Report to Congress

Preferred Disposition Plan for Sodium-Bonded Spent Nuclear Fuel

Prepared by
U.S. Department of Energy
March 2006

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EXECUTIVE SUMMARY

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This report was prepared by the Department of Energy (DOE) in response to Congressional direction included in the Energy and Water Development Appropriations Act for FY 2006. The Congressional language states "The Committee directs the Department to undertake a study to evaluate and propose a disposal solution for the entire 62 tons of sodium-bonded spent nuclear fuel (SNF) and to consider what minimal amount of fuel is needed for future experiments under the Advanced Fuel Cycle Initiative (AFCI)."

The inventory of sodium-bonded spent fuel is stored in Idaho or planned for shipment to Idaho. Because DOE is committed to meeting its agreement with the State (Settlement and Consent order issued on October 17, 1995, in the actions of *Public Service Co. of Colorado v. Batt*, No. CV 91-0035-S-EJL [D. Id.] and *United States v. Batt*, No. CV 91-0054-EJL [D. Id]), all spent fuel, including sodium-bonded spent fuel, must leave Idaho by 2035.

Sodium-bonded fuel was principally used in three different reactors: Experimental Breeder Reactor (EBR-II), Enrico Fermi Atomic Power Plant (Fermi-1), and Fast Flux Test Facility (FFTF). The quantity of fuel from each reactor, along with a small quantity that is at Sandia National Laboratory, is shown in the table below.

Fuel Type	EBR-II Driver (MTHM)	EBR-II Blanket (MTHM)	FFTF Driver (MTHM)	Fermi-1 Blanket (MTHM)	Sandia Sodium Rubble Bed Materials (MTHM)	Total Sodium-Bonded Fuel (MTHM)
Initial Fuel June 1996	3.1	22.4	0.25	34.0	0.05	59.8
Fuel Treated as of September 2005	0.7	2.5	0	0	0	3.2
Remaining Untreated Fuel	2.4	19.9	0.25	34.0	0.05	56.6

Unless the sodium-bonded spent fuel can be shown to not be regulated under the Resource Conservation and Recovery Act (RCRA), sodium-bonded fuel disposal options need to include either physical removal or chemical deactivation of the sodium. Based on fuel characteristics, driver fuel will require some type of chemical treatment because the elemental sodium has become infused into the fuel. For the blanket fuel, physical separation of the sodium or chemical processes may be considered. Pyroprocessing and sodium removal are the two approaches that have been studied in greatest detail.

A summary of disposal options is provided in the table below, with the Department's preference for treatment of each fuel type indicated. The five main options are pyroprocessing, sodium removal via MEDEC, sodium removal via alcohol wash, UREX+, and direct disposal. Pyroprocessing of EBR-II fuel is ongoing at INL and could be applied to all types of sodium-bonded fuel. The Record of Decision (ROD) for the related Environmental Impact Statement (EIS) identified it as the preferred treatment for all sodium-bonded fuel except the Fermi-1 blanket. MEDEC and alcohol wash are alternative sodium removal technologies. They can be applied to both EBR-II and Fermi-1 blankets. MEDEC tests were performed as recently as 2004, the alcohol wash process was last performed in the 1980s, while UREX+ has been demonstrated at laboratory-scale with commercial oxide spent fuel. UREX+ tests with sodium-bonded spent fuel have not been performed, but metal fuel has been processed by other aqueous technologies after bond-sodium was removed. Direct disposal may be the preferred disposal option for Fermi-1 blanket and FFTF driver spent fuel if that sodium-bonded fuel can be shown to not be a RCRA regulated material. Backup treatment options are MEDEC or alcohol wash for Fermi-1 and pyroprocessing for FFTF spent fuel.

Fuel Type	Pyroprocess	MEDEC	Alcohol Wash	UREX+	Direct Disposal	Comments
EBR-II driver	**On-going operations (preferred).**	N/A	N/A	N/A	N/A	Sodium logged within the fuel matrix.
FFTF driver	**Backup**	N/A	N/A	N/A	Preferred if feasible.	Sodium logged within the fuel matrix.
EBR-II blanket	**On-going operations (preferred).**	Demonstrated on engineering-scale non-irradiated fuel in 1980s. Lab-scale demonstrations in 2004.	Demonstrated on engineering scale in 1980s.	Feasible for transuranic recovery after sodium removal.	N/A	Bulk of sodium separate from fuel matrix. High plutonium content due to long irradiation.
Fermi-1 blanket	Feasible.	**Backup.**	Backup.	Not useful due to low transuranic content.	Preferred if feasible	Bulk of sodium separate from fuel matrix. Low plutonium content due to short irradiation.

