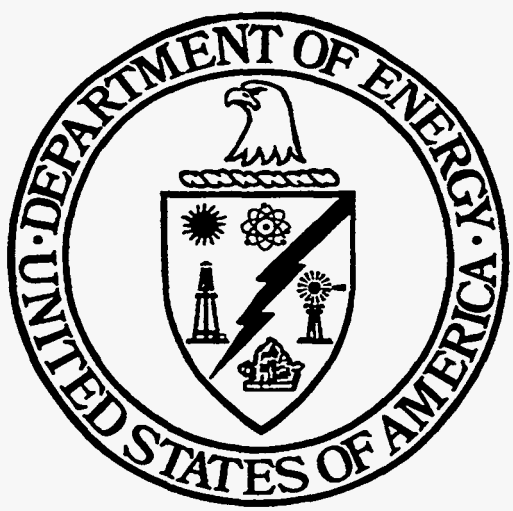
DOE/SNF/REP-014

United States Department of Energy

National Spent Nuclear Fuel Program

Deployment Evaluation Methodology for the Electrometallurgical Treatment of DOE-EM Spent Nuclear Fuel



July 1998

U.S. Department of Energy
Assistant Secretary for Environmental Management
Office of Spent Fuel Management and Special Projects

DISCLAIMER

DOE/SNF/REP-014

Deployment Evaluation Methodology for the Electrometallurgical Treatment of DOE-EM Spent Nuclear Fuel

C. A Dahl
J. P. Adams
R. J. Ramer

Published July 1998

Prepared for the
U.S. Department of Energy
Contract DE-AC07-94ID13223

INEL FORM
L-0412.15#
(08-96 - Rev. #00)

DOCUMENT MANAGEMENT CONTROL SYSTEM (DMCS)
DOCUMENT APPROVAL SHEET

Document Type: Report — Document Identifier: DOE/SNF/REP-014

Title: USDOE NSNF Deployment Evaluation Methodology for the Electrometallurgical Treatment of DOE-EM Spent Nuclear Fuel

Author: C. A. Dahl, J. P. Adams, R. J. Ramer — Phone: 208-526-3446

Document Owner: T. J. Hill — Phone: 208-526-1711

REVIEW CONCURRENCE AND APPROVAL SIGNATURES
Denote R for review concurrence, A for approval, as appropriate

Type or printed name / Signature	R/A	Date	Organization Discipline	Mailing Address
T. J. Hill S. C. Gladson for T. J. Hill	R/A	7/23/98	4110/Nuclear Engineering/ National SNF Program	MS 3456
J. H. Boyd	R/A	7/23/98	DOE-ID National SNF Program	MS 1154
C. L. Bendixsen C. L. Bendixsen	R/A	7/23/98	5320/National SNF Program	MS 3135

ABSTRACT

Part of the Department of Energy (DOE) spent nuclear fuel (SNF) inventory may require some type of treatment to meet acceptance criteria at various disposition sites. The current focus for much of this spent nuclear fuel is the electrometallurgical treatment process under development at Argonne National Laboratory. Potential flowsheets for this treatment process are presented. Deployment of the process for the treatment of the spent nuclear fuel requires evaluation to determine the spent nuclear fuel program need for treatment and compatibility of the spent nuclear fuel with the process. The evaluation of need includes considerations of cost, technical feasibility, process material disposition, and schedule to treat a proposed fuel. A siting evaluation methodology has been developed to account for these variables. A work breakdown structure is proposed to gather life-cycle cost information to allow evaluation of alternative siting strategies on a similar basis. The evaluation methodology, while created specifically for the electrometallurgical evaluation, has been written such that it could be applied to any potential treatment process that is a disposition option for spent nuclear fuel. Future work to complete the evaluation of the process for electrometallurgical treatment is discussed.

SUMMARY

The Department of Energy Environmental Management (DOE-EM) National Spent Nuclear Fuel Program (NSNFP) is charged with the disposition of legacy Spent Nuclear Fuel (SNF). While direct repository disposal of the SNF may be the primary disposition option, some DOE SNF may need treatment to ensure acceptability. Evaluations of treatment needs and options have been previously prepared, and further evaluations are ongoing activities in the DOE-EM NSNFP. As a planning basis, a need is assumed for a treatment process, either as a primary or backup technology, that is compatible with, and cost-effective for, this portion of the DOE-EM inventory. A current planning option for treating this SNF, pending completion of development work and National Environmental Policy Act (NEPA) analysis, is the electrometallurgical treatment (EMT) process under development by Argonne National Laboratory (ANL). A decision on the deployment of the EMT is pending completion of an engineering scale demonstration currently in progress at ANL.

One of the major issues associated with SNF treatment is final disposition of treatment products and associated waste streams. During conventional SNF treatment, various chemicals are added that may increase the product and waste stream masses and volumes that are eventually handled, stored, and dispositioned. Thus, when assessing whether or not to treat SNF, the costs associated with final disposition must be determined, in addition to the technical issues and costs associated with the treatment process itself.

Five principal product streams result from SNF treatment by the EMT. These streams, and a preliminary discussion of final disposition of each stream, are:

- Fuel assembly hardware, removed prior to treatment. The fuel assembly hardware may meet the criteria for disposal as low-level waste (LLW).

