregated, characterized, and incorporated into recycle or waste streams within the AFCF processing plant.

2.2.10 Development Hot Cells/Bench-Scale R&D Facility

A separate hot cell facility is provided for laboratory- or bench-scale research and development activities to address problems that arise within the processing areas and to support development of new or improved fuel separations, processing, fabrication, and testing concepts. These technology development hot cells may be housed in a stand alone facility. Wastes from the development hot cells will be appropriately segregated, characterized, and incorporated into recycle or waste streams within the AFCF processing plant.

2.3 Facility Requirements

The proposed concept for the AFCF includes process buildings and support buildings as shown schematically in Figure 8. An artists' rendition of this concept is shown in Figure 9. The total site area shown within the property protection fence is 144 acres, and this area bounds the final site area.

2.3.1 Security

The majority of the process facilities of the AFCF would be located within a Perimeter Intrusion, Detection and Assessment System (PIDAS) to protect the nuclear material from diversion or sabotage. The site area within the PIDAS is expected to be approximately 62 acres. The PIDAS is a multiple-sensor system within a zone enclosed by two fences that surround the entire Security Protection Area. In addition, there would be clear zones on either side of the PIDAS. Entry control facilities at the entrance to the security protection areas would allow security personnel to inspect all vehicles and all personnel entering and leaving the AFCF. Physical security would be provided by armed guards.

2.3.2 Process Buildings

The proposed concept for the AFCF divides the plant into one or more major process buildings. The major functions of this building or group of buildings are:

- receiving and storing SNF, including head-end preparation of SNF;
- processing, recovering, purifying and storing uranium and transuranic elements;
- feed conditioning, fabricating, storing and shipping LTAs;
- processing, characterizing, storing (interim), and shipping wastes.

All of these process functions require shielding provided by hot cells and/or canyons. The proposed process areas could be separated into different buildings or contained within a single, large building. The process buildings would generally be multi-storied, reinforced concrete structures, with hot cell facilities below grade and equipment handling above grade. The process buildings would be hardened to provide safeguards. Containment, confinement, shielding and criticality control measures are integrated into the facility design and layout to provide multiple barriers to ensure personnel protection and environmental protection from exposure to radioactive and hazardous substances.

The floor area for the shielded processing area is estimated to be on the order of 90,000 ft² (including shielded areas in the byproduct solidification/waste storage building but not the shielded area in the bench-scale R&D building). The shielded processing area would be contained in processing buildings having a total footprint area of approximately 515,000 ft². The additional footprint provides space for processing area support functions including mechanical, electrical, and process control equipment; analytical laboratory spaces; cold storage; and access corridors. In the current concept, the shielded areas are placed below grade (to depths approaching 50 feet), and the overhead cranes and other support equipment required for unloading and moving shipping casks and processing equipment extend to heights up to 70 feet above grade. For the purpose of bounding the processing building footprint, this report assumes a total processing building area of 545,000 ft² and a total support building area of 375,000 ft². Construction estimates (concrete, aggregate, water, structural steel, etc.) presented in this report are based on this assumed footprint.

2.3.3 Support Buildings Within PIDAS

The major support buildings and structures that would be located within the PIDAS include a bench-scale R&D facility, several utility/mechanical buildings, a process gas storage area, storage areas for rail- or trailer-mounted shipping casks, and one or more exhaust stacks. These buildings comprise an estimated total footprint less than 275,000 ft².

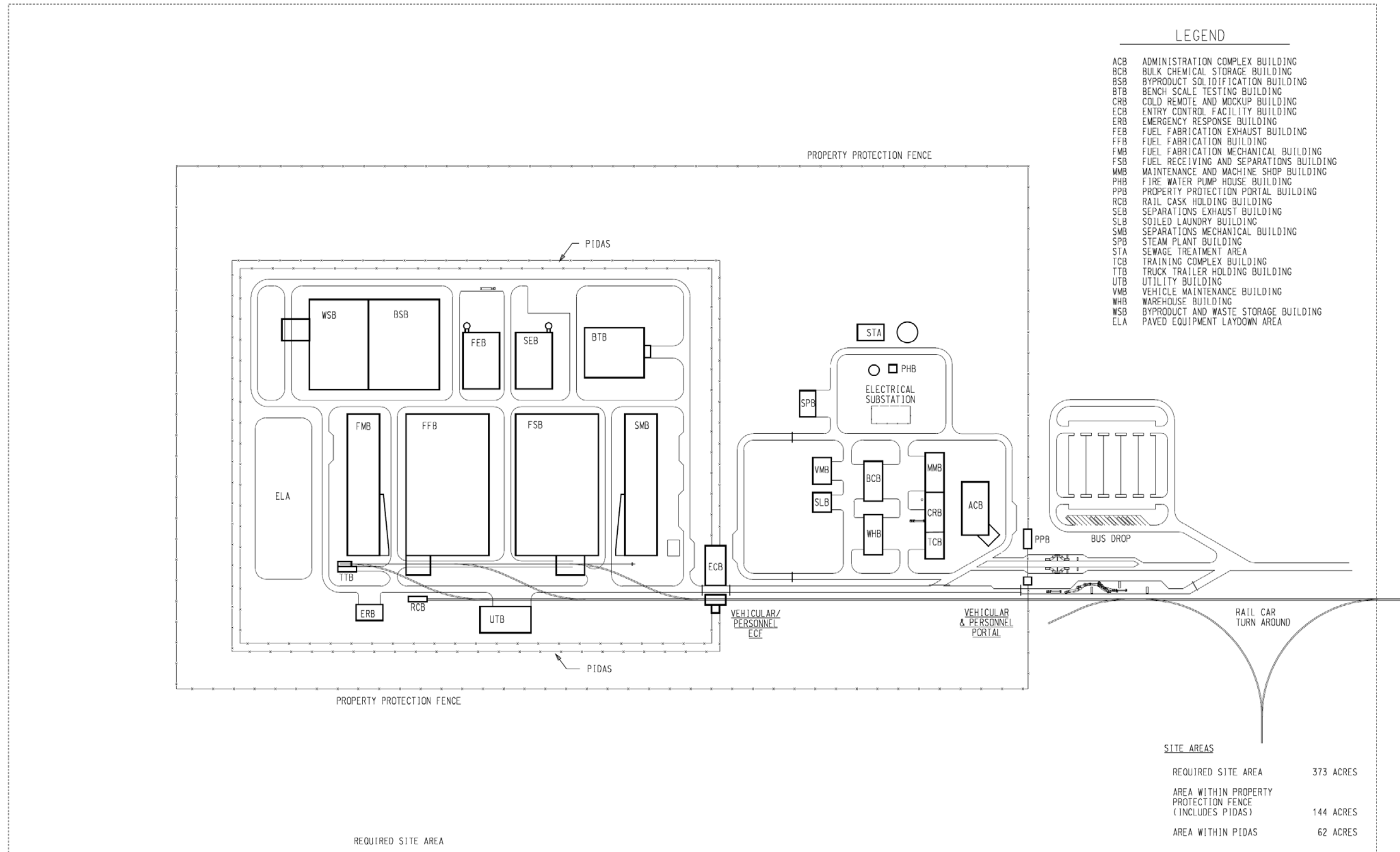


Figure 8. Conceptual AFCF Facility Layout

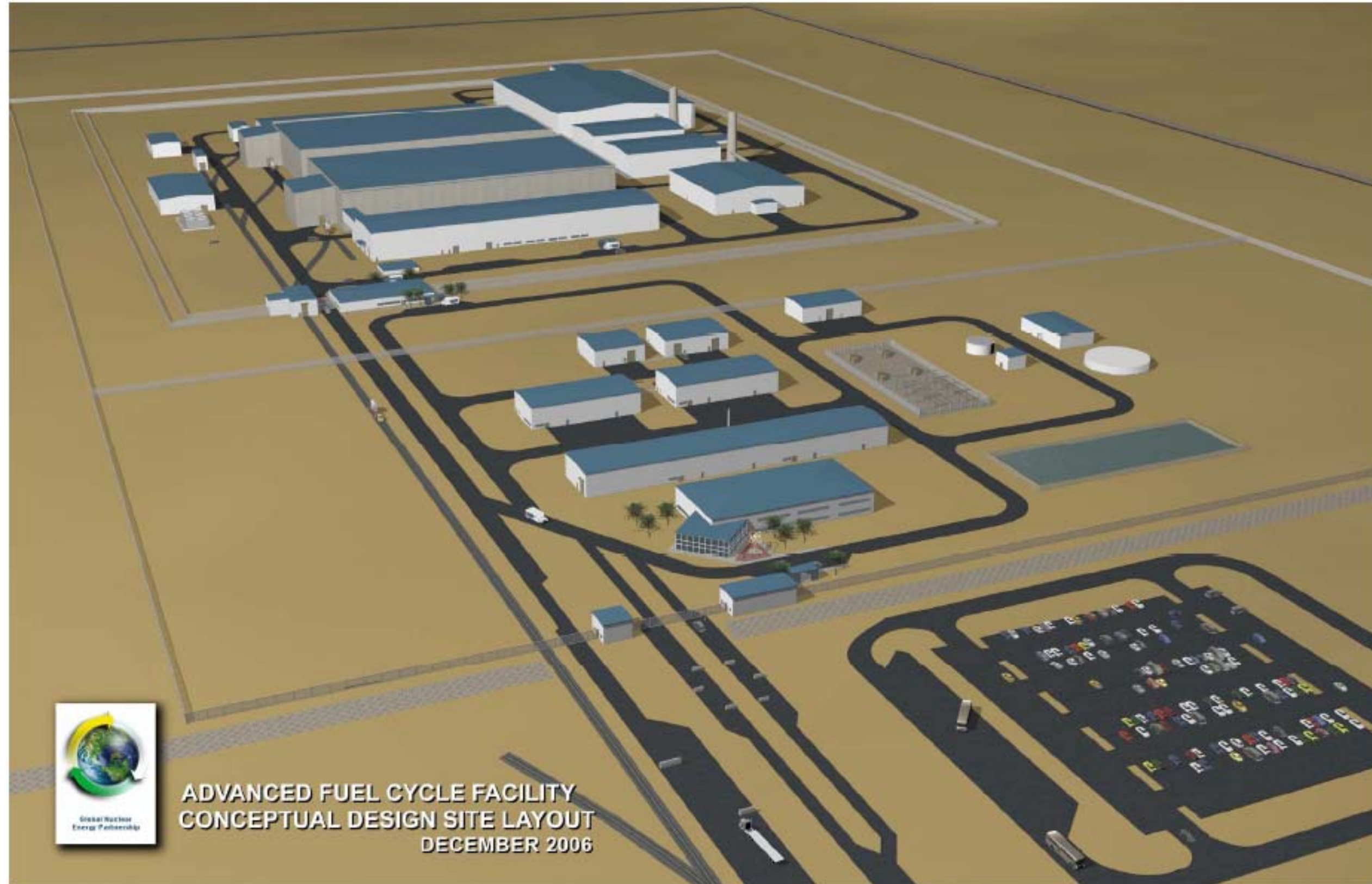


Figure 9. Artist's Rendering of the AFCF Facility

2.3.4 Support Buildings Outside PIDAS

Support buildings and structures that would be located outside the PIDAS include a temporary Concrete Batch Plant (approximately 6 acres) and a temporary Construction Laydown Area (approximately 16 acres) that would be required during the construction phase. Permanent structures include a maintenance/machine shop, a cold assembly and test laboratory, a mock-up and training building, an administration building, a bulk chemical storage building, a warehouse, a laundry, an emergency response/fire facility, personnel access points, a sewage treatment facility, an electrical substation, a storm water detention area, and a parking area. The total footprint of support structures outside the PIDAS is estimated to be less than 100,000 ft².

Support buildings such as the laundry, steam plant and sewage treatment plants have solid and/or liquid effluents. The laundry effluent could include radioactive or hazardous constituents, and therefore, the effluent from this facility will be transferred into the water treatment plant within the waste solidification and storage building. Effluents from the steam plant and the sewage treatment plant are not expected to contain hazardous or radioactive materials, and therefore, these effluents will be appropriately tested, treated, and discharged to outfalls or to permitted commercial solid waste disposal facilities.

2.3.5 Construction Estimates

The construction of this facility is estimated to occur over a four year period. Construction materials, utilities and wastes are summarized in Tables 3 and 30. The construction materials are estimated based on an estimated AFCF processing area footprint of 545,000 ft² and a total support building footprint of 332,000 ft². Fuel consumption during construction is based on estimates of the machinery and operating requirements for excavation of the processing building areas and do not include other site preparation (e.g., grading). For the purpose of estimating the air quality impacts of construction, it should be assumed that the entire site area of 144 acres will be disturbed by grading and other site preparation activities. Estimates of these impacts are not included in Table 3 because of the heavy dependence of these estimates on the actual site topography and vegetation. Site-specific grading and preparation impacts should be added to the excavation impacts presented in Table 3 as they become available. Water requirements include water for dust suppression, for making concrete, and for equipment washdown. Aggregate includes both aggregate in concrete and aggregate distributed on the site (e.g., road base). Structural steel includes reinforcing steel embedded in concrete in addition to all other structural steel required.

2.3.6 Operations Materials and Wastes

During normal operations, the AFCF will process SNF to produce actinide products, new reactor fuel, and radioactive wastes. Bounding annual and equivalent daily throughputs of these materials, shown in Table 4, are based on the conceptual process flowsheets that are currently under development. Estimates of bulk rates are based on anticipated allowable loadings of radioactive materials derived from expected criticality limits, waste loading to meet disposal site acceptance criteria, etc.

Table 3. Construction Requirements for the AFCF

Basis: The construction period for the AFCF is estimated to be 4 years.

Materials/Resources	
Electrical Energy (MWh)	200,000
Peak Electricity (MWe)	6
Concrete (yd ³)	
Total	278,000
Peak Yearly	111,000
Aggregate (yd ³)	
Total	586,000
Peak Yearly	219,000
Structural Steel (tons)	
Total	357,000
Peak Yearly	143,000
Liquid Fuels (gallons)	
Total	2,350,000
Peak Yearly	950,000
Water (gallons)	
Total	35,000,000
Peak Yearly	13,350,000
Gases (cubic meters)	
Total	20,000
Peak Yearly	6,000
Employment	
Total (Worker Years)	6,750
Peak (Workers)	2,250

Radioactive wastes from operations will generally fall into two categories: High Level Radioactive Wastes (HLW) that result from reprocessing spent nuclear fuel⁹, and Low Level Radioactive Wastes (LLW) that are all other radioactive wastes. LLW is further categorized¹⁰ as Class A, Class B, or Class C. Radioactive wastes that contain isotopes with a half-life greater than 20 years or activities greater than 100 nCi/g (10⁻⁷ Ci/g) are classified as “Greater-Than-Class-C” (GTCC) low level radioactive waste¹¹. When wastes contain both hazardous (i.e., chemical) and radioactive constituents, those wastes are termed “mixed” wastes.

Most of the radioactive wastes generated in the AFCF would be classified as HLW. However, some of these wastes may be disposed as LLW because of their low activities and/or short half-lives of the radioactive species. Estimates of radioactive wastes

⁹ HLW is defined in 10 CFR 60.2

¹⁰ See 10 CFR 61.7(b)(2)-(b)(4)

¹¹ See 10 CFR 61.7(b)(5)

Table 4. Estimates of SNF Processing Materials and Wastes from Operations			
Feed/Product/Waste	Steady-State Daily Rate	NEPA Bounding Annual Rate	Annual Bulk Container Rate
Aqueous Separations (75 MTIHM LWR/2 MTIHM ABR Blended over 365-days for daily rate)			
LWR Fuel	250 kg IHM	75 MTIHM	150 LWR assemblies
ABR Fuel	5.5 kg IHM	2 MTIHM	150 ABR assemblies
UO ₃ powder	264 kg	79 MT	345 ea 35-gal drums
Tc metal	0.52 kg	156 kg	Included in hulls waste
Pu/Np oxide powder	5.0 kg	1.5 MT	300 cans
Am oxide powder	0.6 kg	169 kg	365 cans (1/day)
Cm oxide powder	0.2 kg	49.5 kg	365 cans (1/day)
UDS	3 kg	875 kg	Included in hulls waste
Hulls	80 kg	22.5 MT	18 HLW-style canisters (includes UDS & Tc)
Cs/Sr hydroceramic waste form	50 kg	14 MT	177 cans (3-in ID x 10-ft long monolith)
FP/Lanthanide vitrified waste form	75 kg	22 MT	12 HLW-style canisters
Inert Fuel Pieces	35 kg	10.5 MT	6 HLW-style canisters
Spent Filters	n/a	65 kg	1 SWB
Spent Equipment	n/a	1 MT	10 SWBs
C-14 waste	1.2 kg	332 kg	2 ea 55-gal drum
Ag/Carbon/Iodine waste	23 kg	6.5 MT	23 ea 55-gal drums
HTO liquid	0.15 kg	43 g	1 ea 55-gal drum
Pyrochemical Separation (Ceramic ABR fuel, 2 MTIHM over 365-days for daily rate)			
ABR Fuel	7 kg IHM	2 MTIHM	150 ABR assemblies
U metal	1 kg	0.31 MT	2 ea 35 gal drums
Pu/Np/Am/Cm/U Metal	4 kg	1.2 MT	342 cans
Cs/Sr ceramic waste form	1.5 kg	0.4 MT	1 HLW-style canister
FP ceramic waste form	15 kg	4.5 MT	3 HLW-style canisters
Metal waste form	25 kg	7.1 MT	5 HLW-style canisters
Inert assembly pieces	20 kg	6.02 MT	6 HLW-style canisters
Volatile FP wastes	1.5 kg	0.41 MT	TBD
HEPA Filters	0.4 kg	0.12 MT	1 SWB (after compaction)
Fuel Fabrication (Ceramic ABR fuel, 2 MTHM over 365-days for daily rate)			
Pu/Np/Am/Cm oxide powder feedstock	4 kg	1.14 MT	225 cans
UO ₃ powder feedstock	4.1 kg	1.20 MT	6 ea 35 gal drums
ABR assemblies	7 kg	2 MTHM	50 ABR LTAs

generated are based on the mass balance calculations performed on the process flows. These materials are tentatively classified as HLW, LLW, or GTCC waste based on the expected half-lives or curie contents and using Figure 7 as a guide. The results are presented in Tables 14 (Aqueous Separations), 20 (Pyrochemical Separations), and 25 (Fuel Fabrication).

Mixed (hazardous and radioactive) wastes containing organic solvents as the hazardous components would be treated to remove the hazardous component. Such treatment would require a RCRA part B permit to ensure that the hazardous components are delisted. Storage of radioactive wastes would be designed to accommodate shielding, security, heat dissipation, inventory, storage duration, inspection, and other requirements. Packaging of radioactive wastes will be in accordance with applicable DOE/NRC/DOT regulations.

Radioactive wastes from support buildings such as the analytical laboratory, the bench-scale R&D facility, the waste treatment & storage facility, and the laundry would be treated within the waste solidification and storage building. Wastes from the machine and maintenance shops would be the same as wastes from similar commercial facilities, and these wastes would be handled in a manner equivalent to these commercial facilities. Sanitary wastes (Table 5) will be processed in the sewage treatment plant. Liquid effluents from the sewage treatment plant could be used on site for landscape watering, and any excess liquids would be discharged to an outfall or evaporation pond. Treated solids would be disposed off-site in an appropriate disposal facility. Other non-hazardous wastes generated at the site include office and cafeteria wastes which will be disposed of in commercial landfills.