Pyroprocessing of EBR-II spent fuel currently supports treatment goals for sodium-bonded spent fuel and R&D activities for AFCI and the proposed GNEP program. Transmutation of transuranics in ABRs is a critical component of this program, and pyroprocessing and metallic fuel are leading candidates for the ABR fuel cycle. Minimum quantities of fuels are needed to support research, development, and demonstration of the pyroprocessing fuel cycle. Key areas of focus include group actinide recovery, effect of transuranic concentrations in an electrorefiner, new materials for high temperature operations, performance of ternary (U-Pu-Zr) fuel separations, and engineering-scale waste operations.

The table below summarizes sodium-bonded fuel needs to support R&D for AFCI.

Fuel Type	Quantity (MTHM)	Technology Needs
EBR-II driver	0.2	Develop advanced crucible materials for processing uranium product and metal waste.
FFTF driver	0.01	Obtain additional experimental data processing ternary (U-Pu-Zr) fuel elements.
EBR-II blanket	4	Obtain additional experimental data for electrorefining and group actinide recovery at different transuranic salt concentrations. Recover transuranic product for fast reactor fuel fabrication.
Fermi-1 blanket	0	None

CONTENTS

FIGURES

March 2006

TABLES

March 2006

ACRONYMS

ABR	Advanced Burner Reactor
AFCI	Advanced Fuel Cycle Initiative
ANL	Argonne National Laboratory
DOE	Department of Energy
EBR-II	Experimental Breeder Reactor-II
EIS	Environmental Impact Statement
EM	Office of Environmental Management
EPA	Environmental Protection Agency
Fermi-1	Enrico Fermi Atomic Power Plant
FFTF	Fast Flux Test Facility
GNEP	Global Nuclear Energy Partnership
INL	Idaho National Laboratory
MEDEC	Melt Drain Evaporate Carbonate
MTHM	Metric Tons Heavy Metal
DOE-NE	Department of Energy, Office of Nuclear Energy, Science, and Technology
NRC	National Research Council
PUREX	Plutonium and Uranium Recovery by Extraction
RCRA	Resource Conservation and Recovery Act
R&D	Research and Development
SNF	Spent Nuclear Fuel
SRS	Savannah River Site
UREX+	Uranium Extraction Plus

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March 2006

PREFERRED DISPOSITION PLAN FOR SODIUM-BONDED SPENT NUCLEAR FUEL

1.0 INTRODUCTION

This report was prepared by the Department of Energy (DOE) in response to Congressional direction included in the Energy and Water Development Appropriations Act for FY 2006. The Congressional language states "The Committee directs the Department to undertake a study to evaluate and propose a disposal solution for the entire 62 tons of sodium-bonded spent nuclear fuel (SNF) and to consider what minimal amount of fuel is needed for future experiments under the Advanced Fuel Cycle Initiative (AFCI)."

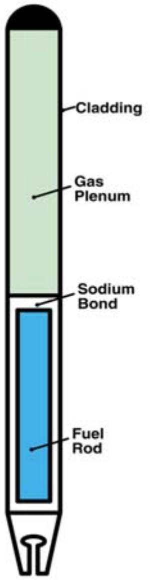
The inventory of sodium-bonded spent fuel is stored in Idaho or planned for shipment to Idaho. Because DOE is committed to meeting its agreement with the State (Settlement and Consent order issued on October 17, 1995, in the actions of *Public Service Co. of Colorado v. Batt*, No. CV 91-0035-S-EJL [D. Id.] and *United States v. Batt*, No. CV 91-0054-EJL [D. Id]), all spent fuel, including sodium-bonded spent fuel, must leave Idaho by 2035.

This report describes how DOE plans to prepare the inventory of sodium-bonded SNF for permanent disposal and identifies the amount of sodium-bonded SNF needed for further development of pyroprocessing.

2.0 SODIUM-BONDED FUEL DESCRIPTION

Typical commercial nuclear reactors use water as a coolant, and the fuel is made of oxide materials. DOE's fast nuclear reactor development program used liquid-sodium metal as a coolant. Metallic fuel was also used in these reactors. It allowed for efficient transfer of heat from fuel rods. The metallic fuel rod was encased in stainless steel cladding and bonded to the cladding with sodium. This cladding served to isolate the fuel and fission products from the reactor coolant. A schematic of an EBR-II sodium-bonded driver fuel element is provided in Figure 1.