- Gaseous fission products. The gaseous fission products will be handled in accordance with applicable operating permits. The semi-volatile fission products form salts in the electrorefiner.

- Uranium ingot, formed from the uranium metal. The uranium ingot will probably also meet the criteria for disposal as LLW, though there is some question regarding the transuranic (TRU) nuclide concentrations. Other possibilities include use as off-specification fuel for commercial reactors (for the enriched uranium) and disposition in the geologic repository (if the TRU element concentrations are higher than the threshold concentrations for definition as TRU waste).

- Metal waste form, formed from the cladding materials and fuel constituents that remain metals in the process.

- Ceramic waste form, formed from the salt containing fuel constituents that form chlorides. These materials are stabilized in a glass-bonded

ceramic. The ceramic waste form will also probably be disposed in the repository.

The dispositions discussed are preliminary assessments, due to the paucity of technical data for the various product streams and the preliminary nature of the acceptance criteria at the geologic repository. As more technical data and criteria become available, these options will be reassessed.

Beyond the technical questions of whether the process can physically work with the selected inventory of SNF, there is a question on how to deploy the process and site facilities across the DOE complex. This question is influenced by many factors including economics of treatment, programmatic need for treatment, life-cycle disposition of process products, and schedule requirements. A siting option evaluation methodology has been developed to capture these factors and provide a mechanism to evaluate treatment processes against programmatic need for treatment of SNF. Although the principle focus of this work has been the EMT process, the methodology is judged to be sufficiently general for application to other treatment processes.

One of the first steps associated with selecting one or more sites for treating SNF in the DOE complex is to determine the cost for each of the options. First, the issues associated with fabrication and operation of a production facility are articulated by a list of specific questions. These questions ensure that all activities associated with each SNF disposition option are identified. Identification of these questions is complete. For each fuel type, a cost for each activity is applied to a work breakdown structure (WBS) matrix, developed for this study, to derive a cost/unit for a fuel to go to final storage. Second, an evaluation is made of treating more than one type of fuel in a location, and evaluating the tradeoffs in the various scenarios.

This evaluation will continue to complete the analysis of the deployment scenarios identified. Completion of the overall evaluation will include:

- Determine the costs for the WBS elements relevant to the identified scenarios and compile those costs into an overall scenario cost. Perform the indicated life-cycle evaluations, including factors of schedule and ability to meet the defined program need.
- Maintain and update the treatment candidate fuels listing, based on the changing program need and further refinement of the repository acceptance criteria.
- Incorporate the technical results of the current demonstration test at ANL and factor those results into all evaluations.

An interim report documenting the analyses will be prepared and issued in FY 1999 with the final evaluation to be issued in FY 2000. The final report will be available as a guide for formal deployment decisions.

CONTENTS

FIGURES

TABLES

ACRONYMS

ANL	Argonne National Laboratory
ANL-W	Argonne National Laboratory – West
CFR	Code of Federal Regulations
CHCS	Criticality Hazards Control Statement
CEQ	Council on Environmental Quality
D&D	decontamination and decommissioning
DOE	Department of Energy
DOE-EM	DOE Office of Environmental Management
DOE-ID	DOE Idaho Operations Office
DOT	Department of Transportation
EA	environmental assessment
EBR-II	Experimental Breeder Reactor II
EIS	Environmental Impact Statement
EMT	Electrometallurgical Treatment
EPA	Environmental Protection Agency
EPCRA	Emergency Planning and Community Right-to-Know Act
FASB	Fuel Assembly and Storage Building
FCF	Fuel Conditioning Facility
FFTF	Fast Flux Test Facility
HFEF	Hot Fuel Examination Facility
HLW	high-level waste
HM	heavy metal
ICPP	Idaho Chemical Processing Plant

IDAPA	Idaho Administrative Procedures Act
INEEL	Idaho National Engineering and Environmental Laboratory
INTEC	Idaho Nuclear Technology Engineering Center (formerly ICPP)
LCA	life-cycle analysis
LLW	low-level waste
MOX	mixed oxide
MT	metric ton
MTHM	metric tons of heavy metal
NEPA	National Environmental Policy Act
NRC	Nuclear Regulatory Commission
NSNF	National Spent Nuclear Fuel
NSNFP	National Spent Nuclear Fuel Program
ORR	Operational Readiness Review
PPA	Pollution Prevention Act
QA	quality assurance
RCRA	Resource Conservation and Recovery Act
RSWF	Radioactive Scrap and Waste Facility
RWMC	Radioactive Waste Management Complex
SNF	spent nuclear fuel
TMI	Three Mile Island
TRU	transuranic
VAD	vertical assembler/disassembler
WBS	work breakdown structure
WIPP	Waste Isolation Pilot Plant
ZPPR	Zero Power Physics Reactor

Deployment Evaluation Methodology for the Electrometallurgical Treatment of DOE-EM Spent Nuclear Fuel

INTRODUCTION

The Department of Energy (DOE) Environmental Management (DOE-EM) National Spent Nuclear Fuel Program (NSNFP) is charged with assisting DOE-EM in the disposition of legacy spent nuclear fuel (SNF). The SNF is located in several locations throughout the country. While direct repository disposal of the SNF may be the primary option for disposition, some DOE-EM SNF may need treatment to ensure acceptability for repository disposition. This SNF is grouped, by the NSNFP, into the following categories:

- SNF with a potential need to remove chemical reactivity resulting from the presence of chemical components, such as metallic sodium bonded to the SNF
- Small lot quantity SNF that may not be cost-effective to characterize for repository disposal
- Metallic SNF with degraded or missing cladding.