Table 5. Estimates of Non-Hazardous Wastes from Operations			
Waste	Steady-State Daily Rate	Bounding Annual Rate	Bounding Annual Bulk Rate
Sanitary Waste	333,000 liters	97,000,000 liters	
Other non-Hazardous Waste (office and cafeteria compacted wastes)	9.6 m ³	2810 m ³	115,000 tons

	Steady-State Daily Value	Bounding Annual Value
Electrical Consumption (MWh)	1000	290,000
Peak Electrical (MWe)	45	
Diesel Fuel (liters)	600	115,000
Argon (m ³)	200	70,000
Domestic Water (liters)	252,000	92,000,000
Cooling Tower Make-up (liters)	927,000	340,000,000
Steam (kg)	3,600,000	467,280,000
Fuel Consumption for Process and HVAC Steam Applications:		
Steam Heating Requirements (million BTU)	1,680 (70MM BTU/hr)	265,500
Natural Gas-Fired Boilers (cuft), or	850,000	260,000,000
Coal-Fired Boilers (lb), or	62,500	19,000,000
Fuel Oil-Fired Boilers (barrels)	150,000	45,600,000
Total Number of Workers (FTEs)		1330
Total Number of RAD Workers (FTEs)		855
Average Annual Dose to Workers (mrem)		<20
Maximum Annual Worker Dose (mrem)		500

3. Nuclear Materials, Products, Wastes, Effluents, Emissions, Reagents and Utilities for Operations and Construction

The previous section of this NEPA Data Study presented summary information about the operations and construction impacts of the AFCF. This section provides more detail about the materials, utilities, products and byproducts of or for construction and operation of the AFCF. Information about the entire facility is presented first, followed by information specific to the major processing areas.

Table 7 shows the types and amounts of nuclear materials processed in one year by various AFCF processes based on the NEPA bounding throughput. For the aqueous separations products and wastes, the material balance on the flowsheet for processing LWR fuel was compared with the material balance on the flowsheet for processing ABR fuel for each individual product or waste, and the larger value was chosen as the entry in this table. For pyrochemical separations, the material balance on the flowsheet for processing ABR metal was compared with the material balance on the flowsheet for ABR oxide, and again, the larger value was chosen as the bounding value for this table.

Nuclear Materials	Source	Inventory or Annual Production
LWR Spent Nuclear Fuel	Transport	225 Assemblies in wet or dry storage 75 MTIHM
Fast Reactor (ABR) Spent Nuclear Fuel	GNEP Transport	50 Assemblies in dry storage 2 MTIHM
Fast Reactor LTAs fabricated by AFCF	Metal or Ceramic Fuel Fabrication	50 LTAs or targets, 2 MTHM
UO ₃ powder	Aqueous Separation	79 MT
Tc metal	Aqueous Separation	156 kg
U metal	Pyrochemical Separation	0.31 MT
TRU Feed-Stock oxide powder	GNEP Transport	1 MT
TRU oxide powder (Np, Pu, Am, Cm)	Aqueous Separation	1.7 MT
TRU/U Metal	Pyrochemical Separation	1.2 MT
Cs/Sr Cermet Waste	Aqueous Separation	14 MT
Cs/Sr Ceramic Waste	Pyrochemical Separation	0.4 MT
FP Vitrified Waste	Aqueous Separation	21.1 MT
FP Ceramic Waste	Pyrochemical Separation	4.5 MT
UDS	Aqueous Separation	875 kg
Hulls	Aqueous Separation	22.5 MT
Assembly and Metals Waste	Pyrochemical Separation	13.1 MT
Radioactive Air Emissions	All Processing Areas	None

There are no liquid effluents from processing operations (Table 8). Aqueous solutions from aqueous processing, scrap recovery and feed conditioning are evaporated and the evaporator bottoms are sent to a steam reforming process for production of a solid waste form. The evaporator overhead is condensed, purified and recycled into the process. Organic solvents are purified and recycled into the process or are destroyed in the steam reformer.

Effluent	Source	Flow Rate (liters/year)
Process liquid wastes	Cleaning, D&D of process equipment, laundry effluent, etc.	1,885,000 liters/year recycled internally in the AFCF. No net discharge of process liquid wastes

There are not expected to be radioactive air emissions from the AFCF. Each process involving radioactive materials is designed so that any radioactive gases or particulates are captured and retained by the appropriate absorption, adsorption, filtration or other

technology. Vessel off-gases are processed or HEPA filtered as close to the vessel as possible. In addition, all filtered vessel off-gases are collected and further treated to ensure that there are no radioactive air emissions.

Approximately 96% of the AFCF emissions of criteria air pollutants from operations (Table 9) are from fossil-fuel fired boilers used for generating steam for space and process heating. The remainder is from diesel exhaust from diesel tractors and trackmobiles for moving and spotting cask cars and trailers, emergency power and backup fire suppression system generators. The Criteria Air Pollutant standards for fossil fuel fired boilers less than 100 million BTU/hour maximum heat input are found in 40CFR60 Subpart Dc (Note: these standards are currently under revision¹², but the proposed revisions do not affect the limiting values for the Criteria Air Pollutant emissions). 40CFR60.42c sets maximum emissions for sulfur dioxide (SO₂) for coal-fired and oil-fired boilers. SO₂ emissions from coal combustion are limited to 1.2 lb SO₂/million BTU heat input. 40CFR60.43 sets the maximum emissions for particulate matter (PM) at 0.1 lb PM/million BTU heat input (coal- and oil-fired boilers) and for opacity of the emissions (<20% for each 6 minute period). 40CFR60 Subpart Dc does not set standards for nitrogen oxides, ozone, volatile organic compounds (VOCs), carbon monoxide, or lead.

Coal-fired boiler emissions estimates (Table 9) are based on emission factors¹³ for bituminous and sub-bituminous coal with 1% sulfur and 8% ash. The sulfur oxides, nitrogen oxides and particulate matter are assumed to be removed with 90% efficiency by stack gas treatment systems. Daily values are calculated from the maximum space and process heating requirements based on a 100 degree day maximum heating requirement for space heating. The annual space heating requirement is adjusted for the heating degree days in Idaho Falls, ID (~7350), which bounds all likely AFCF sites. Process heating requirements are taken to be independent of ambient temperatures.

Emissions	Diesel Engines		Coal-Fired Boilers	
	Daily Emission (kg)	Annual Emission (MT)	Daily Emission (kg)	Annual Emission (MT)
Carbon Monoxide	28	10	80	13
Lead	0	0		
Nitrogen Oxide	35	12	190	30
Particulate Matter	0.4	0.2	2,880	470
Ozone	0	0		
Sulfur Oxides	0.01	0.03	600	100
Volatile Organic Compounds	0.01	0.04		

¹² see Proposed Rule 72 FR 6319, 02/09/2007 and Notice 72 FR 9903, 03/06/2007 for New Source Performance Standards for Boilers (<http://www.epa.gov/ttn/atw/combust/boiler/boilnsp.html>)

¹³ *Compilation of Air Pollutant Emission Factors*, US EPA report AP-42, Fifth Edition, January 1995, <http://www.epa.gov/ttn/chief/ap42/ch01/index.html>

Diesel generator estimates are assumed to meet the year 2015 Tier 4 emission standards¹⁴. Emergency generator capacity is estimated to be 35 MW, and includes 76 hours per year of operation (primarily surveillance testing and maintenance). On-site movement of casks and wastes is estimated to require 8 hours operation of a diesel-powered vehicle per shipment. The bounding number of spent fuel receipts (both truck and rail) from Table 27 was added to the bounding number of new fuel shipments from Table 28 and to the bounding number of LLW, GTCC and HLW shipments¹⁵ from Table 29. The result is 570 total shipments per year, giving a total of 4560 operating hours per year for on-site diesel-powered vehicles. Diesel is treated as a process utility.

AFCF utility requirements summarized in Table 10 include makeup water and gases for process operations, electricity, natural gas, coal or fuel oil for generating heating and process steam, and diesel for emergency power and on-site transport applications. Diesel emissions from generators and on-site transportation applications are already included in Table 9. Water consumption for process steam, process water, cold and hot water utilities, and potable water are calculated on a once-through basis. This assumption is probably correct for the potable water and cooling water uses, but they overestimate the other consumption because of recycle. Process water losses will be primarily from blowdown of process equipment and losses through the off-gas system.

Utility	Daily Usage	Bounding Annual Rate
Process & Space Heating Steam (kg)	1,536,263	467,280,000
Cold Water Supply (liters)	1,803,300	658,200,000
Hot Water Supply (liters)	12,240	4,467,604
Deionized Water (makeup)	10,000	2,525,000
Process Water (liters)	18,600	6,785,000
Potable Water (liters)	1,106,000	403,620,000
Make-up Process Water (liters)	40,000	12,000,000
Argon Make-up (liters)	240,000	70,000,000
Nitrogen Make-up (liters)	2,550	745,000
Carbon Dioxide Make-up (liters)	58,000	16,708,000
Plant Air (liters)	3,500,000	1,020,000,000
Hydrogen Make-up (liters)	1,200	350,000
Fuel Consumption for Process and HVAC Steam Applications:		
Natural Gas-Fired Boilers (cuft), or	850,000	260,000,000
Coal-Fired Boilers (lb), or	62,500	19,000,000
Fuel Oil-Fired Boilers (barrels)	150,000	45,600,000
Diesel (generators & on-site transport vehicles) (liters)	600	115,000

¹⁴ <http://www.dieselnet.com/standards/us/offroad.html#tier4>

¹⁵ Note: the bounding number of waste shipments per year assumes that HLW and GTCC wastes are accumulated for ten years pending opening of geologic disposal facilities, and that the accumulated wastes are shipped off-site within two years.

3.1 Aqueous Separations

Estimates of reagents, products and wastes for aqueous separations processes are based on two conceptual flowsheets, one for processing LWR fuels and one for processing ABR fuels. These flowsheets include conceptual designs based on separations processes required to remove fission products from the spent fuel and to separate and recover actinides (U, Np, Pu, Am, and Cm). Depending on the specific separations process used, the separations could result in a separate stream for each actinide or in combined streams where two or more elements are separated together (e.g., Pu/Np and Am/Cm).

Reagents used in aqueous separations processes and the annual consumption of these reagents are shown in Table 11. Some of these reagents (e.g., nitric acid) are recovered and recycled, and therefore some entries in Table 11 are overestimates.

Reagent	Annual Usage
Nitric Acid	5,900,000 liters
Hydrofluoric Acid	3,650 liters
Sodium Carbonate	2,560,000 liters
Aluminum Carbonate	938,000 liters
Sodium Hydroxide	11 liters
Guanidine Carbonate/ DTPA	703,000 liters
Metakaolin	7.75 MT
Nitric Acid/ Oxalic Acid	200,420 liters
AHA	375,000 liters
Hydrated Lime	302 liters
Lactic Acid/DTPA	1,252,000 liters
Ferrous Sulfamate	2,630 liters
Steam Reformer Additives	97 MT
TBP	1,350,000 liters
CCD	7,300 liters
PEG	1,530 liters
n-dodecane	7,065,000 liters
dibutyl ketone	1,536,600 liters
CMPO	42,230 liters
HDEHP	197,000 liters
SANDEX	301,000 liters
phenyltrifluoro-methylsulfone	355,600 liters

Utilities required for aqueous separations processes and estimated annual consumption of these utilities are shown in Table 12. Steam requirements are for heating process vessels. Electrical power includes electrical heating applications as well as motors for pumps, contactors, etc.

Utility	Annual Usage
Process Steam	13,275,000 lbs/yr
Power	46 GW-hr
DI Water	680,000 lit/yr
Process Water	60,000 lit/yr

Table 13 presents the calculated activities of aqueous separations products based on calculated isotope distributions. These activities can be used in calculating dose rates for separated products.

Element/Isotope	Daily Rate		Annual Rate	
	g/day	Ci/day	kg/yr	Ci/yr
UO₃ Powder Product				
U	178,200		65,043	
Tc	427		156	
U234		1.1		385.6
U236		0.2		84.6
U237		1.1		384.8
U238		0.06		21.5
Tc99		7.3		2,665
Tc metal				
Tc	431.1		157.3	
Tc99		7.4		2692.8
Pu/Np oxide powder				
Np	413		150.9	
Pu	3280		1196.5	
Np237		0.3		113.5
Np238		0.04		14.5
Np239		0.3		10666.1
Pu236		0.2		55.9
Pu238		4330.1		1580497.9
Pu239		110.2		40233.5
Pu240		166.9		60932.1
Pu241		44859.3		16373656.6
Pu242		1.6		566.7
Am oxide powder				
Am	152.2		55.6	
Am241		1168.7		426565.5
Am242m		6.1		2217.3
Am242		6.0		2207.4
Am243		20.1		7321.5

Element/Isotope	Daily Rate		Annual Rate	
	g/day	Ci/day	kg/yr	Ci/yr
Cm oxide powder				
Cm	120.0		43.8	
Cm242		63.0		23000.1
Cm243		36.6		13363.4
Cm244		7603.8		2775391.5
Cm245		284.8		103947.6
Cm246		4.6		1674.2

Table 14 identifies the wastes generated by the aqueous separations processes as well as estimates of the amounts of wastes generated.

Source	Annual Mass	Comments
Metal Wastes	11.8 MT	UDS, Hulls, Tc, Assembly wastes, 1.5 m ³ /yr
Grouted Wastes	200 kg	0.1 m ³ /yr as 3" dia by 12" long cylinders
NaCl/Fe	42 kg	From head-end processing to remove sodium metal from assemblies < 0.1 m ³ /yr
Cs/Sr hydroceramic waste form	14 MT	3 m ³ /yr as 3" dia by 10 ft long cylinders
Lanthanide FP Vitrified waste form	21.1 MT	54 m ³ /yr as 3" dia by 10 ft long cylinders

Table 15 presents the calculated activities of aqueous separations wastes based on calculated isotope distributions. These activities can be used in calculating dose rates for aqueous separations wastes.

Element/Isotope	Daily Rate		Annual Rate	
	g/day	Ci/day	kg/yr	Ci/yr
Undissolved Solids				
Sr	6.5		2.4	
Y	4.0		1.5	
Ru	18		6.6	
Rh	2.5		0.9	
Te	3.2		1.2	
Cs	19.6		7.1	
Ba	12.8		4.7	
Ce	16.8		6.1	

Table 15. Curie Analysis for Aqueous Separations Wastes

Element/Isotope	Daily Rate		Annual Rate	
	g/day	Ci/day	kg/yr	Ci/yr
Pr	8.7		3.2	
Sm	5.5		2.0	
Pu	36.9		13.5	
Am	2.5		0.9	
Sr90		523		190,849
Y90		563		205,591
Ru106		91		33,081
Rh106		90		32,956
Te125m		2.8		1,017
Cs134		278		101,648
Cs137		631		230,150
Ba137m		593		216,386
Ce144		42		15,452
Pr144		47		17,024
Pr144m		0.7		238
Pm147		158		57,817
Sm151		2.8		1,016
Eu154		45		16,405
Eu155		12		4,307
Pu238		49		17,771
Pu241		504		184,101
Am241		20		7,099
Cm244		87		31,699
Hulls				
Cr	6,110		2230	
Mn	288		105.1	
Fe	44,150		16,115	
Ni	288		105	
Zr	509		186	
Zr93		0.25		90
Mn54		34.3		12,500
Fe55		10,030		3,662,000
Ni59		0.2		80

Table 15. Curie Analysis for Aqueous Separations Wastes				
Element/Isotope	Daily Rate		Annual Rate	
	g/day	Ci/day	kg/yr	Ci/yr
Ni63		30		11,050
Cs/Sr Waste Form				
Ca	81		29.5	
Fe	38		14.0	
Sr	1,995		728.2	
Cs	4,034		1,472.5	
Ba	3,098		1,130.8	
Co	2.7		1.0	
Ca45		19.0		6,947
Fe55		8.7		3,178
Sr90		160,872		58,718,171
Cs134		57,396		20,949,483
Cs135		1.2		427
Cs137		129,955		47,433,499
Ba133		0.4		129
Ba137m		143,878		52,515,420
Co56		359.0		131,036
FP/Lanthanide Waste Form				
Fe	5,468		1,996	
Ag	30		11	
Ce	1,742		636	
Eu	96		35	
Nb	2		1	
Pm	17		6	
Pr	820		299	
Pu	26		10	
Rh	236		86	
Ru	1,792		654	
Sb	6		2	
Sm	545		199	
Sn	42		15	
Te	349		127	
Y	396		145	

Table 15. Curie Analysis for Aqueous Separations Wastes				
Element/Isotope	Daily Rate		Annual Rate	
	g/day	Ci/day	kg/yr	Ci/yr
Co	0		0	
Fe55		1,242		453,492
Ag110m		17		6,079
Ce144		4,401		1,606,316
Eu152		5		1,944
Eu154		4,443		1,621,599
Eu155		1,166		425,700
Nb93m		1,047		382,136
Pm147		15,686		5,725,215
Pr144		4,407		1,608,490
Pr144m		62		22,513
Pu238		35		12,728
Pu241		361		131,861
Rh106		8,411		3,069,901
Ru106		8,972		3,274,791
Sb125		1,206		440,371
Sm151		276		100,616
Sn121m		11		4,104
Te125m		306		111,821
Y90		55,762		20,353,116
Co60		16		5,987
Carbon 14 waste				
C	68		25	
C-14		314		114,600
Iodine waste				
I	104.6		38.2	
I129		0.02		5.8
Tritium Waste				
H	0.118		0.043	
H3		1,373		501,200
Head-end off-gas emissions (99% sequestration of H, C and I)				
H	0.0244		0.00043	
C	64.4		0.23	

Element/Isotope	Daily Rate		Annual Rate	
	g/day	Ci/day	kg/yr	Ci/yr
Kr	238		0.89	
Xe	3032		1131.0	
I	0.1		38.7	
H3		284		103,500
C14		298		108,800
Kr89		4237		1,546,000
I129		0.00016		0.058

3.2 Pyrochemical Separations

Estimates of reagents (Table 16), products (Table 17), wastes (Table 18) and utility requirements (Table 19) for pyrochemical separations processes are based on two conceptual flowsheets, one for processing ceramic (oxide) fuels and one for processing metal fuels. The primary differences between these flowsheets are mainly in the additional requirements of the ceramic flowsheet for the capability to further oxidize the ceramic fuel (“high-temperature” voloxidation) which ruptures the cladding, allowing easier removal of the fuel from the cladding. This oxide, with the ruptured cladding (hulls) is sent to an electrolytic process that reduces the oxide feed to metal. Beyond these initial processing steps, the oxide and metal flowsheets are essentially identical. The reagent, product, and waste masses from these processing options are similar. For NEPA bounding purposes, the larger mass from either flowsheet is chosen as the bounding value. Isotope distributions for products and wastes are presented in Table 20.