Figure 1 – Sodium-Bonded EBR-II Driver Fuel Element



2.1 Sodium-Bonded Fuel Types and Characteristics

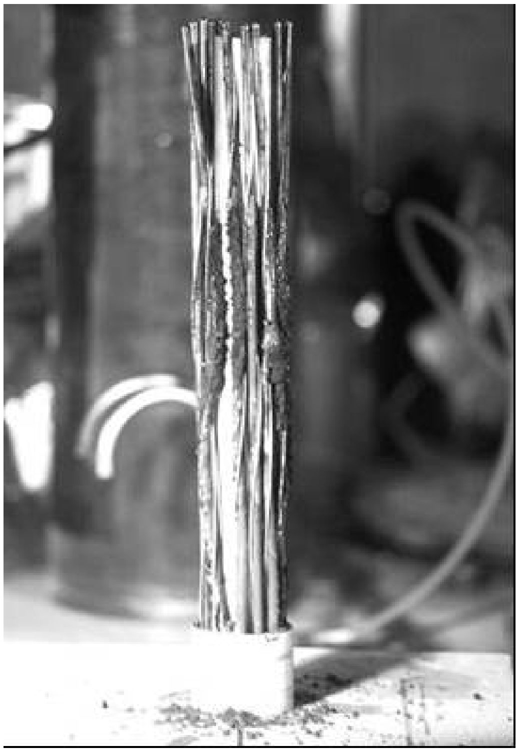
DOE’s fast reactors used two fuel types: driver and blanket fuels. Each fuel type has different isotopic compositions that affect processing for final disposal. Driver fuel contains fissile isotopes that limit the quantity of spent fuel that can be processed at one time. Blanket fuel contains mostly non-fissile uranium-238. The low fissile content of blanket fuel allows greater quantities to be processed at one time relative to driver fuel.

From a treatment and disposal perspective, the important difference between driver and some of the blanket fuel inventory is the degree of interaction of bond sodium with the metallic fuel rods. Within the reactor, fissioning of uranium-235 in driver fuel produces fission products that cause the fuel rods to swell and develop porosity. The porosity allows sodium to become infused into the fuel rods. Separation of bond-sodium from driver fuel requires dissolution or melting of the fuel. The Fermi blanket fuel experienced little fissioning, so fuel swelling and porosity were significantly less. This lack of porosity keeps most sodium outside the blanket fuel rods, allowing either chemical or physical methods to be considered for sodium removal.

2.2 Storage Requirements

Sodium-bonded fuel should be stored in a dry, inert environment. The stainless steel cladding is known to gradually deteriorate when in contact with water, and exposed sodium will react with water. Experience at the Idaho National Laboratory (INL) with sodium-bonded fuel stored in sealed metallic canisters in water storage basins resulted in some elements (Figure 2) reacting with water to produce hydrogen gas [ref. 1]. Additionally, some driver fuel (Figure 3) that was kept in dry storage inside seal-welded containers at INL was found to have reacted with moisture in the internal atmosphere in the storage canisters.

Figure 2 – Fuel from Storage Canister that Leaked in Water Storage Basin



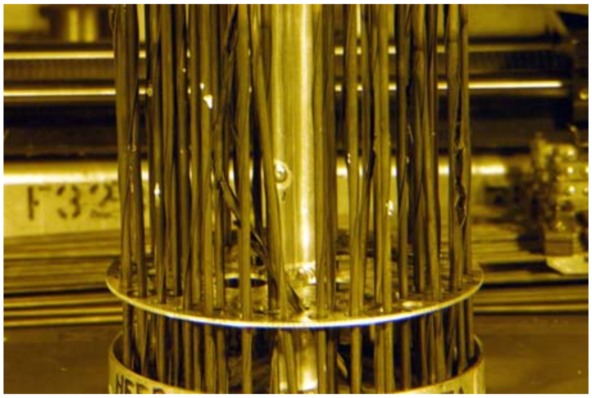


Figure 3 – Fuel that Reacted with Moisture in Container Kept in Dry Storage

Hydrogen was evolved and accumulated in the storage canisters due to reaction of water with sodium. Such deterioration of cladding has not yet been seen with blanket fuel. Due to this reactive nature, all operations with sodium-bonded fuels are performed in an inert atmosphere.

2.3 Source and Quantities of Sodium-Bonded Spent Nuclear Fuel

Sodium-bonded fuel was principally used in three different reactors: Experimental Breeder Reactor (EBR-II), Enrico Fermi Atomic Power Plant (Fermi-1), and Fast Flux Test Facility (FFTF). The quantity of fuel from each reactor, along with a small quantity that is at Sandia National Laboratories, NM, is shown in Table 1.