Evaluations of treatment needs and options have been previously prepared and further evaluations are ongoing activities in the DOE-EM SNF program.[1,2] A planning option for treatment of some of this SNF, pending completion of development work and environmental analysis, is the electrometallurgical treatment (EMT) process under development by Argonne National Laboratory (ANL). The DOE has noted this process as a promising technology to treat some SNF. The National Research Council independently assessed the potential application of the technology.[3] The Council recommended that DOE demonstrate the feasibility of EMT. The EMT process is currently undergoing an engineering scale demonstration with a selected amount of SNF at Argonne National Laboratory-West (ANL-W). A decision on deployment is pending completion of the engineering scale demonstration currently in progress at ANL.

The ANL-W Demonstration test will investigate the applicability of this process to treating Experimental Breeder Reactor – II (EBR-II) SNF.[4] The NSNFP is evaluating what other SNF, in concert with programmatic need to treat fuels prior to disposition, may be treated with the EMT process. Evaluation of requirements for converting the process to a scale suitable for identified SNF treatment needs is currently underway. This evaluation includes the analysis of process performance as well as identification of SNF treatment requirements, and obtaining required environmental analysis information. ANL and the NSNFP are currently performing evaluations for ultimate disposition of the process products. This evaluation is exploring the possibility of disposing some treatment products at sites other than the national repository. Waste form qualification is required, and planned, for the EMT products, but some preliminary testing has been done that indicates the potential to be qualified.

In addition to technical questions of whether the process can physically work with the selected inventory of SNF, there is a question on how to deploy the process and locate facilities to process SNF from across the DOE complex. This issue is influenced by many factors, including economics, programmatic need for treatment, life-cycle disposition of the process products, and schedule pressures. The evaluation methodology assembled for this activity attempts to capture all of these factors and

provide a mechanism to evaluate the usefulness of this, or any other, treatment process against the programmatic need for SNF treatment.

This report is intended to provide information on the EMT and the siting evaluation methodology being designed to the individual site programs. It also documents the methodology for future reference, providing a baseline prior to executing the methodology to evaluate the different siting options. To this end, the report includes the following:

- Descriptions of the EMT flowsheet, with discussions of the individual unit operations for the generic case, the specific demonstration activities at ANL, and an indication of areas that may require more investigation to transform the flowsheet into a full production scale activity.

- Discussions of the criteria for identifying DOE-SNF that is under consideration as candidates for treatment using the EMT process. This also includes discussions of the quantities of that SNF and current location, according to the current version of the SNF database maintained by the NSNFP.

- An overview of environmental considerations that may be relevant to evaluating costs and schedules for a production size facility, either new construction or placing the EMT in an existing facility.

- A preliminary discussion of disposal options for the various treatment products.

- The criteria for evaluating different siting options for a treatment facility and discussions of the various scenarios to be evaluated for siting a facility.

- An overview of the work necessary to complete the siting evaluations.

ELECTROMETALLURGICAL TREATMENT PROCESS

The EMT process has been considered an option to treat certain SNF. The EMT is being tested in the ANL-W demonstration test. Several operations are required to complete the required separations as shown in Figure 1. The steps consist of the following:

- SNF must be transported from current interim storage into a facility where fuel will be treated. DOE and DOT approved plans will be required to transport SNF over public roadways.

- When the SNF cask reaches the treatment facility, the transportation casks will need to be unloaded and the SNF placed in an atmosphere conducive to the treatment operation.

- Fuel assembly components not containing fissile material will not need to pass through the electrorefiner. Fuel assemblies will be disassembled to remove as much non-SNF hardware from the fuel as possible.

- SNF hardware containing fissionable material will then need to be chopped to convert it to appropriate size. The surface area of the chopped fuel affects the successful operation of the electrorefining.