Reagent	Annual Flow (metric tons)
LiCl-KCl-UCl ₃	1.1
Zr	1.0
Fe	0.5
FeCl ₂	1.5 kg
Cd	0.2
Air or O ₂	0.05
Zeolite	1.46
Glass	2.21

Table 17. Products of Pyrochemical Separations Operations

Product	Annual Mass (metric tons)
U Product	0.31
U/TRU Product	1.18

Table 18. Wastes from Pyrochemical Separations Operations

Source	Annual Mass (metric tons)	Annual Volume (m ³ /yr)
Assembly Waste	6.0	760
Metal Waste	7.1	710
Ceramic Fission Product Waste	4.5	1840
Cs/Sr Ceramic Waste	0.4	80
Cd Waste	0.2	0.02
HEPA Filters	0.1	0.02
Off-gases	0.4	260

Table 19. Utilities required for Pyrochemical Separations Operations

Utility	Annual Usage
Electricity	3.94 GW-hr
Argon Blanket	125 liters
Cooling Argon	1,402,000 liters
Oxygen	35,100 liters
Nitrogen	8,800 liters

Table 20. Curie Analysis for Pyrochemical Separations

Feed/Product/Waste	Daily Rate		Annual Rate	
	g/day	Ci/day	Kg/yr	Ci/yr
TRU/U metal				
U	459.648		167.77152	
U230		6.227E-16		2.273E-13
U231		2.197E-34		8.020E-32
U232		2.432E-06		8.877E-04
U233		7.672E-06		2.800E-03
U234		1.159E-01		4.230E+01
U235		2.238E-06		8.167E-04
U236		1.191E-04		4.346E-02
U237		1.699E-01		6.203E+01
U238		1.536E-04		5.605E-02
U240		4.876E-09		1.780E-06
Np	114.36		41.7414	
Np237		9.376E-02		3.422E+01

Table 20. Curie Analysis for Pyrochemical Separations

Feed/Product/Waste	Daily Rate		Annual Rate	
	g/day	Ci/day	Kg/yr	Ci/yr
Np238		3.535E-01		1.290E+02
Np239		1.934E+01		7.060E+03
Np240		1.387E-08		5.064E-06
Pu	2345.832		856.22868	
Pu236		3.103E-05		1.132E-02
Pu237		4.879E-02		1.781E+01
Pu238		2.495E+03		9.108E+05
Pu239		5.300E+01		1.935E+04
Pu240		1.959E+02		7.149E+04
Pu241		1.970E+04		7.189E+06
Pu242		1.280E+00		4.673E+02
Pu243		1.499E-06		5.470E-04
Pu244		1.389E-08		5.069E-06
Pu246		2.909E-15		1.062E-12
Am	235.632		86.00568	
Am241		9.805E+02		3.579E+05
Am242m		7.062E+01		2.578E+04
Am242		7.030E+01		2.566E+04
Am243		1.933E+01		7.054E+03
Am245		5.759E-08		2.102E-05
Am246		2.908E-15		1.061E-12
Cm	61.848		22.57452	
Cm241		1.949E-05		7.114E-03
Cm242		4.120E+03		1.504E+06
Cm243		1.875E+01		6.842E+03
Cm244		4.057E+03		1.481E+06
Cm245		1.620E+00		5.913E+02
Cm246		1.992E-01		7.270E+01
Cm247		1.498E-06		5.468E-04
Cm248		2.159E-06		7.879E-04
Cm249		7.258E-18		2.649E-15
Cm250		1.135E-14		4.143E-12
U Metal				
U	847.92		309.4908	
U230		1.149E-15		4.193E-13
U231		4.053E-34		1.479E-31
U232		4.486E-06		1.638E-03
U233		1.415E-05		5.166E-03
U234		2.138E-01		7.803E+01
U235		4.128E-06		1.507E-03
U236		2.197E-04		8.018E-02
U237		3.135E-01		1.144E+02

Table 20. Curie Analysis for Pyrochemical Separations				
Feed/Product/Waste	Daily Rate		Annual Rate	
Element/Isotope	g/day	Ci/day	Kg/yr	Ci/yr
U238		2.833E-04		1.034E-01
U240		8.994E-09		3.283E-06
Assembly Waste Form (see Note)				
Na	74.6		27.2	
Mn	86.6		31.6	
Fe	13,499.3		4,927.2	
Co	0.1		0.0	
Ni	87.0		31.8	
Nb	0.0		0.0	
Mn54		2,940.8		1,073,380.9
Fe55		504.3		184,051.5
Fe59		0.2		63.1
Co58		19.7		7,193.3
Co60		3.6		1,322.0
Ni63		0.7		260.8
Nb95		41.2		15,039.5
Nb95m		0.1		51.4
Metal Waste Form (see Note)				
Na	66.2		24.2	
Cr	1,660.2		606.0	
Mn	76.8		28.0	
Fe	11,971.1		4,369.4	
Co	0.1		0.0	
Ni	77.2		28.2	
Zr	612.9		223.7	
Nb	0.0		0.0	
Cr51		0.1		32.4
Mn54		2,607.9		951,866.6
Fe55		447.2		163,215.5
Fe59		0.2		55.9
Co58		17.5		6,378.9
Co60		3.2		1,172.4
Ni63		0.6		231.2
Zr95		16.8		6,140.5
Nb95		36.5		13,336.9
Nb95m		0.1		45.5
FP Ceramic Waste Form (see Note)				
Ba	58.1		21.2	
Y	8.9		3.2	
Ce	84.8		30.9	
Pr	43.2		15.8	
Sm	41.3		15.1	

Table 20. Curie Analysis for Pyrochemical Separations

Feed/Product/Waste	Daily Rate		Annual Rate	
	g/day	Ci/day	Kg/yr	Ci/yr
Eu	5.1		1.9	
Gd	4.8		1.7	
Pm	5.2		1.9	
Te	23.9		8.7	
Sr	16.4		6.0	
Cs	149.5		54.6	
Ba137m		3,753.3		1,369,947.9
Y90		1,320.9		482,121.9
Y91		155.0		56,573.5
Ce141		10.7		3,899.1
Ce144		7,668.5		2,798,995.6
Pr144		7,697.3		2,809,508.3
Pr144m		92.4		33,726.1
Sm151		142.5		52,017.2
Eu152		4.1		1,487.3
Eu154		213.6		77,966.8
Eu155		485.3		177,141.3
Gd153		2.9		1,047.5
Pm146		1.0		348.8
Pm147		4,789.0		1,747,978.3
Pm148		0.3		116.4
Te123m		0.1		23.7
Te125m		134.5		49,091.5
Te127		35.9		13,089.1
Te127m		36.6		13,363.1
Te129		0.3		119.9
Te29m		0.5		184.1
Sr89		53.9		19,680.1
Sr90		1,309.1		477,805.9
Cs134		2,383.8		870,099.5
Cs135		0.1		23.4
Cs137		3,926.0		1,433,000.5
Volatile FP Emissions				
H	1.0		0.4	
Xe	178.1		65.0	
Kr	8.7		3.2	
I	13.4		4.9	
H3		5.1		1,844.9
Xe127		0.0		0.0
Xe129m		0.0		0.0
Xe131m		0.0		0.0

Feed/Product/Waste	Daily Rate		Annual Rate	
Element/Isotope	g/day	Ci/day	Kg/yr	Ci/yr
Xe133		0.0		0.0
Kr81		0.0		0.0
Kr85		193.4		70,589.4
I129		0.0		0.6
I131		0.0		0.0

Note: components having a low Ci/year value have been dropped from this table.

3.3 Fuel Fabrication

Estimates of reagents (Table 21), products (Table 22), wastes (Table 23) and utility requirements (Table 24) for fuel fabrication processes are based on two conceptual flowsheets, one for fabricating ceramic (oxide) fuels and one for metal fuels. The estimates presented here are for the oxide fuel flowsheet which bounds the metal fuel case because of the form of the nuclear material (dispersible powder as opposed to metal ingots), the reagent requirements, utility requirements and footprint. Additional fuel fabrication flow sheets are currently being developed for (ceramic) nitride fuels and for dispersed fuels (sphere-pac and inert matrix fuels). The (ceramic) nitride flowsheet is similar to the (ceramic) oxide flowsheet, but requires additional equipment and chemicals (especially, nitrogen-15) and bounds the hydrogen and other gas use. The additional equipment required for the nitride flowsheet is already taken into account in the facility footprint.

The primary impact of particle fuel fabrication is in the feed conditioning process. Impacts in the fuel fabrication process primarily involve loading the fuel into a vertical fuel rod rather than in the horizontal orientation used in loading ceramic or metal fuel.

Isotope distributions for ceramic oxide fuels are shown in Table 25.

Reagent	Annual Flow (liters)
Nitric Acid	30,000
Ascorbic Acid	550
Hydrazine	550
Oxalic Acid	17,500
PEG	3.5 kg
Zn stearate	4.2 kg
Hydrogen	350,000
Nitrogen-15	140,000

Product	Annual Production
ABR Lead Test Assemblies	50 (as many LTAs as required to use 2 metric tons of fuel.)

Table 23. Wastes from Fuel Fabrication Operations

Source	Annual Number	Comments
Failed fuel elements	7	Fuel elements loaded with fuel fail the welding or inspection process. The rod ends are cut and the pellets are removed. The remaining hulls are sent to the hulls washing process (aqueous processing) for fines removal.

Table 24. Utilities required for Fuel Fabrication Operations

Utility	Annual Usage
Electrical Power to furnaces	175.2 GW-Hr
Process Argon Makeup	5500 liters
Process Nitrogen Makeup	6,000 liters
Helium for Rod Filling	450 liters

Table 25. Curie Analysis for Fuel Fabrication – Ceramic Oxide Fuel

Element/Isotope	Daily Rate		Annual Rate	
	g/day	Ci/day	Kg/yr	Ci/yr
U	2704.1		987.0	
U230		1.137E-35		4.151E-33
U232		5.266E-04		1.922E-01
U233		1.346E-06		4.913E-04
U234		1.603E-02		5.851E+00
U235		1.771E-04		6.464E-02
U236		3.516E-03		1.283E+00
U237		1.600E-02		5.839E+00
U238		8.945E-04		3.265E-01
U240		8.356E-09		3.050E-06
Np	287.4		104.9	
Np235		7.789E-04		2.843E-01
Np236		3.004E-06		1.096E-03
Np237		2.161E-01		7.888E+01
Np238		2.768E-02		1.010E+01
Np239		2.031E+01		7.414E+03
Np240m		3.828E-07		1.397E-04
Np240		4.595E-10		1.677E-07
Pu	2238.1		816.9	
Pu236		1.046E-01		3.817E+01
Pu237		3.954E-12		1.443E-09
Pu238		2.956E+03		1.079E+06
Pu239		7.526E+01		2.747E+04

Table 25. Curie Analysis for Fuel Fabrication – Ceramic Oxide Fuel

Element/Isotope	Daily Rate		Annual Rate	
	g/day	Ci/day	Kg/yr	Ci/yr
Pu240		1.140E+02		4.160E+04
Pu241		3.063E+04		1.118E+07
Pu242		1.060E+00		3.869E+02
Pu243		3.375E-06		1.232E-03
Pu244		3.835E-07		1.400E-04
Pu246		1.144E-10		4.176E-08
Am	154.0		56.2	
Am241		1.182E+03		4.315E+05
Am242m		6.146E+00		2.243E+03
Am242		6.118E+00		2.233E+03
Am243		2.029E+01		7.407E+03
Am245		3.825E-08		1.396E-05
Am246		1.143E-10		4.171E-08
Cm	25.4		9.3	
Cm241		1.646E-19		6.010E-17
Cm242		1.336E+01		4.877E+03
Cm243		1.478E+01		5.396E+03
Cm244		5.285E+03		1.929E+06
Cm245		9.531E-01		3.479E+02
Cm246		4.099E-01		1.496E+02
Cm247		3.375E-06		1.232E-03
Cm248		2.176E-05		7.941E-03
Cm249		1.260E-36		4.598E-34
Cm250		4.577E-10		1.671E-07

3.4 SNF and LTA Shipping & Receiving

The bounding throughput of the AFCF is 75 MTIHM of LWR (either PWR or BWR) fuel and 2 MTIHM of FR fuel. This converts to approximately 225 LWR assemblies and 50 FR assemblies per year that could be received by the AFCF. The number of shipments per year depends on how many assemblies are in each shipment.

Table 26 lists NRC-certified shipping casks for transporting spent nuclear fuel by truck or by rail. Many of the larger, dual use casks require the use of a sealed (welded) canister as highlighted in red text in the description. However, the AFCF F&OR assumes (section 2.3.2.3) that the AFCF will not receive welded canisters containing spent nuclear fuel. This assumption limits the number of assemblies that can be transported in a single cask. Typically, a cask transported by truck can hold two BWR assemblies or one PWR assembly (e.g., the NLI-1/2, the NAC-LWT, and the NFS-4). The number of shipments required per year to bring 75 MTIHM of LWR fuel to the AFCF

Table 26. Transport Casks for LWR and FR Spent Nuclear Fuel

CASK	PURPOSE AND NORMAL TRANSPORT MODE	FUEL	STUDY REF./PAGE NO.	APPROXIMATE OVERALL CASK SIZE (IN.) WITH IMPACT LIMITERS	APPROXIMATE OVERALL CASK SIZE (IN.) WITHOUT IMPACT LIMITERS	APPROXIMATE CAVITY SIZE (IN.)	APPROXIMATE LOADED WEIGHT (TONS) WITH IMPACT LIMITERS	APPROXIMATE LOADED WEIGHT (TONS) WITHOUT IMPACT LIMITERS	APPROXIMATE EMPTY WEIGHT (TONS) (1)
NLI-1/2	TRANSPORT ONLY – TRUCK	1 PWR (ASSY), 2 BWR (ASSY), 2 PWR (RODS), 4 BWR (RODS), METAL FUEL, FR EBR 2	TC, (B-29 THRU B-43), S, (CERT. #9010)	237 LG X 75 OD	195.25 LG X 47.13 OD	178 LG X 13.38 ID	24.6	23.1	22.3
NAC-LWT	TRANSPORT ONLY – TRUCK	2 BWR (3.7 W/O; 4.0 W/O ENRICHMENT), 1 PWR, 15 METALLIC FUEL RODS	TC, (B-77 THRU B-85), S, (CERT. #9225)	232 LG X 65 OD	199.8 LG X 44.2 OD	180.90 LG X 13.38 ID	26.0	25.6	24
NLI-10/24	TRANSPORT ONLY – RAIL	24 BWR, 10 PWR	TC, (B-128 THRU B-135), S, (CERT. #9023)	INFORMATION WAS NOT FOUND	204.5 LG X 88 OD	179.5 LG X 45 ID	97.0	96.5	89
TN-8/8L	TRANSPORT ONLY - OVER-WEIGHT TRUCK	3 PWR	TC, (B-96 THRU B-102), S, (CERT. #9015)	IMPACT LIMITERS NOT MENTIONED IN C OF C	192 LG X 67.5 OD	168 LG X IRREGULAR ID	IMPACT LIMITERS NOT MENTIONED IN C OF C	39.3	36.9
TN-9	TRANSPORT ONLY - OVER-WEIGHT TRUCK	7 BWR	TC, (B-103 THRU B-108), S, (CERT. #9016)	IMPACT LIMITERS NOT MENTIONED IN C OF C	200 LG X 66 OD	178 LG X IRREGULAR ID	IMPACT LIMITERS NOT MENTIONED IN C OF C	39.1	36.8
IF-300	TRANSPORT ONLY – RAIL	18 BWR, 7 PWR	TC, (B-118 THRU B-127), S, (CERT. #9001)	208 LG X 64 OD (2)	208 LG X 64 OD	180.25 LG X 37.5 ID	70.0	47.5	59.5
NFS-4 (NAC-1)	TRANSPORT ONLY – TRUCK	1 PWR, 2 BWR, METAL FUEL	TC, (B-58 THRU B-64), S, (AFTER CERT. #9225)	CERTIFICATE OF COMPLIANCE NOT FOUND	194.4 LG X 38 OD	178 LG X 13.5 ID	CERTIFICATE OF COMPLIANCE NOT FOUND	23	22
TN-FSV (TERMINATION LETTER APRIL 19, 2006)	TRANSPORT ONLY – TRUCK	HIGH TEMPERATURE GAS COOLED REACTOR (HTGR)	TC, (B-91 THRU B-95)	247 LG X 78 OD	207 LG X 31 OD	199 LG X 18 ID	23.5	INFORMATION NOT FOUND	21
T-3	TRANSPORT ONLY – TRUCK	FFTF AND OTHERS	CERTIFICATE OF COMPLIANCE USA/9132/B(M)F (DOE)	213.2 LG X 52 OD	177.2 LG X 26.4 OD	147 LG X 8 ID	19.0	INFORMATION NOT FOUND	INFORMATION NOT FOUND
HI-STAR 100	DUAL-PURPOSE (STORAGE AND RAIL TRANSPORT) USING SEALED CANISTER	24 PWR, 68 BWR, GTCC	USA/9261/B(U)F-85	239.5 LG X 126 OD	203 LG X 96 OD	68.8 OD	141.0	124	77
TRANSTOR	DUAL-PURPOSE (STORAGE AND RAIL TRANSPORT) USING SEALED CANISTER	24 PWR, 61 BWR	TROJAN-SITE SPECIFIC	295 LG X 140 OD	192.3 LG X 66 OD	INFORMATION NOT FOUND	130.0	INFORMATION NOT FOUND	INFORMATION NOT FOUND
NAC-UMS	DUAL-PURPOSE (STORAGE AND RAIL TRANSPORT) USING SEALED CANISTER	24 PWR, 56 BWR	US 72-1015	273.3 LG X 124 OD	209.3 LG X 92.9 OD	192 (max.) LG X 67 OD	128.5 (max.)	INFORMATION NOT FOUND	INFORMATION NOT FOUND
NAC-MPC	DUAL-PURPOSE (STORAGE AND TRANSPORT) SEALED CANISTER - TRANSPORTABLE BY THE NAC-STC	37 PWR, 89 BWR	USA/9235/B()F-85 (NAC-STC)	257 LG X 124 OD	193 LG X 87 OD	165 LG X 71 ID	130.0	INFORMATION NOT FOUND	110.175

Table 26. Transport Casks for LWR and FR Spent Nuclear Fuel

CASK	PURPOSE AND NORMAL TRANSPORT MODE	FUEL	STUDY REF./PAGE NO.	APPROXIMATE OVERALL CASK SIZE (IN.) WITH IMPACT LIMITERS	APPROXIMATE OVERALL CASK SIZE (IN.) WITHOUT IMPACT LIMITERS	APPROXIMATE CAVITY SIZE (IN.)	APPROXIMATE LOADED WEIGHT (TONS) WITH IMPACT LIMITERS	APPROXIMATE LOADED WEIGHT (TONS) WITHOUT IMPACT LIMITERS	APPROXIMATE EMPTY WEIGHT (TONS) (1)
NAC-STC	DUAL-PURPOSE (STORAGE AND TRANSPORT) USING SEALED CANISTER ; TRANSPORT ONLY IN THE U.S.)	24 PWR AND GTCC	USA/9235/B(U)F-85	257 LG X 99 OD	193 LG X 87 OD	165 LG X 71 ID	130.0	INFORMATION NOT FOUND	110.175
NUHOMS/MP-187	DUAL-PURPOSE (TRANSPORT AND STORAGE USING SEALED CANISTER; TRANSPORT ONLY IN THE U.S.)	24 PWR AND VARIOUS OTHERS	USA/9255/B(U)F-85	300 LG X 93 OD	200 LG X 93 OD	187 LG X 68 ID	141.0	125.2	100.45
NUHOMS/MP-197	DUAL-PURPOSE (TRANSPORT AND STORAGE USING SEALED CANISTER; TRANSPORT ONLY IN THE U.S.)	ALL NUHOMS CANISTERS	USA/9302/B(U)F-85	INFORMATION WAS NOT FOUND	208 LG X 91.5 OD	197 LG X 67 OD	130.0	116	74.42
NUHOMS-61BT	DUAL-PURPOSE (STORAGE AND TRANSPORT) SEALED CANISTER - TRANSPORTABLE BY THE NUHOMS/MP-197	61 BWR	1004	N/A	196 LG X 67 OD	180 LG	N/A	44.2	22.7
GA-4	TRANSPORT ONLY – TRUCK	VARIOUS MATERIAL (SEE C OF C)	USA/9226/B(U)F-85	234 LG X 90 OD	188 LG X 40 OD	SEE PAGE 1 PARAGRAPH 3 OF C OF C.	27.5	25.5	24.2
TN-68*	DUAL-PURPOSE (STORAGE AND RAIL TRANSPORT) NOT USING SEALED CANISTER	68 BWR	SFT, (CERT. #9293, 1-9)	271 LG X 144 OD	197 LG X 98 OD	178 LG X 69.5 ID	136	120	112

Study Reference

TC = Transportation Capabilities Study for DOE SNF

S = SFTF Scoping Study

SFT = Spent Fuel Transportation and Low-Level Waste Casks for the AFCF (White Paper)

* This is the maximum bounding design cask (with an overall 340 inch length with impact limiters) per the DOE OCRWM report for Yucca Mountain casks receipt,

(1) In most instances this weight is based on maximum weight minus the maximum payload weight.