EBR-II was a research and test reactor in Idaho used to demonstrate the engineering feasibility of a sodium-cooled, liquid metal fast reactor with a steam electric power plant and an integrated fuel cycle. Full operations began in November 1962 and continued until September 1994. During its operation, numerous fuel designs were tested, but sodium-bonded fuel was always used for both its driver and blanket fuel. The driver fuel was comprised of highly enriched uranium metal alloyed with either zirconium metal, a mixture of noble metals, or plutonium-zirconium metal. Fresh blanket fuel was pure depleted uranium metal, while spent blanket fuel contains about 1 wt% plutonium. Pyroprocessing is currently being used for treatment of EBR-II driver fuel.

Fermi-1 was a sodium-cooled fast reactor in Monroe Beach, Michigan. The reactor started operations in 1963 and operated until September 1972. This fast reactor used a metal driver fuel without a sodium bond and a sodium-bonded blanket fuel. This report discusses only the Fermi-1 blanket SNF, which was a depleted uranium-molybdenum alloy in a stainless steel cladding. Fermi-1 blanket elements are similar to EBR-II blanket elements with respect to enrichment but are physically larger and have very low neutron exposure in the reactor. After the Fermi-1 reactor was permanently shut down, the blanket assemblies

Table 1 – Summary of DOE Sodium-Bonded SNF in Storage

Fuel Type	EBR-II Driver (MTHM)	EBR-II Blanket (MTHM)	FFTF Driver (MTHM)	Fermi-1 Blanket (MTHM)	Sandia Sodium Rubble Bed Materials (MTHM)	Total Sodium-Bonded Fuel (MTHM)
Initial Fuel June 1996	3.1	22.4	0.25	34.0	0.05	59.8
Fuel Treated as of September 2005	0.7	2.5	0	0	0	3.2
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were placed into fourteen canisters and transported to DOE's Idaho Site in 1974 and 1975. The canisters were placed into an underground dry storage system.

FFTF, on the DOE Hanford Site near Richland, Washington, operated as part of DOE's fast reactor development program in the 1980s and tested various fuel types. A small quantity (0.25 metric tons heavy metal [MTHM]) of experimental sodium-bonded driver fuel is currently stored at the Hanford site in Washington. DOE plans to transport this fuel to INL pursuant to the Record of Decision for the Programmatic Spent Nuclear Fuel Environmental Impact Statement (EIS) of 1995 [ref. 2]. The fuel is mostly either uranium-zirconium or uranium-plutonium-zirconium metal alloy. Most of this material was irradiated and has characteristics similar to EBR-II driver fuel. The unirradiated fuel consists of one intact assembly and 87 fuel pins.

DOE's sodium-bonded fuel inventory also includes a small quantity (0.05 MTHM) of uranium oxide fuel particulate dispersed in sodium metal. This material was used in passive cooling experiments at Sandia National Laboratory from 1977 to 1985. Due to the small amount of fuel in this category, it will not be addressed in the remainder of this report.

3.0 DISPOSAL OPTIONS

Unless sodium-bonded spent fuel can be shown to not be regulated under RCRA, sodium-bonded fuel disposal options need to include either physical removal or chemical deactivation of the sodium. These options include pyroprocessing, MEDEC, and alcohol wash, which are discussed below, along with direct disposal.

3.1 Pyroprocessing

Pyroprocessing (also known as electrometallurgical treatment) is a chemical process that converts bond sodium into sodium chloride (common table salt) while separating SNF into a uranium product and acceptable high-level waste forms. The pyroprocessing flowsheet (Figure 4) uses a high temperature electrolytic cell containing molten salts, lithium chloride/potassium chloride, and steel electrodes. One electrode contains chopped spent fuel, which is electrochemically dissolved in the molten salt when a voltage is applied to the system. Oxidation of metals from the fuel to chlorides in the salt occurs at the anode, resulting in the formation of sodium chloride, uranium chloride, and various fission product and transuranic chlorides. Simultaneously, uranium is deposited on a solid metal cathode immersed in the molten salt. This recovered uranium is stored for use as new fuel for reactors. Treatment of EBR-II spent fuel by pyroprocessing is presently performed as part of AFCI.

The technical viability of pyroprocessing for treatment of sodium-bonded fuel was demonstrated to the NRC. An April 2000 NRC report noted that the pyroprocessing demonstration met all success criteria [ref. 3]. More than 3.2 MTHM of EBR-II spent fuel have now been treated.