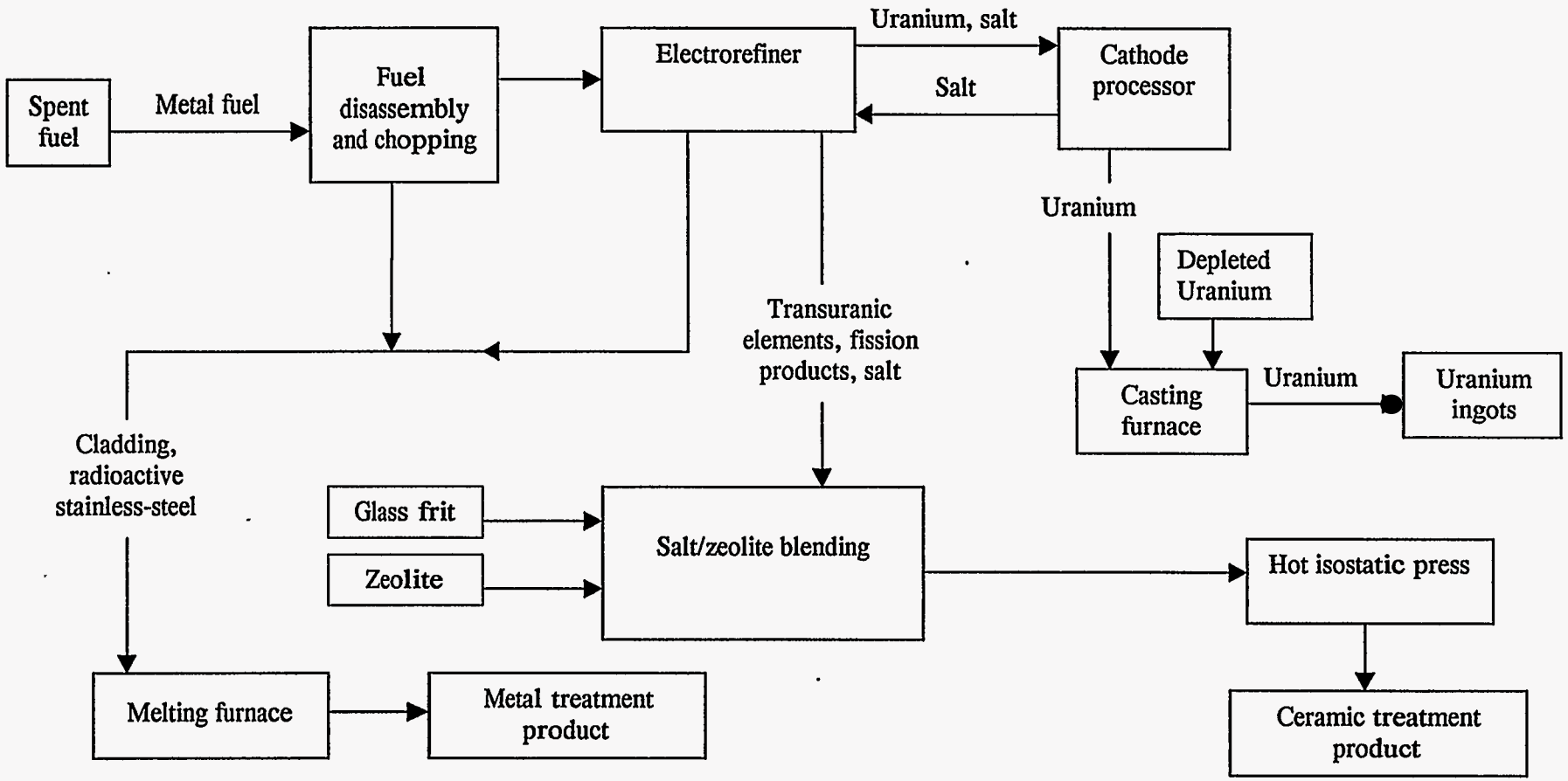


Figure 1. Spent fuel electrometallurgical treatment process steps.

- Chopped fuel is then placed in an anode basket and placed in the electrorefiner. The electrorefiner contains a molten salt. The uranium, transuranic (TRU) elements, and most of the fission products dissolve when voltage is applied and uranium is transferred to and deposited on the cathode.

- The uranium is sent to a cathode processor which vacuum extracts any adhering salt and melts the uranium into ingots.

- Any highly radioactive metal waste removed in the SNF disassembler/chopper and the stainless steel cladding hulls remaining after electrorefining will be melted to form metal ingots.

- The salt is treated to form a ceramic glass/zeolite waste by heating and compressing it to minimize the final waste volume.

- The uranium ingots, metal waste ingots, and the ceramic wastes will need to be loaded into casks for shipment to a permanent storage site(s).

- The other operational wastes produced in the EMT process also need to be disposed appropriately.

A more detailed description of the flowsheet operation for the treatment of fuel in the EMT is illustrated in Figures 2–11. The overall process is shown in Figure 1. Addressed in this section are the generic flowsheet, the demonstration flowsheet, and a flowsheet for a production scale system. The generic flowsheet describes the general process. The demonstration test flowsheet describes the ANL-W demonstration test, which is evaluating the applicability of this process for treating EBR-II fuel. The production flowsheet addresses production scale plant concerns. Some fuel may require additional head end steps to be treated in the EMT process.

Cask Operation

Generic — A transportation plan will be required to transport fuel over public roadways. Fuel to be treated will arrive in Nuclear Regulatory Commission (NRC)-approved shipping casks if transportation over public roadways is required. The facility will require a cask receiving area for unloading the cask and placing the fuel into storage. Logistic plans will be required to address cask operation (procurement, maintenance, transportation, and scheduling).

Demonstration Test — For the demonstration tests, 1.6 metric tons of heavy metal (MTHM) of EBR-II fuel will be treated. A portion of the EBR-II fuel to be treated will be moved to the Fuel Conditioning Facility (FCF) from the Radioactive Scrap and Waste Facility (RSWF). Some of the fuel will come directly from the reactor. The time in the demonstration facility to open doors, put a cask in, unload and empty one cask is about 8 hours. About 3 to 4 casks per week have been emptied in the past.