(2) 450 LG X 96 OD IF-300 Railcar Transport Skid Dimensions, with impact fins integral to the cask

depends on the mix of PWR and BWR fuels and on how close to capacity the cask is filled. Although a transport cask can typically hold twice as many BWR assemblies as PWR assemblies, the initial fuel loading for a PWR assembly is more than twice the fuel loading of the BWR assemblies. Thus, the maximum number of shipments required for shipping 75 MTIHM of BWR fuel (assuming each cask is completely full) is on the order of 210 truck shipments per year using casks capable of transporting 2 BWR assemblies/shipment. For the operations case (25 MTIHM/year, and assuming 2/3 of the inventory is in PWR assemblies) the expected annual truck shipments would be about 60.

Rail transport casks have much greater capacity for SNF than truck transport casks as shown in Table 26. Three rail transport casks shown in this table do not require a sealed canister – the NLI-10/24, the IF-300, and the TN-68. The smallest of these casks, the IF-300, can transport up to 7 PWR or 18 BWR assemblies. Assuming that the cask is full, the maximum number of shipments required for shipping 75 MTIHM LWR fuel is 24 for BWR and 22 for PWR. Eight shipments by rail would be required to ship 25 MTIHM of either PWR or BWR fuel to AFCF. These results are summarized in Table 27.

	Expected Annual	Bounding Annual
Truck Shipments of SNF in the NLI-1/2, NAC-LWT or NFS-4 casks	60	210
Rail Shipments of SNF in the IF-300 cask	8	24

Because new LTAs fabricated at the AFCF would emit gamma radiation, shipment of LTAs from AFCF would require shielded casks similar to the SNF shipping casks shown in Table 26. For a cask to carry ABR fuel, it must have certification for that fuel type. Of the casks listed in Table 26, only the NLI-1/2 indicates certification for fast reactor (EBR-2) fuel. Because the AFCF fabricates LTAs for testing in a variety of reactors (as opposed to producing fuel for refueling a reactor), we assume that only one LTA is included in each shipment. Thus, the bounding number of outbound fuel shipments from AFCF is the same as the number of LTAs. For the NEPA bounding case of 2 MTHM, this is 50 shipments per year. The AFCF F&OR specifies that the AFCF be capable of producing up to 10 LTAs per year, and this sets the expected number of annual shipments.

	Expected Annual	Bounding Annual
FR LTAs fabricated at AFCF	10	50

3.5 Waste Shipping

Waste shipments from AFCF will depend primarily on the availability of appropriate disposal facilities. Radioactive wastes for which there is no current disposal pathway (for example, HLW, GTCC, Cs/Sr wastes) will be stored at AFCF (or at another suitable, licensed storage facility) pending availability of a licensed disposal facility.

Three LLW disposal facilities are licensed by the NRC (or by agreement states) – Barnwell, SC (operated by Chem-Nuclear/Duratek); the Energy Solutions (formerly Envirocare) facility in Clive, Utah; and the US Ecology facility at Hanford, Washington. Barnwell¹⁶ and Hanford are licensed to accept classes A-C. The Envirocare facility is only licensed to accept class A LLW. Disposal of DOE-generated LLW is authorized at Hanford, Idaho National Laboratory, Los Alamos National Laboratory, Nevada Test Site, Oak Ridge Reservation and the Savannah River Site. Of these six sites, only Hanford and Nevada Test Site are authorized to receive LLW from off-site (DOE) sources.

The Low-Level Radioactive Waste Policy Amendments Act of 1985 (LLRWPA) assigned responsibility for developing licensable means of disposal of GTCC LLW to the DOE. In 2005, the DOE published an Advanced Notice of Intent to prepare an Environmental Impact Statement for the disposal of GTCC LLW¹⁷. The EIS is scheduled to be issued in 2008 and a Record of Decision is expected in 2009. If the selected alternative is an existing, operating geologic repository, GTCC wastes could be shipped from the AFCF as soon as the AFCF is generating GTCC LLW. If the selected alternative requires development of a new facility, that facility would not be able to accept GTCC wastes before about 2019.

High-Level Wastes require disposal in a geologic repository such as Yucca Mountain, NV. The DOE is currently preparing a license application for construction of the repository with a planned submission date to NRC of mid 2008. The current Yucca Mountain schedule calls for construction authorization in 2011, submittal of an operating license application in 2013, and commencement of repository operations in 2017.

Given the schedule for opening of the various disposal sites, the AFCF could be required to store several years' accumulation of HLW, GTCC, and Cs/Sr wastes. Once licensed disposal facilities commence disposal operations, the AFCF would ship wastes to those facilities as expeditiously as possible to reduce on-site storage. Thus, the expected number of annual off-site shipments of radioactive wastes would be higher in the early years of AFCF operation than would be expected from steady-state operation.

To bound the number of shipments of wastes, we will assume that the AFCF has accumulated 10 years' production of HLW, GTCC, and Cs/Sr wastes - the allowable inventory based on the F&OR - as shown in Table 1. After ten years, the GTCC and HLW are scheduled for shipment such that the accumulated waste is removed within two years. The results are presented in Table 29.

¹⁶ The Barnwell facility is currently slated to stop receiving wastes before the AFCF is operational.

¹⁷ Federal Register, **70**(90), pp 24775-24778, May 11, 2005

	LLW Annual Steady-State	GTCC Annual Steady-State	GTCC Annual Bounding	HLW Annual Steady-State	HLW Annual Bounding
Shipments per year	2-5	2-5	20-40	55 HLW canisters	240 HLW canisters
Packaging Description	55 gal drums or SWB	Type A or Type B 55 gal drums		HLW canisters	
Mass per Container	<650 lb drums/ <3300 lb SWB	< 650 lb		<2 MT HLW, <3 MT total	
Containers per Vehicle	40 ea drums/ 4 ea SWB	40		1	
Destination	Licensed LLW disposal facility	Licensed geologic repository		Licensed geologic repository	
Physical Description of Container Contents	Waste forms depend on specific treatment process, but are typically stabilized in a bulk form				
Chemical/Radiological Composition of Container Contents	Chemical/radiological compositions are presented in the more detailed tables for each process area.				

3.6 Construction

Construction data presented in earlier discussions of this NEPA Data Study for the AFCF are summarized in Tables 30 and 31.

Building	Area
Processing Buildings Footprint	545,000 ft ²
Support Buildings Footprint	332,000 ft ²
Total Buildings Footprint	877,000 ft ²
Area inside PIDAS	62 acres
Temporary Concrete Batch Plant Area	6 acres
Temporary Laydown Area	16 acres
Post Construction Developed Area	144 acres

Waste	Volume (cubic meters)	Mass (tons)
Debris from site clearing operations	360,000	
Excavated material	1,350,000	
Structural Backfill	400,000	
Metal Scrap		9,000
Dunnage	11,000	
Contaminated soils	3,000	

4. List of Acronyms and Abbreviations

ABR – advanced burner reactor – a nuclear reactor designed to operate with a high neutron flux capable of transmuting actinides to fission products

AFCF – Advanced Fuel Cycle Facility

ARF – airborne release fraction – the portion of a powder or liquid that remains suspended in the air upon being released into the air

BWR – boiling water reactor – a type of LWR designed to allow the primary coolant to boil

CFR – Code of Federal Regulations (<http://www.gpoaccess.gov/cfr/index.html>)

Ci – curies – a measure of radioactivity

DOE – US Department of Energy

DOT – US Department of Transportation

ECF – entry control facility

EPA – US Environmental Protection Agency

FB – fluidized bed

FP – fission products

FR – fast reactor – a generic term for reactors designed for operation with a high neutron flux. An ABR is a fast reactor.

GEN IV – generation 4 – a designation for a new type of nuclear reactors

GNEP – Global Nuclear Energy Partnership

GTCC – greater-than-class-C LLW (see 10 CFR 61.7(b)(5))

GWD – gigawatt-days – a measure of the amount of energy extracted from nuclear fuel.

GW-hr – gigawatt hours (1 GW-hr = 1000 MW-hr)

HEPA – high efficiency particulate air (filter)

HLW – high level (radioactive) waste as defined in 10 CFR 60.2

HM – heavy metal – elements used as nuclear fuel

HVAC – heating, ventilation, and air conditioning

IX – ion exchange

LLW – low level (radioactive) waste (see 10 CFR 61.7(b)(2)-(b)(4))

LTA – lead test assembly – a fuel assembly used for qualifying a new type of nuclear fuel

LWR – light water reactor – includes PWRs and BWRs

MLLW – mixed low level waste – a mixture of LLW (radioactive) and hazardous (or chemical) wastes

MT – metric ton – 1000 kg

MTIHM – metric tons of initial heavy metal – the weight of actinide elements in nuclear fuel before the fuel is irradiated in a reactor

MWe – megawatts, electric

MW-hr – megawatt hours

NEPA – National Environmental Policy Act

NFB – Non-fuel bearing

NRC – US Nuclear Regulatory Commission

PIDAS – perimeter intrusion, detection and assessment system

PWR – pressurized water reactor – a type of LWR that is pressurized to prevent boiling in the primary coolant

RAD – radiation (as in RAD workers – workers with the potential to be exposed to ionizing radiation)
RCRA – resource conservation and recovery act
RF – respirable fraction – the portion of airborne particles that is retained in the lungs when breathed in, generally submicron particles.
SLB – shallow land burial (for disposal of LLW)
SNF – spent nuclear fuel
SNM – special nuclear material
SS – stainless steel
SWB – standard waste box
TRU – in this study, trans-uranium elements (e.g., elements 93 and higher). Not to be confused with “TRU waste” – a DOE waste category
UDS – undissolved solids
UREX – URanium EXtraction – the name of a related family of solvent extraction processes for purifying uranium by removing it (and other actinides) from solution

Chemical elements and groups of elements

Ag – silver (element 47)
AHA – acetohydroxamic acid
Am – americium (element 95, an actinide that grows in to SNF, a strong gamma emitter)
An – actinides (elements 90 through 103)
C – carbon (element 12, one isotope of which is radioactive)
CCD – chlorinated cobalt dicarbolyde
Cd – cadmium (element 48)
Cl – chlorine (element 17)
Cm – curium (element 96, an actinide that grows in to SNF, several isotopes are strong gamma emitters)
Cs – cesium (element 55, a highly radioactive fission product)
CMPO – N, N di-isobutyl octylphenyl carbamoyl methyl phosphine oxide
DI - deionized
DTPA – diethylene triamine pentaacetic acid
Fe – iron (element 26)
H – hydrogen (element 1)
HDEHP – di-2-ethylhexyl phosphoric acid
He – helium (element 2)
HMTA – hexamethylene tetraamine
HTO – tritiated water where T represents tritium (^3H), a radioactive isotope of hydrogen
I – iodine (element 53, a radioactive fission product)
K – potassium (element 19)
Kr – krypton (element 36, a radioactive fission product)
La – lanthanides (elements 58 through 71)
Li – lithium (element 3)
Na – sodium (element 11)
Np – neptunium (element 93, an actinide that grows in to SNF, has a rapidly-growing daughter product that is a strong beta emitter)
O – oxygen (element 8)

PEG – polyethylene glycol

Pu – plutonium (element 94, an actinide that grows in to SNF, one isotope is used in nuclear weapons)

SANDEX – solvent for a proprietary process

Sr – strontium (element 38, a highly radioactive fission product)

T – tritium (a radioactive isotope of hydrogen)

TBP – tributyl phosphate

Tc – technetium (element 43, a highly radioactive fission product)

U – uranium (element 92, the only naturally-occurring actinide. Used in nuclear fuel, and one isotope is used in nuclear weapons)

Xe – xenon (element 54, a radioactive decay product)

Zn – zinc (element 30)

Appendices

A-1. Brownfield Construction Alternatives

A-2. Elemental Composition of LWR Fuel, 100 GWD/MT, 5 year cooled and ABR Fuel, 250 GWD/MT, 1 year cooled

A-3. Activity of LWR Fuel, 100 GWD/MT, 5 year cooled

A-4. Activity of ABR Fuel, 250 GWD/MT, 1 year cooled

Appendix A-1 **Brownfield Construction Alternatives**

An alternative to constructing an entirely new (“greenfield”) Advanced Fuel Cycle facility is to refurbish an existing facility that can house part or all of the AFCF mission (the “brownfield” alternative). Two existing candidate facilities have been identified that could serve as the nucleus of a brownfield alternative: the Idaho Nuclear Technology and Engineering Center (INTEC) at Idaho National Laboratory and the Fuels and Materials Examination Facility (FMEF) at Hanford. These facilities, their possible use in supporting the AFCF mission, and the reduction in environmental impact from the baseline (“greenfield”) alternative is discussed below.

Summary and Results

The AFCF NEPA Data Study (to which this alternatives analysis is appended) provides supporting data for evaluating the environmental impacts of the construction and operation of a “greenfield” (totally newly constructed) facility. This appendix uses that study as the baseline for construction impacts and evaluates departures from the baseline that result from use of existing DOE facilities. In all cases evaluated, the departures reduce the expected construction impact because use of existing facilities offsets the need to construct some portion of the baseline facility. Operation impacts are not considered in this appendix.

For existing buildings, the environmental impacts of the construction have already occurred. There may be additional environmental impacts from any required modification of existing buildings to adapt those buildings to the AFCF mission. However, detailed facility-specific studies are needed to evaluate the construction and operation impacts of proposed modifications.

For either of the brownfield alternatives considered, this study estimates that the construction impacts are reduced from the baseline impact on the order of 22-25% for materials and excavation, and 16-17% for fuel consumption and the attendant air emissions from diesel exhaust. These savings should be considered to be, at best, order-of-magnitude estimates. However, there are several issues that should be identified and quantified if the brownfield alternatives are to be evaluated on an equivalent footing with the greenfield alternative (the baseline), including:

- meeting the 40+ year lifetime requirement for the AFCF with facilities that are already 20+ years old,
- meeting AFCF mission requirements for flexibility in changing out processing and other equipment in facilities that were designed for other, more limited purposes,
- demonstrating full integration and remote maintainability of processing equipment,
- material transfers between and among distributed facilities
- meeting current codes and standards for nuclear facility licensing, safeguards, security, and facility design basis.

INTEC at Idaho National Laboratory (INL)

INTEC (see Figure A1-1), was established in the 1950s for extracting reusable uranium from spent nuclear fuel (SNF). INTEC consists of existing and new (under construction) facilities that



Figure A1-1. Aerial view of INTEC at INL. Labeled facilities proposed for supporting the AFCF mission are described in the text.

could be used for the AFCF mission, including the Fuel Processing Restoration (FPR) facility, the Fluorine Dissolution Process and Fuel Storage (FAST) facility, the Remote Analytical Laboratory (RAL), the Liquid Effluent Treatment and Disposal (LET&D) facility, the New Waste Calcining Facility (NWCF), and the Integrated Waste Treatment Unit (IWTU). In addition, the INTEC includes infrastructure support such as electric power, water and steam generation, fire and emergency response, backup generator, and office facilities. The site is currently used for storage of spent nuclear fuel, solidification of liquid radioactive waste, and packaging of solidified radioactive wastes. Potential use of these facilities to support the AFCF mission is described in Table A1-1.

Table A1-1. Existing and New (under construction) INTEC Facilities for Supporting the AFCF Mission		
INTEC Facility	Current Use	Proposed AFCF Use
FPR – Fuel Processing Restoration	Standby – available for use	Aqueous separations
FAST – Fluorinel Dissolution Process and Fuel Storage	Spent fuel wet storage	Cask unloading and spent fuel storage
LET&D – Liquid Effluent Treatment & Disposal	Aqueous effluent treatment	Aqueous effluent treatment
NWCF – New Waste Calcining Facility	Standby (backup for waste solidification in IWTU)	Decontamination of equipment
RAL – Remote Analytical Laboratory	Analytical laboratory	Analytical laboratory
IWTU – Integrated Waste Treatment Unit	Under construction – steam reformer for radioactive waste solidification	Cs/Sr liquid extract solidification

Fuel Processing Restoration Facility

The FPR was originally designed as an aqueous separations facility for reprocessing spent nuclear fuel to recover highly enriched uranium (HEU). This facility is a 170,000 ft² reinforced concrete structure that was more than 50% complete when construction was stopped in 1992. However, the facility construction was shut down in a manner that preserves the facility for possible re-use.

The FPR has six levels, three of which are below grade. Hot cells and support equipment are listed in Table A1-2. Nine 45-foot deep underground, stainless steel-lined concrete cells are available for remote separations processing. The process cells have removable roof hatches and an overhead maintenance area for crane and telescoping PAR access. These features provide an enhanced but limited capability for change out of equipment to facilitate demonstration of candidate technologies.

These cells were designed for static equipment (such as tanks or pulse columns) where maintenance or replacement activities were expected to be infrequent or unlikely. Modification or replacement of equipment in these process cells would require personnel entry to cut and to re-weld piping connections.

A Pump and Valve (P&V) corridor is located along one side of the process cells for remote equipment maintenance of items that have a higher failure frequency, and two shielded sample preparation cells are located on the other side of the process cells. Shielded windows, cranes, and manipulators facilitate equipment operation and maintenance in the P&V corridor.

Table A1-2. Fuel Processing Restoration (FPR) Facility at Idaho National Laboratory			
Hot Cells			
Hot Cell Designators	Nominal Hot Cell Dimensions (w x l x h)	Hot Cell Original Design Function	Hot Cell AFCF Design Function
Cells 1 through 9	20' x 35' x 40'	Process cells	Separations Process Tanks
Cell 10	16' x 13' x 40'	Process cell	Spare
Cells 11 and 12	16' x 22' x 20'	Process cells	U solidification
Cells 13 and 14	15' x 20' x 14'	Decontamination cells	Decontamination cells
Cells 15 and 16		Sample cells	Sample cells
P&V	13' x 193' x 45'	Pump & Valve Corridor	Separations process equipment
New Hot Cell			TRU solidification
Overall Shielded Processing Area	71' x 220' x 40'		
Support Equipment			
Equipment	Description		Status
Overhead Crane	50 ton with 5-ton auxiliary hook accesses cells 1-10		Installed
Hoists	2 each @ 15 ton capacity access cells 1-10		Installed
Master-Slave Manipulators			Some in storage pending installation
Shielding Windows	58 each		Some in storage pending installation
Wall PAR	Remote maintenance of P&V corridor equipment		In storage pending installation
Diesel Generator	Auxiliary diesel generator for emergency/backup power		Installed but not connected
Control Room	Command & control center, UPS, separate HVAC & emergency power		Control Room

Conceptual design layouts for the FPR facility as a component of the AFCF were prepared to identify the amount of shielded space that would not have to be constructed if the FPR were used to house all or part of the aqueous separations process.

A schematic layout of the UREX+1a process area in the FPR is shown in Figure A1-2. This schematic layout includes U/Tc separation, Cs/Sr separation, TRU & lanthanide fission product separation, and the final TRU separation processes within the existing P&V corridor. Surge and storage tanks are located in hot cells 1-9. Uranium byproduct solidification is housed in Cell 11/12. The layout includes the modification of the existing FPR facility to add a new shielded area between the sample acquisition cells for TRU solidification and associated materials handling processes. Note that all the shielded processing area is sufficiently large to accommodate all the required aqueous separations processing equipment.