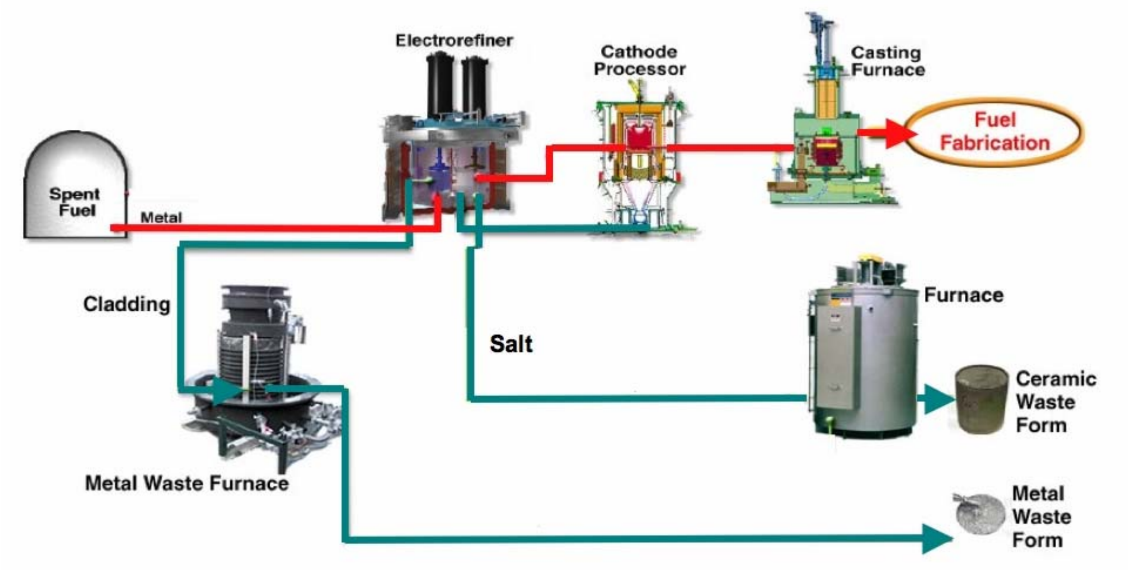

Figure 4 – The Pyroprocessing Flowsheet

3.2 Sodium Removal and Deactivation

Two different processes, melt drain evaporate carbonate (MEDEC) and fuel decladding and sodium removal through alcohol wash, have been used or tested for removal and deactivation of sodium from sodium-bonded fuel. These processes are only applicable to either Fermi-1 or EBR-II blanket fuels. The recovered slugs from either sodium removal process would be packaged for permanent disposal at the geologic repository. For driver fuel, the sodium removal option would not be viable because elemental sodium has become infused into the fuel alloy. It cannot be completely removed without dissolving the fuel.

3.2.1 MEDEC

The MEDEC technology was initially developed and tested in the 1980s to remove sodium from EBR-II fuel elements that had not been irradiated. The process uses a combination of heat and reduced pressure to melt and vaporize bond sodium, removing it from the metal fuel. The fuel elements are prepared by cutting off the ends. The elements are then heated to 650°C under reduced pressure (200 mTorr). After melting, the sodium evaporates and is condensed in a separate container. Once the sodium has been successfully removed, the cleaned fuel rods (Figure 5) can be packaged for direct disposal. The entire process is undertaken within an argon atmosphere to prevent reaction of sodium with oxygen or moisture in the atmosphere.

In FY 2002, MEDEC tests were performed on unirradiated Fermi-1 fuel to verify process operating parameters and to support development of a cost estimate. In FY 2003, additional MEDEC tests were run on an EBR-II blanket element that had been irradiated to a low burn-up similar to that experienced by the Fermi-1 blanket. The tests with irradiated fuel showed that the process was still viable. Radioactive cesium and trace amounts of plutonium were measured in the evaporated elemental sodium. This information was used to develop concepts and cost estimates for processing both Fermi-1 and EBR-II blanket. Fermi-1 blanket could be treated in a glovebox, but EBR-II blanket will need to be treated in a hot cell. The evaporated sodium must be converted into a final waste form. At DOE’s Idaho site, a facility exists for performing sodium metal conversion to sodium carbonate; however, this facility has restrictive limits on acceptable plutonium levels and limited shielding for radioisotopes like cesium. This facility could be used for treatment of sodium from Fermi-1 blankets, but the presence of plutonium and cesium in the sodium from EBR-II blankets might preclude its use. Additional evaluations are needed to determine if this conversion method is feasible.