For the EBR-II fuel, the shipping cask containing the fuel is transported from the RSWF cask storage area. The EBR-II fuel is transported in a Hot Fuel Examination Facility-5 (HFEF-5) cask. The HFEF-5 will hold three Mark II assemblies or two Mark III assemblies. The FCF contains two operating cells, one with an air atmosphere for handling intact fuel and the other with an inert argon atmosphere for conducting operations, including electrorefining, with exposed reactive components/materials. Several casks from the RSWF can interface with the FCF air cell fuel assembly transfer port (Figure 2). The casks are lifted from the transport vehicle into the FCF with a crane or forklift. The primary method is to move the cask to a 25-ton transfer cart.

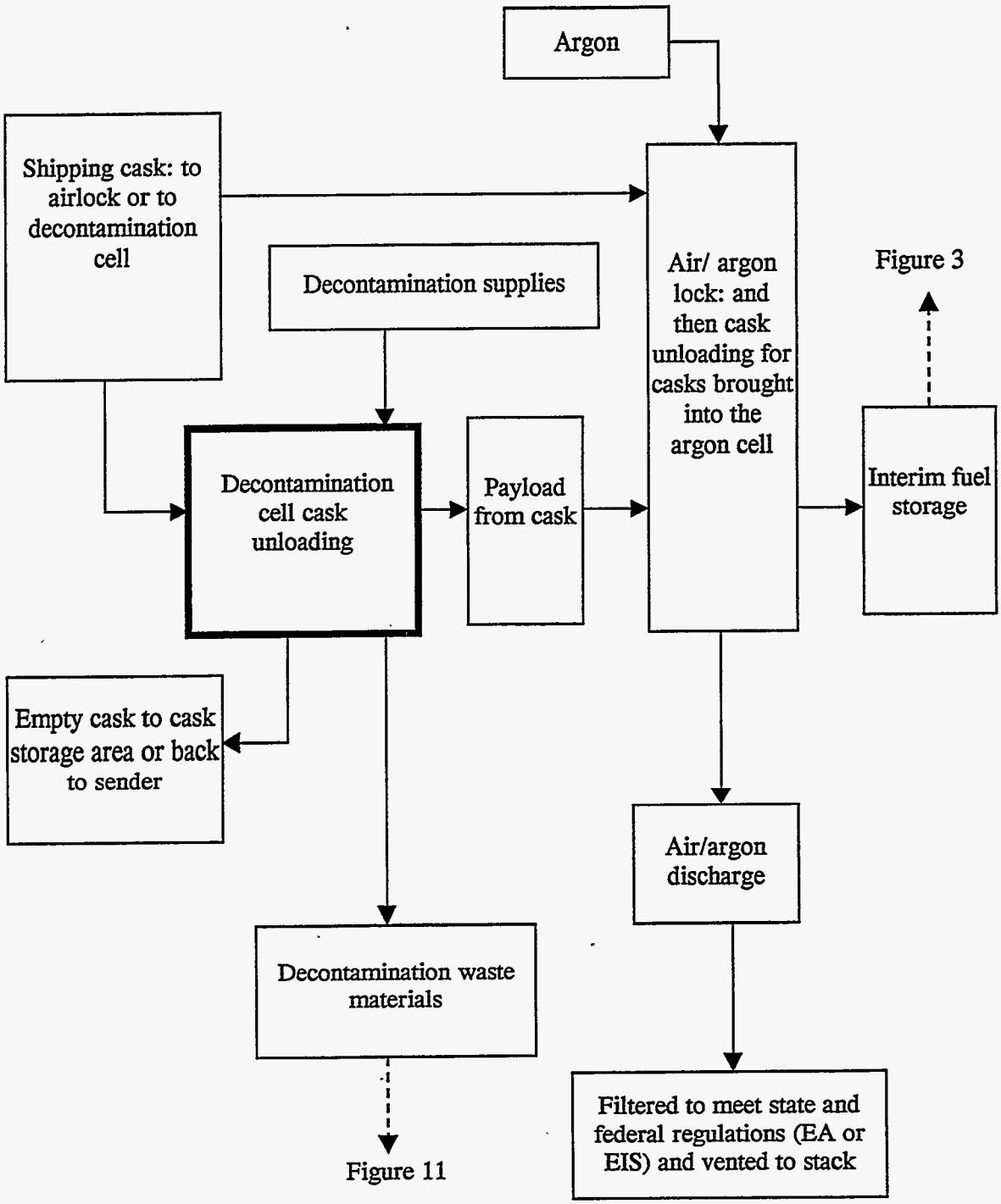


Figure 2. Cask unloading.