Figure A1-3 shows a schematic layout for the UREX+4 flowsheet that adds the Np/Pu separation, Am separation and Cm separation to the UREX+1a process. In this case,

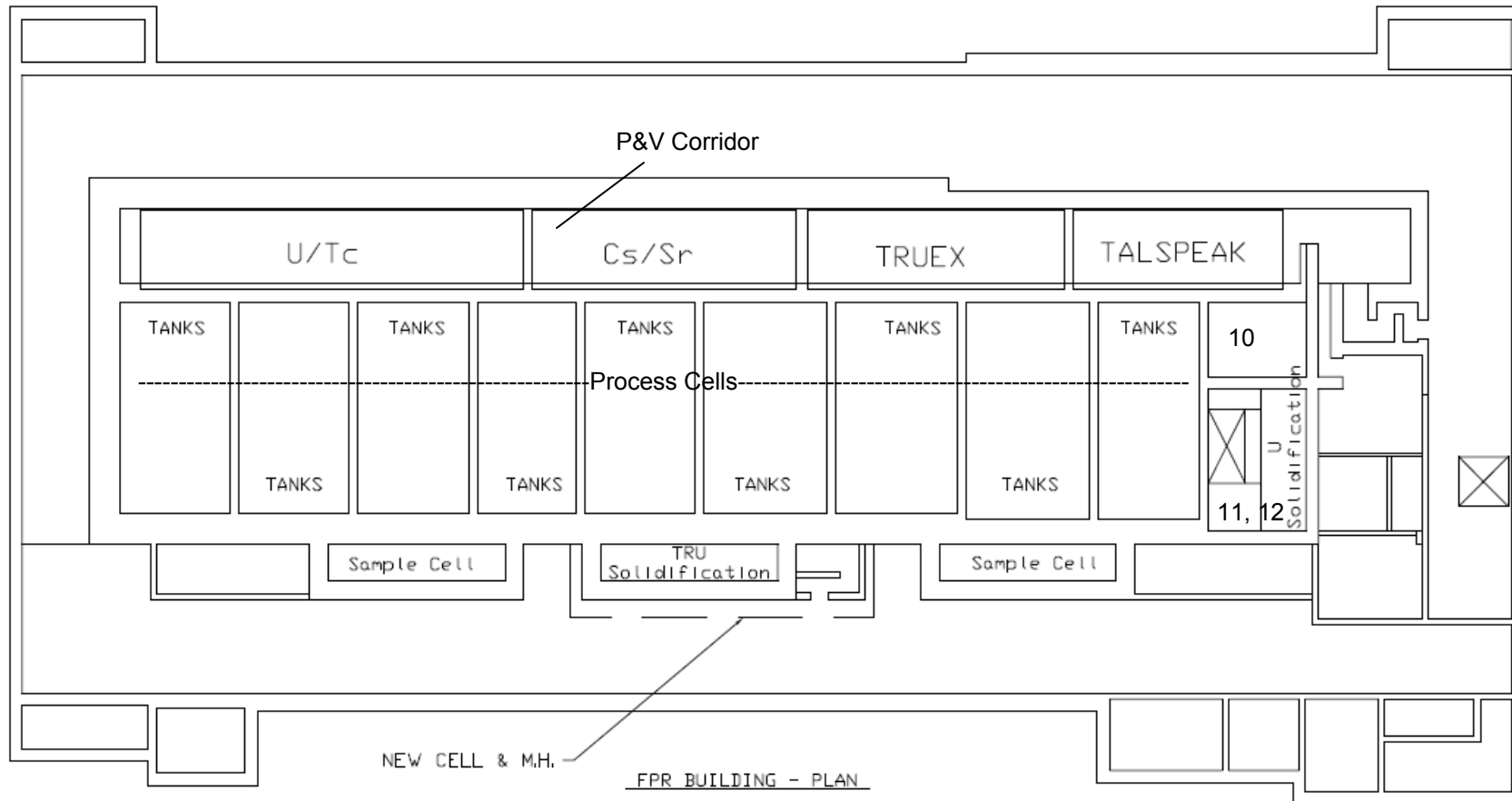
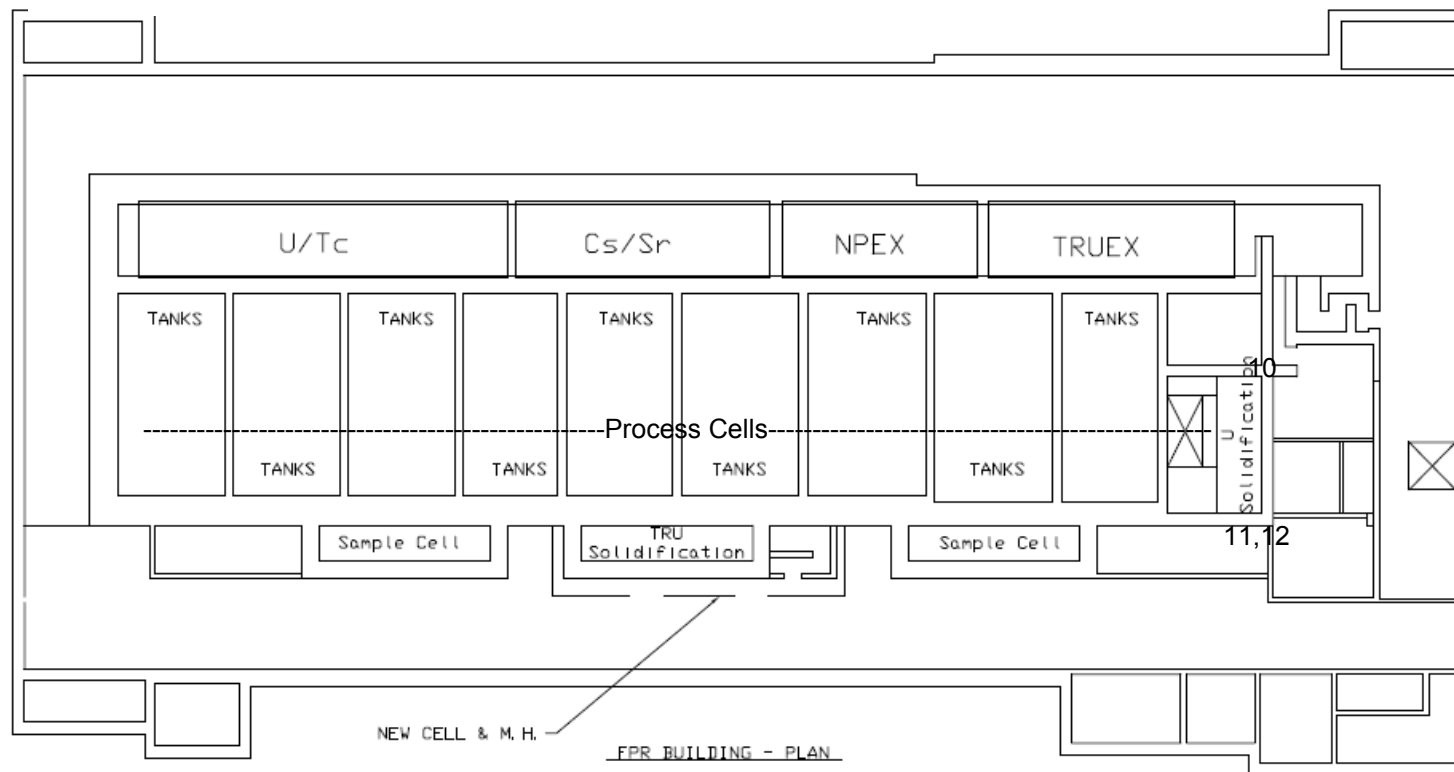
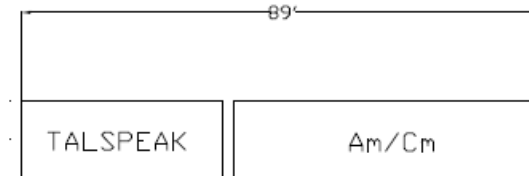


Figure A1-2. Concept sketch for the UREX+1a aqueous separations process layout in the Fuel Processing Restoration (FPR) Facility at Idaho National Laboratory. The UREX+1a contactors are housed within the Pump & Valve Corridor.

Figure A1-3. Concept sketch for the UREX+4 aqueous separations process layout in the Fuel Processing Restoration (FPR) Facility at Idaho National Laboratory. Note that not all of the contactors required for UREX+4 fit in the Pump & Valve Corridor. The additional hot cell internal length required for the additional contactors is ~110 ft – 90 ft for the process equipment and 10 ft on each side of the process equipment for access and operating space.



the FPR Pump & Valve corridor is not sufficiently long to support these additional processes. The primary constraint is set by the reach of the wall-mounted PAR. To be able to maintain the aqueous separations processing equipment, the P&V corridor would have to be at least 270 ft long, equivalent to the length of the AFCF baseline aqueous separations layout. Although the FPR P&V corridor is 220 ft long, the additional space required to house the additional separations process is on the order of 110 ft - ~90 ft for the process equipment and 10 ft access space on each end of the process equipment train. Thus, use of the FPR for housing the aqueous separations process would lead to reduced separations capability or to the need to construct additional new shielded process space for the NPEX and Am/Cm separations processes.

Fluorinal Dissolution Process and Fuel Storage Facility

The FAST facility has the capacity to receive and unload commercial spent fuel transport casks containing multiple assemblies. The receiving capability includes both rail and truck transport, and these casks can be unloaded and the fuel stored in spent fuel storage pools or in dry storage. There are six storage pools capable of storing 50-100 MT of SNF total. Existing SNF dry storage capability is located near the FAST facility. The FAST facility also has the capability to receive and store other special nuclear materials that might be received from other sites in support of the AFCF mission. In addition to fuel receiving and storage capabilities, the FAST facility contains spent fuel dissolvers that might be reconfigured to support AFCF head end processing. Shielded space in this facility might also be used for inspection or for chopping of spent fuel. The facility is designed to be expanded with the addition of a head end processing wing.

Liquid Effluent Treatment & Disposal Facility

The LET&D facility is used to treat liquid radioactive wastes. The AFCF could potentially use the existing capability in recycling spent solutions and in concentrating liquid wastes for solidification.

New Waste Calcining Facility

The NWCF was built to calcine wastes from spent fuel reprocessing. This facility operated until the early 1990's when the calcining process was terminated due to excessive air emissions. Existing equipment and systems within the NWCF could be used as a decontamination facility to support the AFCF mission.

Remote Analytical Laboratory

The RAL is an operating analytical laboratory that supports INTEC operations. Samples are transferred via an overhead shuttle connected to process buildings. The AFCF could use this facility to support its operations.

Integrated Waste Treatment Unit

The IWTU is under construction to support a fluidized bed steam reforming waste solidification process. This facility can be used for treatment, packaging and storage of Cs/Sr wastes. Other AFCF liquid waste streams such as spent solvents might also be processed at the IWTU.

New Facilities Required at INTEC to Support AFCF

The existing facilities at INTEC could support many of the AFCF functions. Certain additional facilities and modifications to existing facilities would be required to fully support the AFCF mission as shown in Table A1-3. A key issue related to the use of existing facilities is the on-site transfer of material or contaminated equipment from one processing area to another.

Table A1-3. Additional Facilities/New Construction Required at the INL INTEC site to Support the AFCF Mission
Head End Processing (SNF chopping, dissolution, metal waste treatment)
Additional Aqueous Processing Hot Cells for UREX+4
Pyrochemical Processing Hot Cells
Fuel Fabrication Hot Cells, LTA Storage Area and LTA Shipping Facility
Waste Solidification and Storage Facility (reduced by the space required for U solidification)
Bench Scale R&D Facility
Support Buildings
Perimeter Intrusion, Detection and Assessment System (PIDAS)

Fuels and Materials Examination Facility (FMEF) at Hanford

The FMEF is located in the 400 Area at Hanford, adjacent to the Fast Flux Test Facility (FFTF) reactor site. Figure A1-4 shows an aerial photograph of the FMEF and the FFTF reactor. The FMEF was originally designed for fuel fabrication, development and post-irradiation examination of breeder reactor fuels. This facility, constructed in the period from 1978 to 1984 as a security Category I structure, was never used for processing nuclear materials. It contains approximately 188,000 ft² of operating space, including several large and many small interconnected hot cells. The processing facility extends from 35 ft below grade to 98 ft above grade and spans 6 levels. A Mechanical Equipment Wing on the west side of the facility houses utility and support equipment, including water treatment equipment, air compressors and a portion of the air conditioning equipment. An Entry Wing is located on the south (front) side.

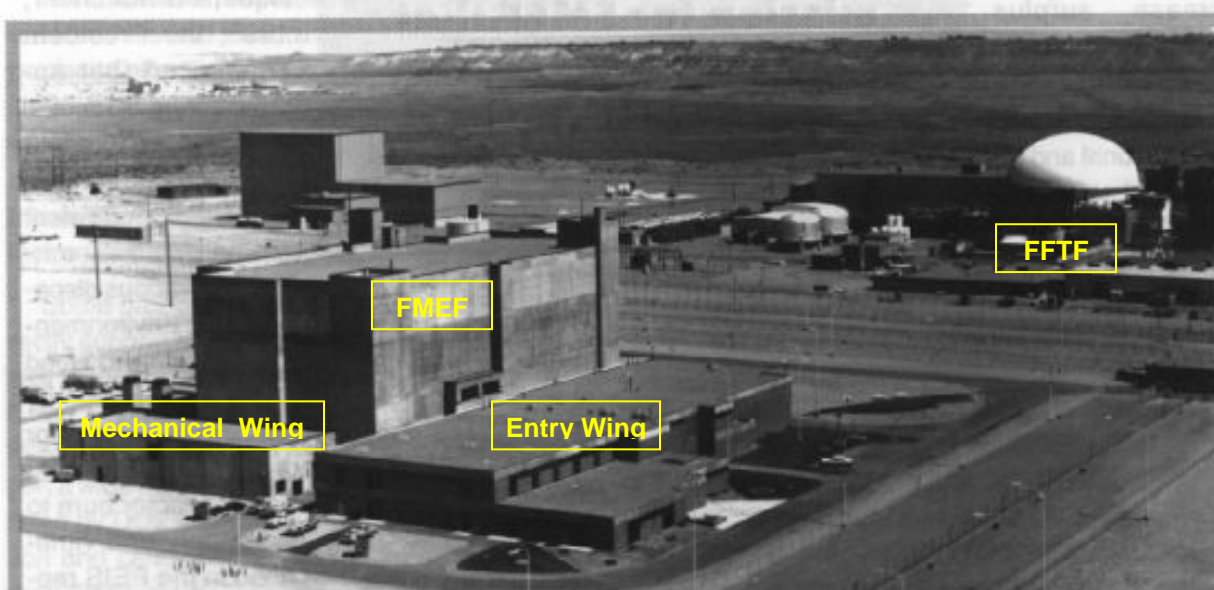


Figure A1-4. Aerial view of the Fuels and Materials Examination Facility at the Hanford Site. In the background (to the right) is the Fast Flux Test Facility.

The south Entry Wing contains a large space originally planned for reactor fuel assembly work and storage area that could be used for cold mock-up, cold machine shop, or other support activity. This wing also includes a lunchroom, change rooms, heating and air conditioning equipment for the wing, and personnel access into the Process Building via a Security Guard Station and automated personnel access control portals located on the first floor of the entry wing. Office space and administration support areas are housed on the second floor of this wing.

Figure A1-5 provides a graphic cut-away view of FMEF. The automated MOX fuel fabrication line (SAF) is shown at the upper 70 ft level. The Upper Process cell (4 ft thick shielding walls) is located at the 42.5 ft level. The Main Process cell (5 ft thick walls) is at the -17 ft level with operator access at the 0.0 ft level. The lower level (not shown) is at the -35 ft level and contains several small and intermediate cells and storage rooms.

The lower (-35 ft level) layout configuration is shown in Figure A1-6. Fourteen process support cells are arranged in two parallel rows along a horizontal transfer corridor. There is currently no connection or means of material transfer directly between adjacent cells. Transfer of material and equipment is made through the central corridor using shielded transfer containers. All of these cells are lined with stainless steel and are capable of being inerted. The smaller cells are 42 sq ft and the larger cells are 78 sq ft, and all have a floor-to-ceiling height of approximately 14 ft. There are a few potential uses for these cells in support of the AFCF mission, including analytical and ceramographic support, process development, and bench scale R&D. The oxide feed conditioning operation would be located in the larger hot cell on this level.

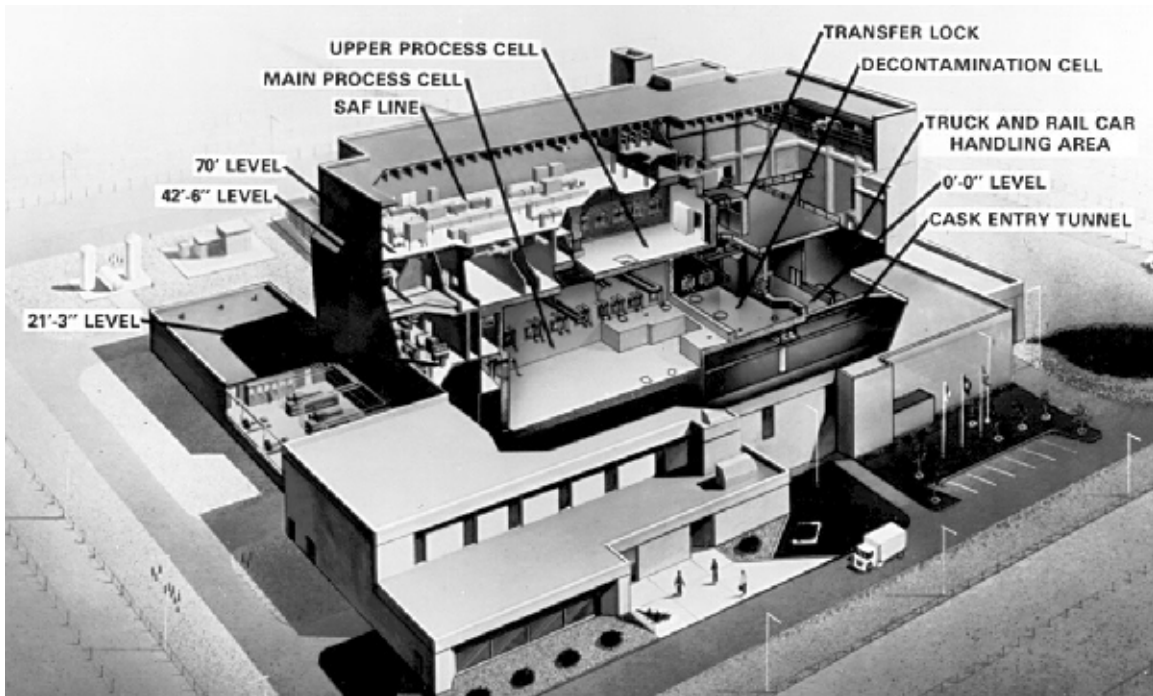


Figure A1-5. Cut away view of the FMEF showing the internal structure of the building.