3.2.2 Alcohol Wash

An alternative to MEDEC for sodium removal is the fuel decladding and sodium removal through alcohol wash process that was used successfully by Rocketdyne Corp (Canoga Park, CA) in the mid 1980s to remove sodium from 17 MTHM of spent EBR-II blanket fuel. In this process, fuel element cladding is cut to expose the fuel slugs, which are then soaked twice in an alcohol bath containing 20% water. The alcohol wash solution would be solidified as sodium carbonate and disposed of as low-level waste. This process was last examined in 1986, and no life cycle cost estimates have been prepared for treating either Fermi-1 or EBR-II blanket fuel.

3.3 Direct Disposal

For direct disposal, fuel assemblies are packaged into standard canisters and shipped to a permanent repository to be disposed of as SNF. If additional containment is needed, the fuel could first be sealed in high-integrity cans and then packaged into standard canisters. This option is being considered for Fermi-1 blanket and FFTF driver spent fuel. For direct disposal to continue to be considered, DOE needs to perform the technical and analytical work required to determine if this spent fuel is a RCRA regulated material. If DOE concludes it is not a RCRA regulated material, discussions with the appropriate regulatory authorities would be conducted. In addition, if direct disposal is to be pursued for the FFTF driver spent fuel, the previous Record of Decision issued for that fuel would need to be reassessed.

Figure 5 – Fermi-1 Blanket Rod after Sodium Removal by MEDEC Process

3.4 Other Disposal Options

Development of the other technologies such as melt and dilute, chloride volatility, fluoride volatility, and plasma arc processing are not currently being considered by DOE for treating sodium-bonded fuel.

3.5 Disposal Options Summary

The four main treatment and disposal options are pyroprocessing, sodium removal via MEDEC, sodium removal via alcohol wash, and direct disposal. Pyroprocessing EBR-II fuel is ongoing at INL and could be applied to all types of sodium-bonded fuel. The Record of Decision for the EIS identified it as the preferred treatment for all sodium-bonded fuel except the Fermi-1 blanket fuel. MEDEC and alcohol wash are both sodium removal technologies. They can be applied to both EBR-II and Fermi-1 blankets. Both technologies have been demonstrated with spent fuel. MEDEC tests were performed as recently as 2004. The alcohol wash process was performed in the 1980s. Direct disposal will require technical and analytical work to determine whether sodium-bonded spent fuel is a RCRA regulated material.

4.0 RESEARCH AND DEVELOPMENT NEEDS

Pyroprocessing of EBR-II spent fuel currently supports treatment goals for sodium-bonded spent fuel and R&D activities for AFCI and the Global Nuclear Energy Partnership (GNEP) program. Transmutation of transuranics in Advanced Burner Reactors (ABRs) is a critical component of this program, and pyroprocessing and metallic fuel are candidates for the ABR fuel cycle. Minimum quantities of spent fuels are needed to support research, development, and demonstration of the pyroprocessing fuel cycle. Key areas of focus include group actinide recovery (Figure 6), effect of transuranic concentrations in an electrorefiner, new materials for high temperature operations, performance of ternary (U-Pu-Zr) fuel separations, and engineering-scale waste operations.

For demonstrating group actinide recovery and assessing the effect of the transuranic concentration in the salt, process tests and experimental data are needed to optimize operations and confirm theoretical models. Additionally, engineering-scale transuranic recovery equipment needs to be tested so the recycle system for an ABR can be designed and materials can be recovered for advanced fuel fabrication. A minimum of 4 MTHM of additional EBR-II blanket would be needed for these operations. Salt from driver electrorefining operations can be used to provide data on fission product contamination in the recovered actinide product. Although sufficient fission product concentrations in electrorefiner salt exist from driver fuel processing to date, additional driver fuel processing will improve data quality.

In AFCI, high recovery efficiency of transuranics is an established criterion to support waste disposal options. Coatings of graphite crucibles are used in high temperature operations to prevent interaction between metal ingots and the crucibles. Application of these coatings is labor-intensive, and the coatings react with process material to form dross. Several promising candidate materials have been tested at laboratory scale, but further testing is needed at engineering scale with representative fission products. The successful scale-up of these materials will improve processing throughput, reduce costs, and minimize the need for handling secondary waste streams. This testing can be conducted simultaneously with treatment of at least 0.2 MTHM of EBR-II driver fuel.

An ABR utilizes fuel containing high concentrations of transuranics. Engineering-scale pyroprocessing operations have been limited to uranium-based fuel. The FFTF driver fuel includes approximately 10 kilograms of ternary fuel (U-Pu-Zr) that can be used to determine process conditions for future applications more closely related to an ABR.