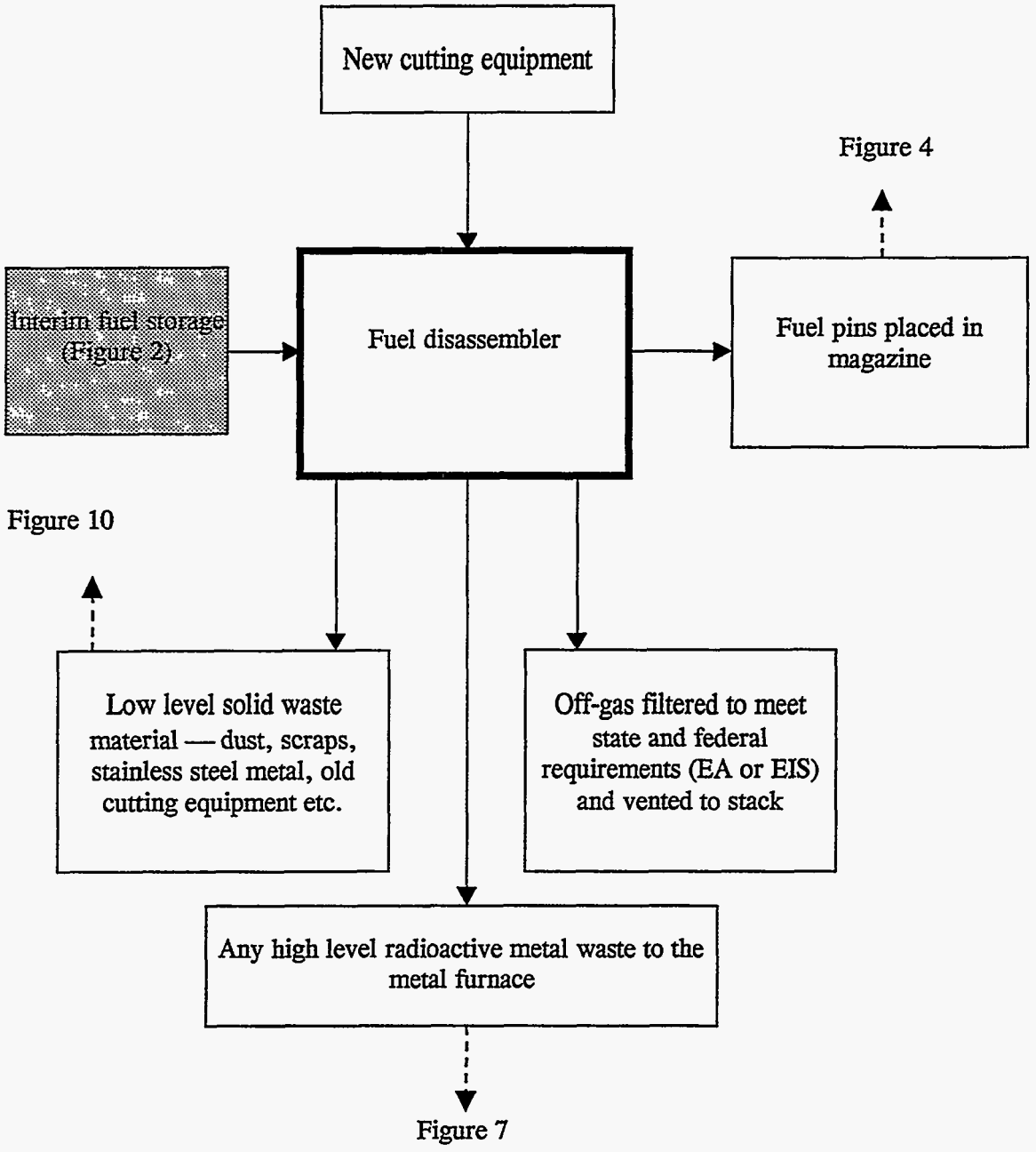


Figure 3. Fuel disassembler.