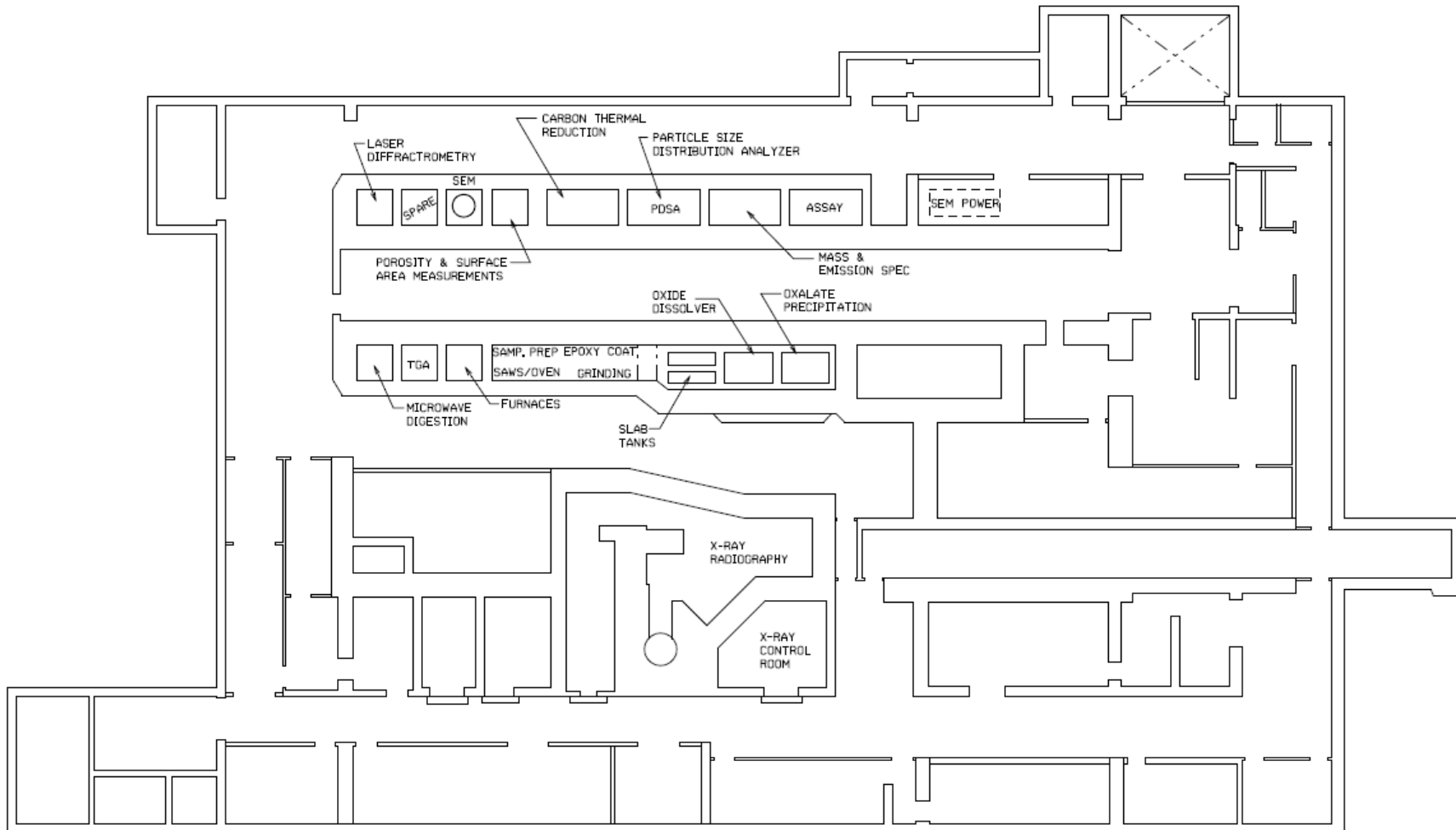


Figure A1-6. FMEF layout for the lower (-35 ft) level. Proposed use of the FMEF hot cells to support AFCF mission requirements is shown in the figure. This level contains feed conditioning and analytical support functions.

Figures A1-7 and A1-8 show potential layouts of the AFCF fuel formation and encapsulation processes using the conceptual design but adapted to the existing FMEF Main and Upper process cells. Figure A1-7 shows fuel formation processes (powder through sintered pellets) housed in the Upper Process Cell. The working area of this cell is approximately 2200 sq ft. (~39 ft wide by ~58 ft long). A continuous pusher style sintering furnace fits along either dimension. There are 14 window openings and 28 manipulator ports located on three sides of this cell. The ceiling height is approximately 24 ft. An overhead crane track is in place but the crane itself was never installed.

Figure A1-8 shows the main process cell floor, located at the -17 ft level. Operator access by manipulators and windows is at the 0.0 ft level. The working area of this cell is approximately 4,900 sq ft. (~39 ft by ~125 ft), and the height of the cell from floor to ceiling is approximately 50 ft. This cell has a carbon steel liner with a corrosive resistant coating of nickel or zinc and was designed to operate under a nitrogen atmosphere. Figure A1-8 shows the fuel encapsulation steps from pellet inspection through final fuel bundle assembly and storage in this cell.

The FMEF contains a (security) Category I shipping and receiving truck and rail car handling area that was designed to receive spent fuel casts. This area could serve as the shipping area for targets or lead test assemblies fabricated within the FMEF as a part of the AFCF.

New Facilities Required at FMEF to Support AFCF

The existing FMEF facility at Hanford could support the oxide fuel fabrication mission of AFCF. Additional facilities and modifications to the existing facility would be required to fully support the AFCF mission as shown in Table A1-4.

Table A1-4. Additional Facilities/New Construction Required at the FMEF at Hanford to Support the AFCF Mission
Spent Fuel Cask Receiving, Unloading, and Spent Fuel Storage Area
Head End Processing (SNF inspection, chopping, dissolution, metal waste treatment)
Aqueous Processing Hot Cells
Pyrochemical Processing Hot Cells
Wet Scrap Recovery Hot Cell
Waste Solidification and Storage Facility
Bench Scale R&D Facility
Support Buildings
Perimeter Intrusion, Detection and Assessment System (PIDAS)

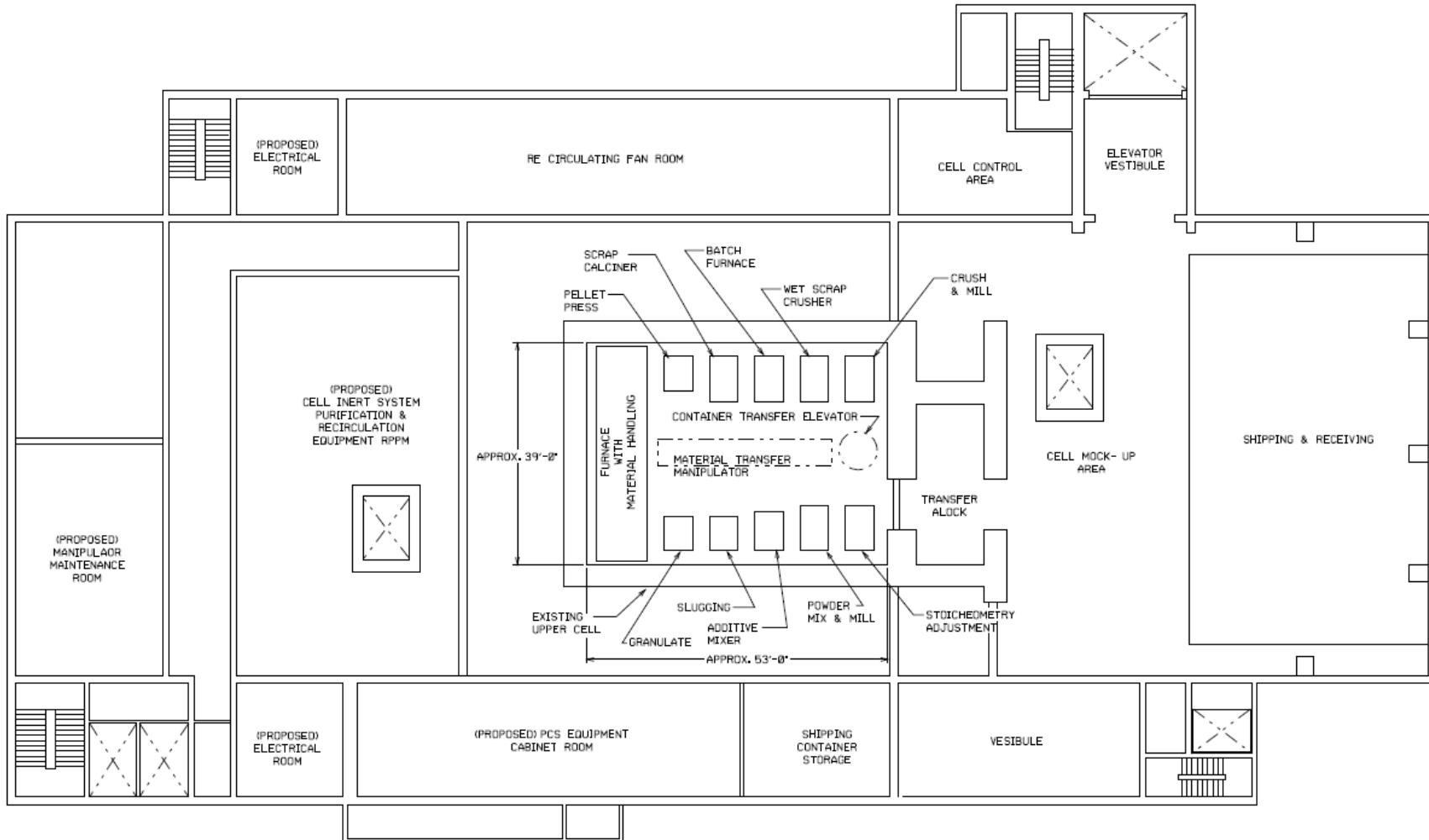


Figure A1-7. FMEF layout for the upper (42.5 ft) level. This figure shows proposed use of the FMEF hot cells at this level for fuel formation equipment.

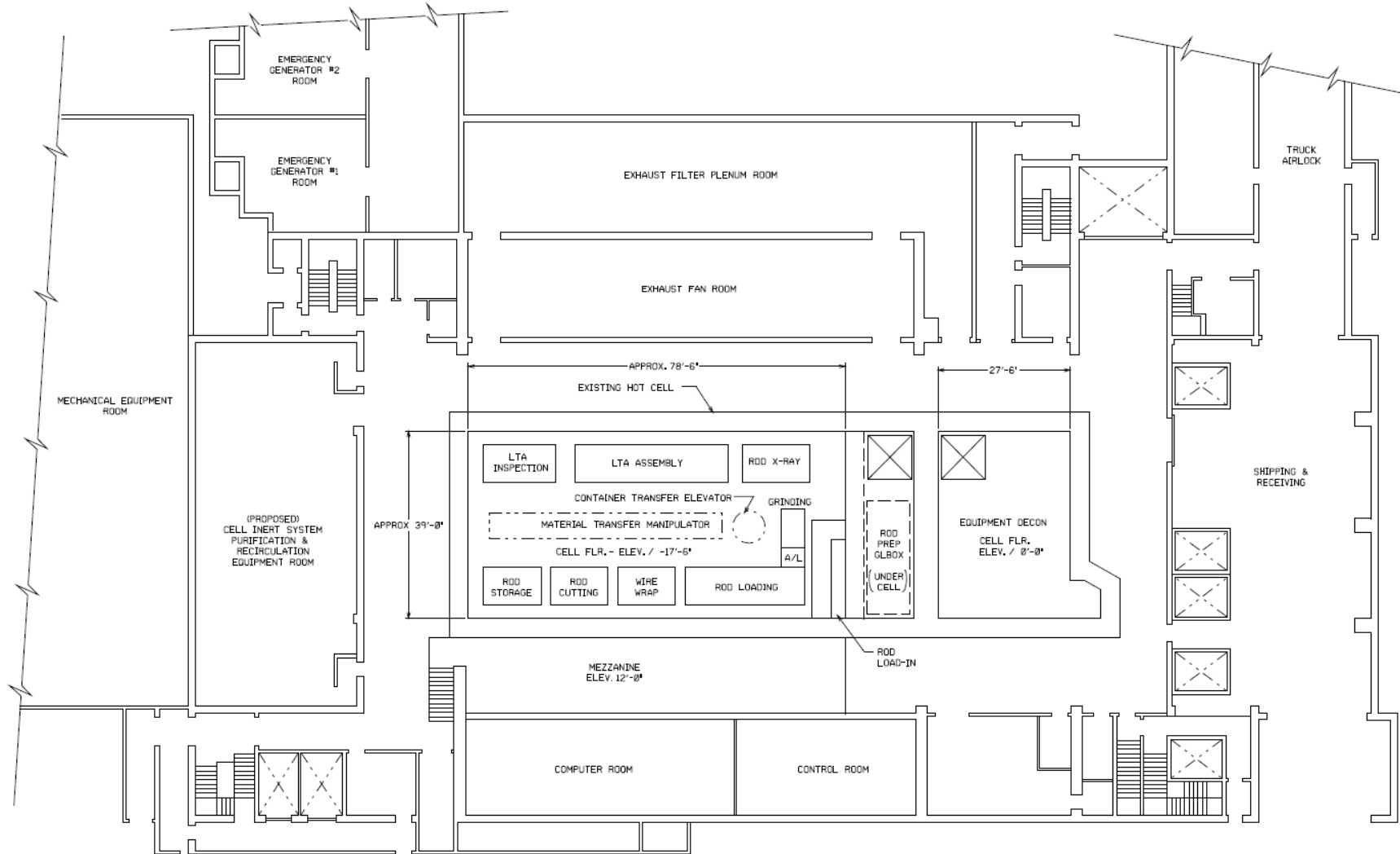


Figure A1-8. FMEF layout for the ground (0 ft) level. This figure shows proposed use of the FMEF hot cells at this level for fuel encapsulation and LTA fabrication equipment.

Tradeoff Analysis

AFCF Baseline Facility

The baseline facility for this analysis is taken from the conceptual design as of November 2006, and is identical to the facility design used in evaluating the construction and operation impacts for the AFCF NEPA Data Study.

In this analysis, it is important to distinguish between two different types of space within a processing building: shielded processing space and operating space. Shielded processing space includes the hot cells and the shield walls for the hot cells. Operating space is all the space within the building outside the shielded processing space. Most of the concrete and steel within the facility are contained within the shielded processing space, and the operating space is assumed to scale linearly with the shielded processing space. For a processing building, a 40% reduction in shielded processing space is assumed to result in a 40% reduction in concrete, aggregate, and steel. The excavation and air emissions impacts will be less than a 40% reduction because of the need to maintain an appropriate slope on the sides of the excavation. Support buildings are assumed to scale with the reduction in shielded processing area. These effects are estimated from a single parameter model that scales with the footprint of the shielded processing area.

INTEC Alternative

For this option, FPR is used for the aqueous separations process equipment, FAST replaces the receiving, unloading and storage for SNF, and RAL replaces 50% of the wet chemistry analytical laboratory (25% of the total analytical space in the conceptual design). In the conceptual design, these functions are located in the Fuel Receiving and Separations Building.

In addition; other INTEC facilities are used for functions that are located in the Byproduct and Waste Solidification Building in the conceptual design: LET&D is used to recover and recycle spent liquids; NWCF replaces baseline decontamination space, and the IWTU replaces the fluidized bed steam reformer for the Cs/Sr and evaporator bottoms processing and solidification processes. These processes have not been sized, and detailed layouts are not available for evaluation of offsets. For the purpose of this study, these functions are assumed to offset 20% of the baseline Byproduct and Waste Solidification Building.

These factors are summarized in Table A1-5. The total reduction in footprint from the conceptual design Fuel Receiving and Separations building is 54% of the baseline footprint. The existing FPR facility support infrastructure such as supply and exhaust ventilation systems, air compressors, air conditioning, etc. can replace some of the AFCF support infrastructure. In the AFCF baseline, most of this equipment is located in a separate mechanical support building or in an exhaust ventilation building. The factor developed for reduction of the processing building footprint is applied to

Table 5. Inputs into the evaluation of construction impact reduction based on use of existing INTEC facilities at INL

INTEC Building	AFCF Function	Location in Conceptual Design	Shielded Processing Offset (ft ²)
FPR	Aqueous Separations	Fuel Receiving & Separations Bldg	24,980 (84%)
FAST	SNF storage		8132 (100%)
RAL	Analytical Laboratory		2250 (25%)
LET&D	Spent Solution Recovery/ Recycle	Byproduct and Waste Solidification Bldg	These functions are not sized in the conceptual design, but are assumed to offset 20% of the footprint of this building
NWCF	Equipment Decontamination		
IWTU	Waste Processing		

these support buildings as well. Construction impacts from needed modifications of the existing INTEC facilities to meet the AFCF mission are not estimated in this analysis.

A total of approximately 54% of the shielded processing footprint and operating corridor footprint in the aqueous separations building is estimated¹⁸ to be offset by the use of the INTEC facilities. This change in new construction footprint is used in a parametric analysis developed for the original NEPA Data Study to evaluate construction impacts such as excavated volume, vehicle fuel consumption (and hence, exhaust emissions) from excavation operations, concrete, aggregate, structural steel, water, etc.

FMEF Alternative

The approach used in assessing potential use of the INTEC facility is also used for the FMEF option. For this option, only the impact of using the shielded process areas in FMEF for fuel fabrication (conditioning, formation, encapsulation, and LTA assembly) activities is considered. As in the case of the INTEC facility, the construction impacts from retrofitting the FMEF to meet AFCF requirements is not considered. In this case, the shielded processing space for fuel fabrication (conditioning, fuel formation, fuel encapsulation, LTA inspection), LTA storage, and LTA shipping are located in the FMEF. This results in a reduction of ~64% in the Fuel Fabrication Building footprint, and the associated mechanical and exhaust buildings. These results are summarized in Table A1-6.

Table A1-6. Inputs into the evaluation of construction impact reduction based on use of the existing FMEF facility at Hanford

FMEF Building	AFCF Function	Location in Conceptual Design	Shielded Processing Offset (ft ²)
FMEF	Fuel Fabrication	Fuel Fabrication Building	20,515 (64%)
	LTA Storage		
	LTA Shipping		

¹⁸ Based on the conceptual design layout

Summary and Analysis of Results

Table A1-7 presents estimated amounts of excavation, bulk materials, and fuels required for the baseline AFCF facility and the reductions or savings in materials and excavation that could result from the use of existing DOE facilities to meet all or part of the AFCF mission. These savings should be considered to be, at best, order-of-magnitude estimates. Table A1-7 shows that, for either of the brownfield alternatives, the estimated construction impacts are reduced from the baseline construction impact on the order of 22-25% for materials and excavation, and 16-17% for fuel consumption and the attendant air emissions from diesel exhaust. These reduced construction impacts do not account for the additional construction impacts associated with retrofitting any of the facilities to meet the AFCF mission. At the present state of knowledge of these existing facilities, the estimated reduction in construction impacts are indistinguishable between the two brownfield alternatives.

This analysis only addresses construction impacts; operational impacts are not analyzed. However, there are several issues that should be identified and quantified if the brownfield alternatives are to be evaluated on an equivalent footing with the greenfield alternative (the baseline). These issues and challenges include:

- meeting the 40+ year lifetime requirement for the AFCF with facilities that are already 20+ years old,
- meeting AFCF mission requirements for flexibility in changing out processing and other equipment in facilities that were designed for other, more limited purposes,
- demonstrating full integration and remote maintainability of processing equipment,
- material transfers between and among distributed facilities
- meeting current codes and standards for nuclear facility licensing, safeguards, security, and facility design basis.