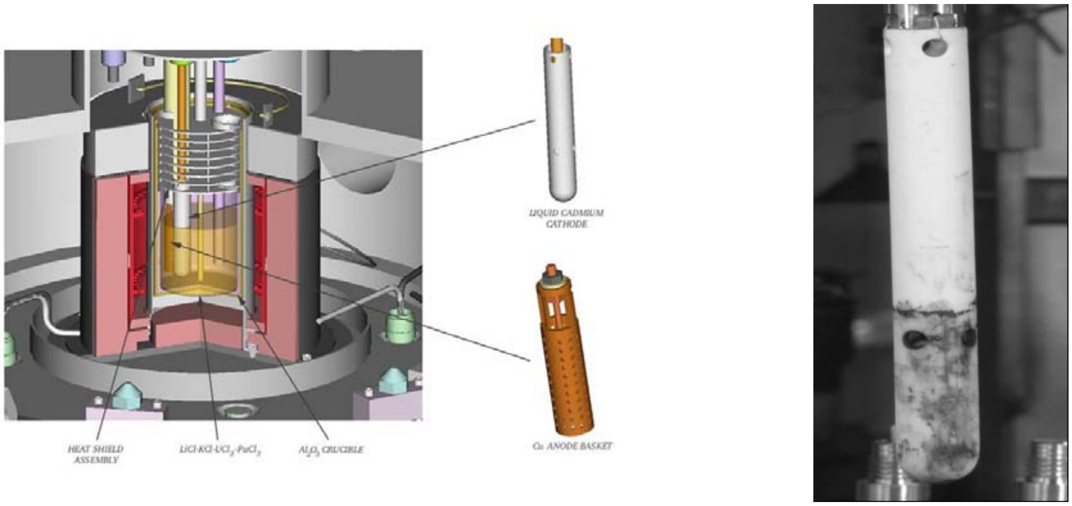

Figure 6 – Laboratory-Scale Equipment for Group Actinide Recovery Experiments using Salt from Treatment of EBR-II Spent Fuel

For any separation process, the production of suitable high-level waste forms is a requirement. The viability of pyroprocessing-generated waste forms has been demonstrated using laboratory-scale samples. Scale-up of these processes has progressed (Figure 7) but still needs to be completed. R&D to support scale-up is essential, even if no additional fuel is processed. Waste materials that accumulated from treatment of 3.2 MTHM of EBR-II spent fuel need to be disposed in the planned repository.

Table 2 summarizes sodium-bonded fuel needs to support R&D for AFCI. An additional 0.2 MTHM of EBR-II driver fuel, 4 MTHM of EBR-II blanket fuel, and 0.01 MTHM of FFTF driver fuel are needed. No need has been identified for R&D activities with Fermi-1 fuel.

Figure 7 – Early Testing of the Prototype Metal Waste Furnace Used for Pyroprocessing

Fuel Type	Quantity (MTHM)	Technology Needs
EBR-II driver	0.2	Develop advanced crucible materials for processing uranium product and metal waste.
FFTF driver	0.01	Obtain additional experimental data processing ternary (U-Pu-Zr) fuel elements.
EBR-II blanket	4	Obtain additional experimental data for electrorefining and group actinide recovery at different transuranic salt concentrations. Recover transuranic product for fast reactor fuel fabrication.
Fermi-1 blanket	0	None

Table 2 – Research and Development Needs by Fuel Type

5.0 LIFE CYCLE COSTS

A number of studies have been commissioned by DOE to estimate life cycle costs for sodium-bonded spent fuel processing options. The focus of recent studies has been on pyroprocessing and MEDEC. Direct disposal, alcohol wash, treatment via PUREX, and the melt and dilute process have not been considered recently, because of the cost study report that was issued in 1999 [ref 4]. In that report, only direct disposal was appreciably cheaper than the other treatment alternatives. Analyses would need to be completed along with discussions with appropriate regulatory authorities before a decision can be made regarding direct disposal. Dilution was found to be very expensive—costing about $200 million more than other processing options. Cost differences between pyroprocessing and PUREX processing options were low and probably within the confidence band of the estimates. Thus, pyroprocessing and MEDEC are the two treatment options discussed further. In Section 5.1, a scenario involving minimum pyroprocessing is described. In Section 5.2, a scenario involving full implementation of pyroprocessing is described. The costs described are the additional estimated cost to completion. Approximately $142 million has been spent on pyroprocessing implementation and treatment of EBR-II driver and blanket fuel through FY 2006.