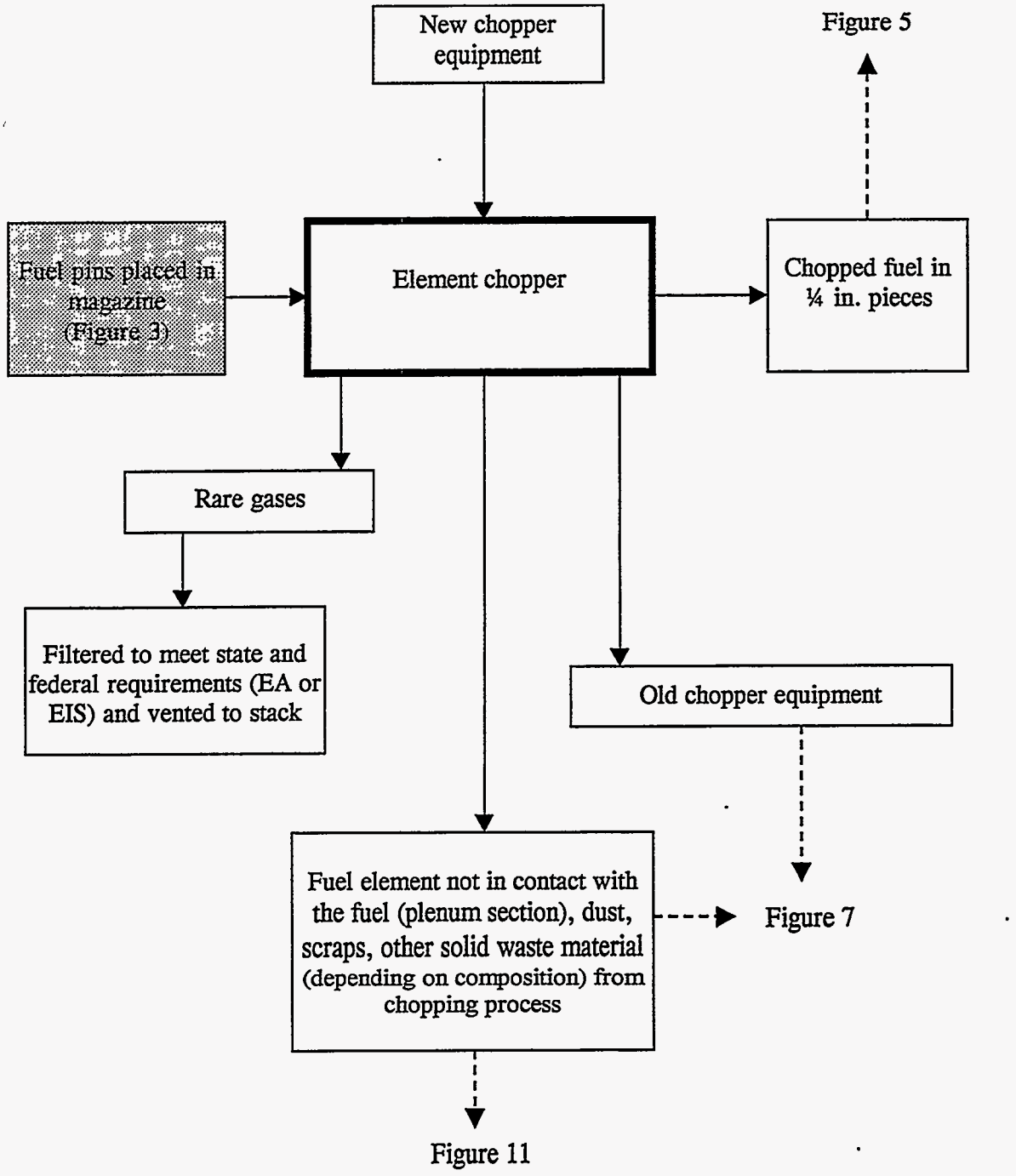


Figure 4. Element chopper.