Table A1-7. Summary of estimated construction impact savings (reduction in impact) for the brownfield alternatives.					
	AFCF Baseline	INL – INTEC Brownfield Alternative		Hanford – FMEF Brownfield Alternative	
	Value	Value	Savings from Baseline	Value	Savings from Baseline
Concrete (CY)	277,550	216,350	22%	211,500	24%
Aggregate in Concrete(CY)	334,000	260,000	22%	254,000	24%
Structural Steel (tons)	356,770	285,100	20%	280,800	21%
Liquid Fuels (gal)	2,334,000	1,965,000	16%	1,927,000	17%
Water (gal)	32,375,200	30,000,000	7%	29,815,000	8%
Excavation (CY)	1,324,074	1,034,000	22%	992,000	25%

Appendix A-2 Elemental Composition of LWR Fuel, 100 GWD/MT, 5 year cooled and ABR Fuel, 250 GWD/MT, 1 year cooled				
Element	75 MTIHM LWR Fuel 100 GWD/MT, 5 year cooled		2 MTIHM ABR Oxide Fuel 250 GWD/MT, 1 year cooled	
	grams/day	Kilograms/year	grams/day	Kilograms/year
U	180006	65702	1377	503
Np	418	152	103	38
Pu	3251	1187	2294	837
Am	224	82	229	83
Cm	37	13	66	24
Sr	550	201	17	6
Rb	242	89	8	3
Cs	1749	638	151	55
Ba	1145	418	59	21
La	774	283	46	17
Ce	1505	549	85	31
Pr	707	258	43	16
Nd	2615	954	136	50
Pm	15	5	5	2
Sm	473	173	41	15
Eu	84	31	5	2
Gd	104	38	5	2
Se	35	13	1	1
Br	13	5	0	0
Y	315	115	9	3
Zr	2414	881	98	36
Nb	0	0	0	0
Mo	2130	777	124	45
Ru	1376	502	120	44
Rh	194	71	36	13
Pd	741	270	106	39
Ag	28	10	11	4
Cd	49	18	9	3
Sn	27	10	6	2
Sb	5	2	2	1
Te	283	103	24	9
He	3	1	1	0.4
C	36	13	0	0
I	106	39	14	5
Kr	243	89	9	3
Xe	3096	1130	182	66
Tc	436	159	32	12

Appendix A-3 Activity of LWR Fuel 100 GWD/MTIHM, 5+ year cooled, Maximum Activity							
Isotope	Ci/MTIHM	Ci/day	Ci/yr	Isotope	Ci/MTIHM	Ci/day	Ci/yr
Activation Products				Activation Products (continued)			
H3	2.30E+00	4.72E-01	1.72E+02	Cd113m	1.57E-07	3.23E-08	1.18E-05
Be10	1.34E-05	2.76E-06	1.01E-03	Cd115m	2.76E-14	5.68E-15	2.07E-12
C14	3.39E+00	6.96E-01	2.54E+02	In113m	3.38E-02	6.94E-03	2.53E+00
Si32	7.39E-05	1.52E-05	5.54E-03	In114	3.62E-09	7.44E-10	2.71E-07
P32	7.39E-05	1.52E-05	5.54E-03	In114m	3.78E-09	7.77E-10	2.84E-07
P33	3.52E-24	7.23E-25	2.64E-22	In115m	3.05E-18	6.27E-19	2.29E-16
S35	3.23E-13	6.64E-14	2.42E-11	Sn113	3.37E-02	6.93E-03	2.53E+00
Ca45	7.98E-05	1.64E-05	5.99E-03	Sn117m	5.83E-37	1.20E-37	4.38E-35
Sc46	1.03E-06	2.11E-07	7.71E-05	Sn119m	2.08E+02	4.28E+01	1.56E+04
Sc47	0.00E+00	0.00E+00	0.00E+00	Sn121	1.22E+00	2.50E-01	9.12E+01
V49	2.68E-05	5.50E-06	2.01E-03	Sn121m	1.57E+00	3.22E-01	1.18E+02
Cr51	4.23E-16	8.68E-17	3.17E-14	Sn123	2.35E-02	4.82E-03	1.76E+00
Mn54	2.72E+01	5.60E+00	2.04E+03	Sn125	0.00E+00	0.00E+00	0.00E+00
Fe55	2.27E+03	4.66E+02	1.70E+05	Sb122	0.00E+00	0.00E+00	0.00E+00
Fe59	2.40E-10	4.93E-11	1.80E-08	Sb124	6.25E-08	1.29E-08	4.69E-06
Co58	1.32E-04	2.72E-05	9.92E-03	Sb125	5.26E+02	1.08E+02	3.95E+04
Co60	8.69E+03	1.79E+03	6.52E+05	Sb126	0.00E+00	0.00E+00	0.00E+00
Ni59	7.28E+00	1.50E+00	5.46E+02	Te123m	4.50E-04	9.24E-05	3.37E-02
Ni63	1.00E+03	2.06E+02	7.52E+04	Te125m	1.29E+02	2.64E+01	9.64E+03
Zn65	4.32E-05	8.88E-06	3.24E-03	Te127	2.06E-06	4.23E-07	1.54E-04
Rb86	1.24E-34	2.55E-35	9.29E-33	Te127m	2.10E-06	4.32E-07	1.58E-04
Sr89	2.75E-10	5.66E-11	2.07E-08	Te129	1.00E-22	2.06E-23	7.51E-21
Sr90	7.61E-03	1.56E-03	5.71E-01	Te129m	1.56E-22	3.21E-23	1.17E-20
Y89m	2.56E-14	5.26E-15	1.92E-12	I126	0.00E+00	0.00E+00	0.00E+00
Y90	7.61E-03	1.56E-03	5.71E-01	Xe127	1.54E-21	3.16E-22	1.15E-19
Y91	5.36E-08	1.10E-08	4.02E-06	Xe129m	0.00E+00	0.00E+00	0.00E+00
Zr89	0.00E+00	0.00E+00	0.00E+00	Actinides and Daughters			
Zr93	2.49E-01	5.11E-02	1.86E+01				
Zr95	1.39E-04	2.85E-05	1.04E-02	Tl207	1.77E-04	3.64E-05	1.33E-02
Nb91	4.86E-05	9.99E-06	3.65E-03	Tl208	5.94E-02	1.22E-02	4.46E+00
Nb92	2.77E-06	5.69E-07	2.08E-04	Tl209	9.19E-08	1.89E-08	6.89E-06
Nb93m	1.14E+02	2.35E+01	8.56E+03	Pb209	4.37E-06	8.99E-07	3.28E-04
Nb94	3.16E+00	6.49E-01	2.37E+02	Pb210	8.15E-06	1.67E-06	6.11E-04
Nb95	3.06E-04	6.28E-05	2.29E-02	Pb211	1.77E-04	3.65E-05	1.33E-02
Nb95m	1.63E-06	3.35E-07	1.22E-04	Pb212	1.65E-01	3.40E-02	1.24E+01
Mo93	1.95E-01	4.00E-02	1.46E+01	Pb214	2.16E-05	4.44E-06	1.62E-03
Mo99	0.00E+00	0.00E+00	0.00E+00	Bi210	8.15E-06	1.67E-06	6.11E-04
Tc98	1.98E-08	4.07E-09	1.49E-06	Bi211	1.77E-04	3.65E-05	1.33E-02
Tc99	2.12E-02	4.37E-03	1.59E+00	Bi212	1.65E-01	3.40E-02	1.24E+01
Tc99m	0.00E+00	0.00E+00	0.00E+00	Bi213	4.37E-06	8.99E-07	3.28E-04
Ru103	5.89E-15	1.21E-15	4.41E-13	Bi214	2.16E-05	4.44E-06	1.62E-03
Rh102	1.20E-07	2.47E-08	9.03E-06	Po210	8.15E-06	1.67E-06	6.11E-04
Rh103m	5.88E-15	1.21E-15	4.41E-13	Po211	4.88E-07	1.00E-07	3.66E-05
Pd103	0.00E+00	0.00E+00	0.00E+00	Po212	1.06E-01	2.18E-02	7.94E+00
Ag109m	3.02E-03	6.21E-04	2.27E-01	Po213	4.28E-06	8.80E-07	3.21E-04
Ag110	1.71E-07	3.52E-08	1.28E-05	Po214	2.16E-05	4.44E-06	1.62E-03
Ag110m	1.26E-05	2.59E-06	9.44E-04	Po215	1.77E-04	3.65E-05	1.33E-02
Ag111	0.00E+00	0.00E+00	0.00E+00	Po216	1.65E-01	3.40E-02	1.24E+01
Cd109	3.02E-03	6.21E-04	2.27E-01	Po218	2.16E-05	4.44E-06	1.62E-03

Appendix A-3 Activity of LWR Fuel 100 GWD/MTIHM, 5+ year cooled, Maximum Activity							
Isotope	Ci/MTIHM	Ci/day	Ci/yr	Isotope	Ci/MTIHM	Ci/day	Ci/yr
Actinides and Daughters (continued)				Actinides and Daughters (continued)			
At217	4.38E-06	8.99E-07	3.28E-04	Pu243	2.39E-05	4.90E-06	1.79E-03
Rn218	0.00E+00	0.00E+00	0.00E+00	Pu244	2.71E-06	5.57E-07	2.03E-04
Rn219	1.77E-04	3.65E-05	1.33E-02	Pu246	8.09E-10	1.66E-10	6.07E-08
Rn220	1.65E-01	3.40E-02	1.24E+01	Am241	8.37E+03	1.72E+03	6.28E+05
Rn222	2.16E-05	4.44E-06	1.62E-03	Am242m	4.35E+01	8.94E+00	3.26E+03
Fr221	4.38E-06	8.99E-07	3.28E-04	Am242	4.33E+01	8.90E+00	3.25E+03
Fr223	2.45E-06	5.03E-07	1.84E-04	Am243	1.44E+02	2.95E+01	1.08E+04
Ra222	3.61E-33	7.41E-34	2.71E-31	Am245	2.71E-07	5.56E-08	2.03E-05
Ra223	1.77E-04	3.65E-05	1.33E-02	Am246	8.09E-10	1.66E-10	6.07E-08
Ra224	1.65E-01	3.40E-02	1.24E+01	Cm241	1.16E-18	2.39E-19	8.73E-17
Ra225	4.38E-06	8.99E-07	3.28E-04	Cm242	9.45E+01	1.94E+01	7.09E+03
Ra226	2.16E-05	4.44E-06	1.62E-03	Cm243	1.05E+02	2.15E+01	7.84E+03
Ac225	4.38E-06	8.99E-07	3.28E-04	Cm244	3.74E+04	7.68E+03	2.80E+06
Ac227	1.77E-04	3.64E-05	1.33E-02	Cm245	6.74E+00	1.38E+00	5.05E+02
Th226	3.70E-33	7.60E-34	2.77E-31	Cm246	2.90E+00	5.95E-01	2.17E+02
Th227	1.75E-04	3.60E-05	1.31E-02	Cm247	2.39E-05	4.90E-06	1.79E-03
Th228	1.65E-01	3.40E-02	1.24E+01	Cm248	1.54E-04	3.16E-05	1.15E-02
Th229	4.37E-06	8.99E-07	3.28E-04	Cm249	8.91E-36	1.83E-36	6.68E-34
Th230	2.02E-03	4.15E-04	1.52E-01	Cm250	3.24E-09	6.65E-10	2.43E-07
Th231	5.74E-02	1.18E-02	4.30E+00	Bk249	1.87E-02	3.84E-03	1.40E+00
Th234	2.90E-01	5.95E-02	2.17E+01	Bk250	2.21E-06	4.55E-07	1.66E-04
Pa231	2.44E-04	5.01E-05	1.83E-02	Bk251	6.37E-19	1.31E-19	4.78E-17
Pa233	1.53E+00	3.14E-01	1.15E+02	Cf249	2.88E-03	5.91E-04	2.16E-01
Pa234m	2.90E-01	5.95E-02	2.17E+01	Cf250	2.87E-02	5.90E-03	2.15E+00
Pa234	3.77E-04	7.74E-05	2.83E-02	Cf251	2.64E-04	5.42E-05	1.98E-02
U230	3.68E-33	7.57E-34	2.76E-31	Cf252	2.80E-02	5.75E-03	2.10E+00
U232	1.71E-01	3.51E-02	1.28E+01	Cf253	1.62E-33	3.34E-34	1.22E-31
U233	4.36E-04	8.96E-05	3.27E-02	Cf254	1.79E-13	3.67E-14	1.34E-11
U234	5.19E+00	1.07E+00	3.89E+02	Es253	1.26E-28	2.60E-29	9.48E-27
U235	5.74E-02	1.18E-02	4.30E+00	Es254	2.21E-06	4.55E-07	1.66E-04
U236	1.14E+00	2.34E-01	8.54E+01	Es255	6.37E-19	1.31E-19	4.77E-17
U237	5.18E+00	1.06E+00	3.89E+02	Fission Products			
U238	2.90E-01	5.95E-02	2.17E+01				
U240	2.71E-06	5.56E-07	2.03E-04	H3	1.79E+03	3.67E+02	1.34E+05
Np235	5.51E-03	1.13E-03	4.13E-01	Be7	6.68E-17	1.37E-17	5.01E-15
Np236	2.12E-05	4.36E-06	1.59E-03	Be10	6.17E-04	1.27E-04	4.63E-02
Np237	1.53E+00	3.14E-01	1.15E+02	C14	3.82E-02	7.86E-03	2.87E+00
Np238	1.96E-01	4.02E-02	1.47E+01	Ge71	0.00E+00	0.00E+00	0.00E+00
Np239	1.44E+02	2.95E+01	1.08E+04	As73	3.23E-12	6.63E-13	2.42E-10
Np240m	2.71E-06	5.56E-07	2.03E-04	As74	1.32E-34	2.71E-35	9.88E-33
Np240	3.25E-09	6.68E-10	2.44E-07	Se75	3.53E-09	7.25E-10	2.64E-07
Pu236	7.39E-01	1.52E-01	5.54E+01	Se79	2.22E-01	4.57E-02	1.67E+01
Pu237	2.80E-11	5.74E-12	2.10E-09	Kr81	1.05E-06	2.15E-07	7.85E-05
Pu238	2.09E+04	4.29E+03	1.57E+06	Rb83	3.18E-09	6.52E-10	2.38E-07
Pu239	5.32E+02	1.09E+02	3.99E+04	Rb84	6.90E-17	1.42E-17	5.17E-15
Pu240	8.06E+02	1.66E+02	6.04E+04	Kr85	2.10E+04	4.32E+03	1.58E+06
Pu241	2.17E+05	4.45E+04	1.62E+07	Sr85	1.24E-11	2.55E-12	9.32E-10
Pu242	7.49E+00	1.54E+00	5.62E+02	Rb86	1.93E-26	3.96E-27	1.44E-24

Appendix A-3 Activity of LWR Fuel 100 GWD/MTIHM, 5+ year cooled, Maximum Activity							
Isotope	Ci/MTIHM	Ci/day	Ci/yr	Isotope	Ci/MTIHM	Ci/day	Ci/yr
Fission Products (continued)				Fission Products (continued)			
Rb87	7.07E-05	1.45E-05	5.30E-03	Sb120m	0.00E+00	0.00E+00	0.00E+00
Y88	4.16E-05	8.55E-06	3.12E-03	Sn121	2.71E+01	5.57E+00	2.03E+03
Zr88	2.03E-13	4.17E-14	1.52E-11	Sn121m	3.49E+01	7.18E+00	2.62E+03
Sr89	1.37E-05	2.81E-06	1.02E-03	Te121	1.47E-08	3.03E-09	1.10E-06
Y89m	1.27E-09	2.61E-10	9.53E-08	Te121m	1.48E-08	3.04E-09	1.11E-06
Sr90	2.16E+05	4.44E+04	1.62E+07	Sb122	0.00E+00	0.00E+00	0.00E+00
Y90	2.16E+05	4.44E+04	1.62E+07	Sn123	1.13E-01	2.32E-02	8.46E+00
Y91	5.43E-04	1.12E-04	4.07E-02	Te123m	9.22E-04	1.90E-04	6.92E-02
Nb91	5.71E-08	1.17E-08	4.28E-06	Sb124	1.96E-06	4.03E-07	1.47E-04
Zr93	5.66E+00	1.16E+00	4.25E+02	Sn125	0.00E+00	0.00E+00	0.00E+00
Nb93m	5.10E+00	1.05E+00	3.82E+02	Sb125	4.95E+03	1.02E+03	3.71E+05
Mo93	7.25E-07	1.49E-07	5.44E-05	Te125m	1.21E+03	2.48E+02	9.07E+04
Nb94	3.49E-04	7.18E-05	2.62E-02	I125	1.28E-14	2.63E-15	9.61E-13
Zr95	4.65E-03	9.55E-04	3.49E-01	Sn126	1.60E+00	3.28E-01	1.20E+02
Nb95	1.02E-02	2.10E-03	7.68E-01	Sb126	2.23E-01	4.59E-02	1.67E+01
Nb95m	5.47E-05	1.12E-05	4.10E-03	Sb126m	1.60E+00	3.28E-01	1.20E+02
Tc97	2.69E-09	5.53E-10	2.02E-07	I126	0.00E+00	0.00E+00	0.00E+00
Tc97m	5.51E-10	1.13E-10	4.13E-08	Sb127	0.00E+00	0.00E+00	0.00E+00
Tc98	3.55E-05	7.29E-06	2.66E-03	Te127	1.73E-01	3.55E-02	1.30E+01
Mo99	0.00E+00	0.00E+00	0.00E+00	Te127m	1.76E-01	3.62E-02	1.32E+01
Tc99	3.63E+01	7.46E+00	2.72E+03	Xe127	5.42E-16	1.11E-16	4.06E-14
Tc99m	0.00E+00	0.00E+00	0.00E+00	Te129	1.69E-12	3.47E-13	1.27E-10
Rh101	3.93E-06	8.08E-07	2.95E-04	Te129m	2.63E-12	5.41E-13	1.97E-10
Rh102	2.26E-02	4.64E-03	1.69E+00	I129	7.82E-02	1.61E-02	5.86E+00
Rh102m	5.74E-05	1.18E-05	4.30E-03	Xe129m	0.00E+00	0.00E+00	0.00E+00
Ru103	1.93E-08	3.96E-09	1.45E-06	I131	0.00E+00	0.00E+00	0.00E+00
Rh103m	1.92E-08	3.95E-09	1.44E-06	Xe131m	0.00E+00	0.00E+00	0.00E+00
Pd103	9.21E-32	1.89E-32	6.91E-30	Cs131	0.00E+00	0.00E+00	0.00E+00
Ag105	1.14E-21	2.34E-22	8.54E-20	Ba131	0.00E+00	0.00E+00	0.00E+00
Ru106	3.35E+04	6.89E+03	2.51E+06	Te132	0.00E+00	0.00E+00	0.00E+00
Rh106	3.35E+04	6.89E+03	2.51E+06	I132	0.00E+00	0.00E+00	0.00E+00
Pd107	3.60E-01	7.41E-02	2.70E+01	Cs132	0.00E+00	0.00E+00	0.00E+00
Ag108	4.80E-06	9.87E-07	3.60E-04	Xe133	0.00E+00	0.00E+00	0.00E+00
Ag108m	5.52E-05	1.14E-05	4.14E-03	Ba133	6.35E-01	1.31E-01	4.76E+01
Ag109m	7.00E-02	1.44E-02	5.25E+00	Cs134	1.21E+05	2.49E+04	9.08E+06
Cd109	7.00E-02	1.44E-02	5.25E+00	Cs135	2.47E+00	5.07E-01	1.85E+02
Ag110	1.04E+00	2.14E-01	7.80E+01	Cs136	3.32E-37	6.81E-38	2.49E-35
Ag110m	7.65E+01	1.57E+01	5.73E+03	Ba136m	0.00E+00	0.00E+00	0.00E+00
Ag111	0.00E+00	0.00E+00	0.00E+00	Cs137	2.74E+05	5.63E+04	2.06E+07
Cd113m	1.19E+00	2.44E-01	8.92E+01	Ba137m	2.59E+05	5.32E+04	1.94E+07
In113m	1.31E-11	2.69E-12	9.83E-10	La137	2.01E-05	4.13E-06	1.51E-03
Sn113	1.31E-11	2.69E-12	9.82E-10	Ce139	4.87E-05	1.00E-05	3.65E-03
In114	2.26E-12	4.65E-13	1.70E-10	Ba140	1.24E-37	2.56E-38	9.34E-36
In114m	2.37E-12	4.86E-13	1.78E-10	La140	2.36E-37	4.86E-38	1.77E-35
Cd115m	3.15E-10	6.48E-11	2.36E-08	Ce141	2.14E-11	4.40E-12	1.61E-09
In115m	3.48E-14	7.15E-15	2.61E-12	Pr143	5.53E-35	1.14E-35	4.15E-33
Sn117m	2.92E-38	5.99E-39	2.19E-36	Pm143	9.02E-11	1.85E-11	6.76E-09
Sn119m	3.66E+00	7.52E-01	2.74E+02	Ce144	1.85E+04	3.80E+03	1.39E+06