5.1 Pyroprocessing for Driver and Sodium Removal for Blankets

One processing approach considered was pyroprocessing of driver fuel (EBR-II driver and FFTF driver) combined with sodium removal via MEDEC for blanket fuel (EBR-II blanket and Fermi-1 blanket). MEDEC for EBR-II blanket would be carried out in a shielded hot cell, and MEDEC for Fermi-1 blanket would be carried out in shielded gloveboxes. The additional cost to completion for this approach is estimated to be $680 million (not escalated or discounted). A breakdown of this cost by fuel type and activity (fuel processing or waste processing) is given in Table 3. MEDEC processing is categorized as Waste Processing for this table, although it could also fit under the fuel processing category. The costs for EBR-II driver treatment are based on an INL internal study from 2006. The costs for FFTF driver treatment are based on an internal INL study from 2006 funded by DOE-EM. Numbers from that report have been adjusted to remove escalation factors. These studies assumed a single shift operation seven days a week. Costs for MEDEC treatment of Fermi-1 blanket come from an internal report prepared by Argonne National Laboratory (ANL) for DOE-EM in 2003. There is also an internal feasibility and cost study on MEDEC of EBR-II blanket that was completed by ANL in 2004.

Treatment of driver fuel along with additional R&D would be completed in FY 2014, and MEDEC treatment of EBR-II blanket and Fermi-1 blanket fuel would be initiated in FY 2017 and be complete by FY 2030. High-level waste disposal would begin in FY 2026 and be complete by FY 2035.

Table 3 – Breakdown of Estimated Costs to Complete Treatment for Pyroprocessing of Driver Fuel Combined with MEDEC Processing of Blanket Fuel.

	Fuel Processing Cost ($K)	**Waste Processing and Disposal Cost ($K)**	**Total Cost ($K)**
EBR-II driver (pyroprocessing)	97,200	94,600	191,800
FFTF driver (pyroprocessing)	35,500	6,700	42,200
EBR-II blanket (MEDEC)	0	284,800	284,800
Fermi-1 blanket (MEDEC)	0	160,900	160,900
Total	132,700	547,000	679,700

5.2 Pyroprocess for Driver and EBR-II Blanket, Sodium Removal for Fermi-1 Blanket

A second processing approach evaluated was pyroprocessing all sodium-bonded spent fuel except Fermi-1 blanket fuel. The Fermi-1 blanket would be treated by MEDEC. Included with this option is recovery of transuranics as part of pyroprocessing. The recovered transuranics may be used for fabricating ABR fuel. Recovery of transuranics also results in lower waste disposal costs because of process limits for transuranics in waste salts. Placing fewer transuranics in the waste forms results in less waste. In Table 4, cost estimates are given for scenarios in which all EBR-II and FFTF fuel is treated via pyroprocessing, while sodium is removed from Fermi-1 fuel via MEDEC. The pyroprocessing data were from 2006 INL internal studies previously mentioned that assumed a single shift operation seven days a week. Disposal costs have been estimated and combined with waste processing costs. The cost to completion is $566 million (not escalated or discounted).

	Fuel Processing Cost ($K)	Waste Processing and Disposal Cost ($K)	Total Cost ($K)
EBR-II driver (pyroprocessing)	97,200	94,600	191,800
FFTF driver (pyroprocessing)	35,500	6,700	42,200
EBR-II blanket (pyroprocessing)	76,200	94,600	170,800
Fermi-1 blanket (MEDEC)	0	160,900	160,900
Total	208,900	356,800	565,700

Table 4 – Breakdown of Life Cycle Costs to Complete Treatment for Pyroprocessing of EBR-II and FFTF Fuel Combined with Sodium Removal of Fermi-1 Fuel

Treatment of driver fuel along with additional R&D would be completed in FY 2014, and EBR-II blanket treatment would continue for an additional seven years. Final production of high-level waste would take an additional three years.

6.0 PREFERRED ALTERNATIVE

The preferred treatment alternative for EBR-II fuel is to pyroprocess all the remaining fuel. The preferred alternative for Fermi-I and FFTF fuel is direct disposal if that fuel can be shown to not be a RCRA regulated material. If that option is not feasible, the Fermi-I blanket fuel would be treated by either the MEDEC or alcohol wash processes and the FFTF driver fuel would be treated by pyroprocessing. Concurrent with treatment operations, R&D on the pyroprocessing fuel cycle in support of AFCI would be completed, including demonstration and implementation of group recovery of actinides and production of high-level wastes for geological disposal.

7.0 REFERENCES

1. R. G. Pahl, “Degradation of EBR-II Driver Fuel during Wet Storage,” Proceedings of the Embedded Topical Meeting on DOE Spent Nuclear Fuel and Fissile Material Management, San Diego, CA, June 4–8, 2000, pp 269–275, ANS, LaGrange Park, IL (2000).

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