Appendix A-3 Activity of LWR Fuel 100 GWD/MTIHM, 5+ year cooled, Maximum Activity							
Isotope	Ci/MTIHM	Ci/day	Ci/yr	Isotope	Ci/MTIHM	Ci/day	Ci/yr
Fission Products (continued)				Fission Products (continued)			
Pr144	1.85E+04	3.80E+03	1.39E+06	Gd153	1.31E-01	2.70E-02	9.86E+00
Pr144m	2.59E+02	5.32E+01	1.94E+04	Eu154	1.89E+04	3.89E+03	1.42E+06
Nd144	5.53E-09	1.14E-09	4.14E-07	Eu155	4.97E+03	1.02E+03	3.72E+05
Pm144	1.36E-07	2.79E-08	1.02E-05	Eu156	5.53E-31	1.14E-31	4.15E-29
Pm145	9.96E-03	2.05E-03	7.47E-01	Tb157	8.63E-06	1.77E-06	6.48E-04
Sm145	4.90E-04	1.01E-04	3.68E-02	Tb158	7.45E-05	1.53E-05	5.59E-03
Pm146	5.81E-01	1.19E-01	4.36E+01	Dy159	1.22E-07	2.50E-08	9.14E-06
Sm146	1.26E-06	2.58E-07	9.42E-05	Tb160	1.17E-04	2.40E-05	8.76E-03
Nd147	0.00E+00	0.00E+00	0.00E+00	Tb161	0.00E+00	0.00E+00	0.00E+00
Pm147	6.63E+04	1.36E+04	4.97E+06	Ho163	1.27E-07	2.61E-08	9.53E-06
Sm147	1.17E-05	2.40E-06	8.75E-04	Dy166	0.00E+00	0.00E+00	0.00E+00
Pm148	2.19E-10	4.49E-11	1.64E-08	Ho166	0.00E+00	0.00E+00	0.00E+00
Pm148m	4.14E-09	8.50E-10	3.10E-07	Ho166m	5.49E-03	1.13E-03	4.12E-01
Pm149	0.00E+00	0.00E+00	0.00E+00	Tm168	6.25E-11	1.28E-11	4.68E-09
Eu149	3.66E-12	7.53E-13	2.75E-10	Er169	0.00E+00	0.00E+00	0.00E+00
Sm151	1.16E+03	2.39E+02	8.74E+04	Yb169	1.98E-22	4.08E-23	1.49E-20
Gd151	4.30E-07	8.83E-08	3.22E-05	Tm170	7.77E-05	1.60E-05	5.82E-03
Eu152	2.27E+01	4.66E+00	1.70E+03	Tm171	4.58E-02	9.41E-03	3.44E+00

Appendix A-4 Activity of ABR Fuel 250 GWD/MTIHM, 1+ year cooled, Maximum Activity							
Isotope	Ci/MTIHM	Ci/day	Ci/yr	Isotope	Ci/MTIHM	Ci/day	Ci/yr
Activation Products				Actinides and Daughters (continued)			
H3	1.440E+00	1.136E-02	2.880E+00	Tl209	2.295E-07	1.811E-09	4.590E-07
Be10	9.388E-05	7.408E-07	1.878E-04	Pb209	1.063E-05	8.388E-08	2.126E-05
C14	2.898E+00	2.287E-02	5.796E+00	Pb210	4.251E-05	3.354E-07	8.502E-05
Ar39	4.077E-16	3.217E-18	8.154E-16	Pb211	6.229E-06	4.915E-08	1.246E-05
K42	2.741E-16	2.163E-18	5.482E-16	Pb212	1.341E-03	1.058E-05	2.682E-03
Ca45	2.440E-05	1.925E-07	4.880E-05	Pb214	1.332E-04	1.051E-06	2.664E-04
Ca47	4.546E-28	3.587E-30	9.092E-28	Bi210m	3.247E-18	2.562E-20	6.494E-18
Sc46	8.302E-09	6.551E-11	1.660E-08	Bi210	4.252E-05	3.355E-07	8.504E-05
Sc47	1.740E-27	1.373E-29	3.480E-27	Bi211	6.229E-06	4.915E-08	1.246E-05
Cr51	3.459E+01	2.729E-01	6.918E+01	Bi212	1.341E-03	1.058E-05	2.682E-03
Mn54	9.894E+05	7.807E+03	1.979E+06	Bi213	1.063E-05	8.388E-08	2.126E-05
Fe55	1.729E+05	1.364E+03	3.458E+05	Bi214	1.332E-04	1.051E-06	2.664E-04
Fe59	5.986E+01	4.723E-01	1.197E+02	Po210	4.252E-05	3.355E-07	8.504E-05
Co58	6.834E+03	5.392E+01	1.367E+04	Po211	1.744E-08	1.376E-10	3.488E-08
Co60	1.250E+03	9.863E+00	2.500E+03	Po212	8.590E-04	6.778E-06	1.718E-03
Ni59	1.781E+00	1.405E-02	3.562E+00	Po213	1.040E-05	8.206E-08	2.080E-05
Ni63	2.540E+02	2.004E+00	5.080E+02	Po214	1.331E-04	1.050E-06	2.662E-04
Zn65	8.574E-06	6.765E-08	1.715E-05	Po215	6.229E-06	4.915E-08	1.246E-05
Sr89	2.166E-04	1.709E-06	4.332E-04	Po216	1.341E-03	1.058E-05	2.682E-03
Sr90	4.896E-05	3.863E-07	9.792E-05	Po218	1.332E-04	1.051E-06	2.664E-04
Y90	4.897E-05	3.864E-07	9.794E-05	At217	1.063E-05	8.388E-08	2.126E-05
Y91	6.911E-05	5.453E-07	1.382E-04	Rn218	3.623E-13	2.859E-15	7.246E-13
Zr93	5.959E-04	4.702E-06	1.192E-03	Rn219	6.229E-06	4.915E-08	1.246E-05
Zr95	1.418E+00	1.119E-02	2.836E+00	Rn220	1.341E-03	1.058E-05	2.682E-03
Nb93m	5.273E-04	4.161E-06	1.055E-03	Rn222	1.332E-04	1.051E-06	2.664E-04
Nb94	5.487E-02	4.329E-04	1.097E-01	Fr221	1.063E-05	8.388E-08	2.126E-05
Nb95	3.158E+00	2.492E-02	6.316E+00	Fr223	8.589E-08	6.777E-10	1.718E-07
Nb95m	1.052E-02	8.301E-05	2.104E-02	Ra222	3.623E-13	2.859E-15	7.246E-13
Mo93	2.492E+00	1.966E-02	4.984E+00	Ra223	6.229E-06	4.915E-08	1.246E-05
Tc98	3.340E-06	2.635E-08	6.680E-06	Ra224	1.341E-03	1.058E-05	2.682E-03
Tc99	9.330E-01	7.362E-03	1.866E+00	Ra225	1.063E-05	8.388E-08	2.126E-05
Ru103	1.075E+00	8.482E-03	2.150E+00	Ra226	1.332E-04	1.051E-06	2.664E-04
Ru106	1.516E-07	1.196E-09	3.032E-07	Ra228	6.662E-11	5.257E-13	1.332E-10
Rh102	2.142E-04	1.690E-06	4.284E-04	Ac225	1.063E-05	8.388E-08	2.126E-05
Rh106	1.516E-07	1.196E-09	3.032E-07	Ac227	6.224E-06	4.911E-08	1.245E-05
Pd107	6.538E-12	5.159E-14	1.308E-11	Ac228	6.662E-11	5.257E-13	1.332E-10
Ag106	1.104E-29	8.711E-32	2.208E-29	Th226	3.623E-13	2.859E-15	7.246E-13
Ag108	9.899E-19	7.811E-21	1.980E-18	Th227	6.143E-06	4.847E-08	1.229E-05
Ag108m	1.112E-17	8.774E-20	2.224E-17	Th228	1.341E-03	1.058E-05	2.682E-03
Ag109m	3.949E-16	3.116E-18	7.898E-16	Th229	1.063E-05	8.388E-08	2.126E-05
Ag110	1.278E-13	1.008E-15	2.556E-13	Th230	1.637E-02	1.292E-04	3.274E-02
Ag110m	9.612E-12	7.584E-14	1.922E-11	Th231	1.162E-03	9.169E-06	2.324E-03
Ag111	3.721E-28	2.936E-30	7.442E-28	Th232	9.163E-11	7.230E-13	1.833E-10
Cd109	3.949E-16	3.116E-18	7.898E-16	Th234	8.397E-02	6.626E-04	1.679E-01
Actinides and Daughters				Pa231	8.134E-06	6.418E-08	1.627E-05
				Pa233	1.554E+01	1.226E-01	3.108E+01
Tl206	3.234E-18	2.552E-20	6.468E-18	Pa234m	8.397E-02	6.626E-04	1.679E-01
Tl207	6.212E-06	4.902E-08	1.242E-05	Pa234	1.092E-04	8.616E-07	2.184E-04
Tl208	4.817E-04	3.801E-06	9.634E-04	U230	3.619E-13	2.856E-15	7.238E-13

Appendix A-4 Activity of ABR Fuel 250 GWD/MTIHM, 1+ year cooled, Maximum Activity							
Isotope	Ci/MTIHM	Ci/day	Ci/yr	Isotope	Ci/MTIHM	Ci/day	Ci/yr
Actinides and Daughters (continued)				Actinides and Daughters (continued)			
U231	1.141E-31	9.003E-34	2.282E-31	Es254m	0.000E+00	0.000E+00	0.000E+00
U232	1.311E-03	1.034E-05	2.622E-03	Es254	6.932E-11	5.470E-13	1.386E-10
U233	3.680E-03	2.904E-05	7.360E-03	Fission Products			
U234	6.220E+01	4.908E-01	1.244E+02				
U235	1.162E-03	9.169E-06	2.324E-03	H3	4.329E+03	3.416E+01	8.658E+03
U236	6.255E-02	4.935E-04	1.251E-01	Be10	2.135E-05	1.685E-07	4.270E-05
U237	8.565E+01	6.758E-01	1.713E+02	C14	8.607E-04	6.791E-06	1.721E-03
U238	8.393E-02	6.622E-04	1.679E-01	Kr81	4.390E-06	3.464E-08	8.780E-06
U240	2.735E-06	2.158E-08	5.470E-06	Kr85	3.527E+04	2.783E+02	7.054E+04
Np237	1.554E+01	1.226E-01	3.108E+01	Rb86	4.580E-02	3.614E-04	9.160E-02
Np238	6.666E+01	5.260E-01	1.333E+02	Rb87	8.513E-05	6.717E-07	1.703E-04
Np239	3.500E+03	2.762E+01	7.000E+03	Sr89	1.013E+04	7.993E+01	2.026E+04
Np240m	2.735E-06	2.158E-08	5.470E-06	Sr90	2.405E+05	1.898E+03	4.810E+05
Pu236	5.472E-03	4.318E-05	1.094E-02	Y90	2.405E+05	1.898E+03	4.810E+05
Pu237	9.032E+00	7.127E-02	1.806E+01	Y91	2.806E+04	2.214E+02	5.612E+04
Pu238	4.685E+05	3.697E+03	9.370E+05	Zr93	9.033E+00	7.127E-02	1.807E+01
Pu239	9.263E+03	7.309E+01	1.853E+04	Nb93m	8.011E+00	6.321E-02	1.602E+01
Pu240	3.554E+04	2.804E+02	7.108E+04	Nb94	3.283E-03	2.590E-05	6.566E-03
Pu241	3.491E+06	2.755E+04	6.982E+06	Zr95	7.780E+04	6.139E+02	1.556E+05
Pu242	2.288E+02	1.805E+00	4.576E+02	Nb95	1.690E+05	1.333E+03	3.380E+05
Pu243	3.990E-04	3.148E-06	7.980E-04	Nb95m	5.771E+02	4.554E+00	1.154E+03
Pu244	2.739E-06	2.161E-08	5.478E-06	Tc98	3.812E-04	3.008E-06	7.624E-04
Pu246	7.211E-13	5.690E-15	1.442E-12	Tc99	9.783E+01	7.719E-01	1.957E+02
Am241	1.722E+05	1.359E+03	3.444E+05	Rh102	1.175E+02	9.271E-01	2.350E+02
Am242m	1.333E+04	1.052E+02	2.666E+04	Ru103	9.872E+03	7.789E+01	1.974E+04
Am242	1.327E+04	1.047E+02	2.654E+04	Rh103m	8.900E+03	7.022E+01	1.780E+04
Am243	3.500E+03	2.762E+01	7.000E+03	Ru106	2.054E+06	1.621E+04	4.108E+06
Am245	1.490E-05	1.176E-07	2.980E-05	Rh106	2.054E+06	1.621E+04	4.108E+06
Am246	7.212E-13	5.691E-15	1.442E-12	Ag106	1.457E-17	1.150E-19	2.914E-17
Cm241	3.692E-03	2.913E-05	7.384E-03	Pd107	1.911E+00	1.508E-02	3.822E+00
Cm242	7.842E+05	6.188E+03	1.568E+06	Ag108	7.259E-05	5.728E-07	1.452E-04
Cm243	4.053E+03	3.198E+01	8.106E+03	Ag108m	8.156E-04	6.435E-06	1.631E-03
Cm244	7.794E+05	6.150E+03	1.559E+06	Ag109m	2.364E+00	1.865E-02	4.728E+00
Cm245	3.309E+02	2.611E+00	6.618E+02	Cd109	2.364E+00	1.865E-02	4.728E+00
Cm246	4.539E+01	3.581E-01	9.078E+01	Ag110	2.757E+02	2.175E+00	5.514E+02
Cm247	3.990E-04	3.148E-06	7.980E-04	Ag110m	2.073E+04	1.636E+02	4.146E+04
Cm248	5.711E-04	4.506E-06	1.142E-03	Ag111	7.454E-10	5.882E-12	1.491E-09
Cm249	1.857E-15	1.465E-17	3.714E-15	Cd113m	8.695E+02	6.861E+00	1.739E+03
Cm250	2.832E-12	2.235E-14	5.664E-12	In114	2.555E-01	2.016E-03	5.110E-01
Bk249	1.027E+00	8.103E-03	2.054E+00	In114m	2.670E-01	2.107E-03	5.340E-01
Bk250	6.975E-11	5.504E-13	1.395E-10	Cd115m	3.265E+01	2.576E-01	6.530E+01
Cf249	9.556E-03	7.540E-05	1.911E-02	In115	4.507E-10	3.556E-12	9.014E-10
Cf250	9.093E-03	7.175E-05	1.819E-02	In115m	2.295E-03	1.811E-05	4.590E-03
Cf251	2.744E-06	2.165E-08	5.488E-06	Sn117m	5.565E-06	4.391E-08	1.113E-05
Cf252	9.135E-06	7.208E-08	1.827E-05	Sn119m	4.995E+02	3.941E+00	9.990E+02
Cf253	5.975E-13	4.715E-15	1.195E-12	Sn121m	7.894E+00	6.229E-02	1.579E+01
Cf254	6.311E-12	4.980E-14	1.262E-11	Sn123	2.686E+03	2.119E+01	5.372E+03
Es253	2.504E-11	1.976E-13	5.008E-11	Te123	1.059E-10	8.356E-13	2.118E-10

Appendix A-4 Activity of ABR Fuel 250 GWD/MTIHM, 1+ year cooled, Maximum Activity							
Isotope	Ci/MTIHM	Ci/day	Ci/yr	Isotope	Ci/MTIHM	Ci/day	Ci/yr
Fission Products (continued)				Fission Products (continued)			
Te123m	1.197E+01	9.445E-02	2.394E+01	La140	1.335E-02	1.053E-04	2.670E-02
Sb124	1.279E+02	1.009E+00	2.558E+02	Ce141	1.985E+03	1.566E+01	3.970E+03
Sn125	1.967E-07	1.552E-09	3.934E-07	Pr143	3.323E-02	2.622E-04	6.646E-02
Sb125	9.861E+04	7.781E+02	1.972E+05	Ce144	1.332E+06	1.051E+04	2.664E+06
Te125m	2.403E+04	1.896E+02	4.806E+04	Pr144	1.332E+06	1.051E+04	2.664E+06
Sn126	9.955E+00	7.855E-02	1.991E+01	Pr144m	1.598E+04	1.261E+02	3.196E+04
Sb126	1.394E+00	1.100E-02	2.788E+00	Pm146	1.694E+02	1.337E+00	3.388E+02
Sb126m	9.955E+00	7.855E-02	1.991E+01	Sm146	3.336E-05	2.632E-07	6.672E-05
Sb127	1.286E-23	1.015E-25	2.572E-23	Nd147	2.225E-04	1.756E-06	4.450E-04
Te127	6.439E+03	5.081E+01	1.288E+04	Pm147	8.552E+05	6.748E+03	1.710E+06
Te127m	6.574E+03	5.187E+01	1.315E+04	Sm147	5.508E-05	4.346E-07	1.102E-04
Xe127	4.820E-03	3.803E-05	9.640E-03	Pm148	5.401E+01	4.262E-01	1.080E+02
Te129	6.145E+01	4.849E-01	1.229E+02	Pm148m	9.589E+02	7.566E+00	1.918E+03
Te129m	9.440E+01	7.449E-01	1.888E+02	Sm151	2.597E+04	2.049E+02	5.194E+04
I129	3.206E-01	2.530E-03	6.412E-01	Eu152	8.103E+02	6.394E+00	1.621E+03
Xe129m	3.599E-13	2.840E-15	7.198E-13	Gd152	7.354E-11	5.803E-13	1.471E-10
I131	7.297E-08	5.758E-10	1.459E-07	Gd153	5.561E+02	4.388E+00	1.112E+03
Xe131m	6.717E-05	5.300E-07	1.343E-04	Eu154	3.931E+04	3.102E+02	7.862E+04
Cs132	1.263E-14	9.966E-17	2.526E-14	Eu155	8.778E+04	6.926E+02	1.756E+05
Xe133	7.866E-15	6.207E-17	1.573E-14	Eu156	1.438E-02	1.135E-04	2.876E-02
Cs134	4.316E+05	3.406E+03	8.632E+05	Tb160	5.317E+02	4.195E+00	1.063E+03
Cs135	1.187E+01	9.366E-02	2.374E+01	Tb161	1.511E-12	1.192E-14	3.022E-12
Cs136	1.105E-03	8.719E-06	2.210E-03	Ho166m	3.023E-02	2.385E-04	6.046E-02
Cs137	7.241E+05	5.713E+03	1.448E+06	Er169	2.644E-12	2.086E-14	5.288E-12
Ba137m	6.850E+05	5.405E+03	1.370E+06	Tm170	3.452E-02	2.724E-04	6.904E-02
La138	2.954E-10	2.331E-12	5.908E-10	Tm171	1.308E-03	1.032E-05	2.616E-03
Ba140	1.160E-02	9.153E-05	2.320E-02				

Attachments – Schematic Process Flow Diagrams

- 1. Aqueous Separations**
- 2. Pyrochemical Separations**
- 3. Fuel Fabrication**
- 4. Secondary Liquid Waste**