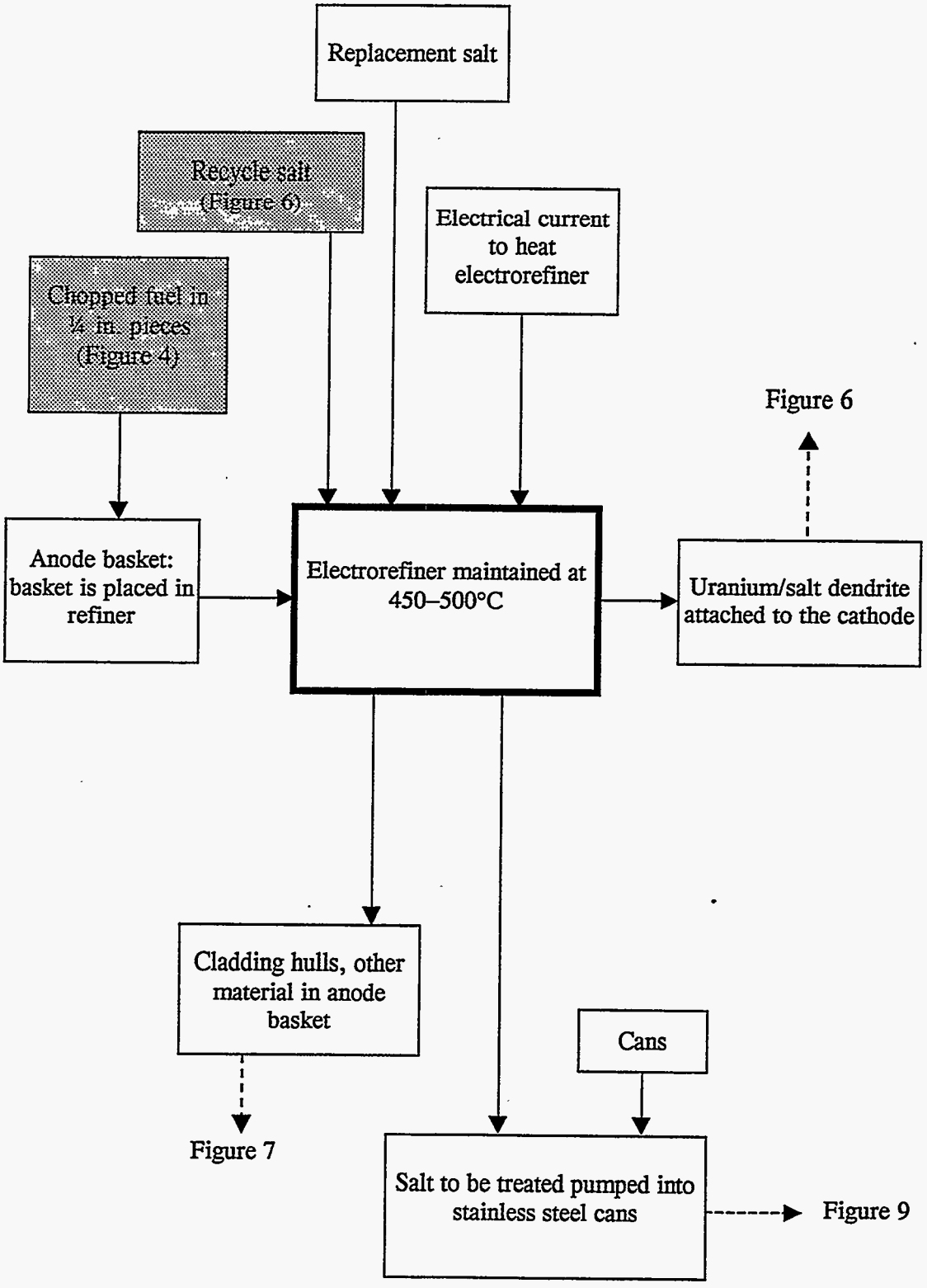


Figure 5. Electrorefiner.

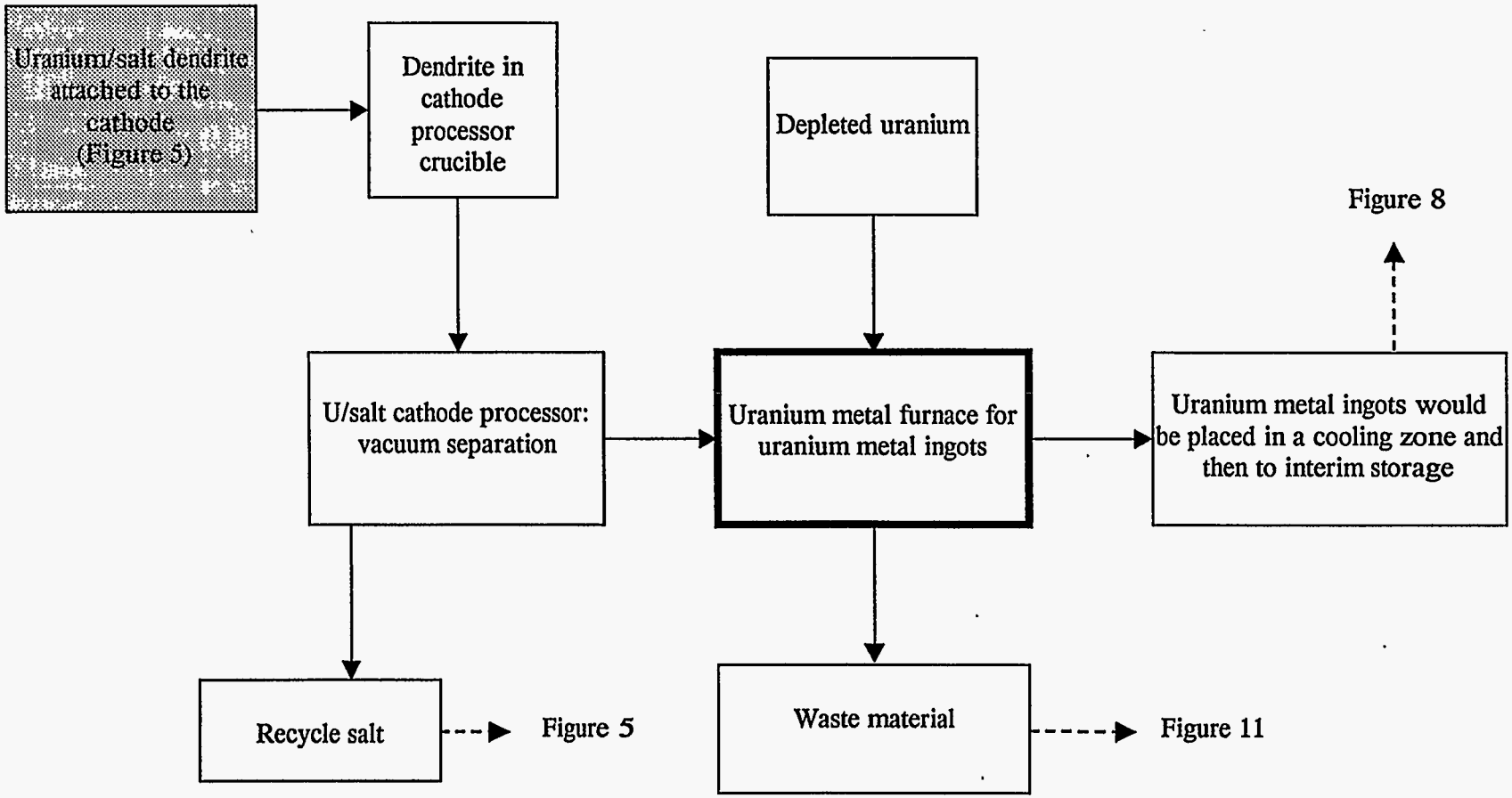


Figure 6. Uranium metal furnace and cathode processor.

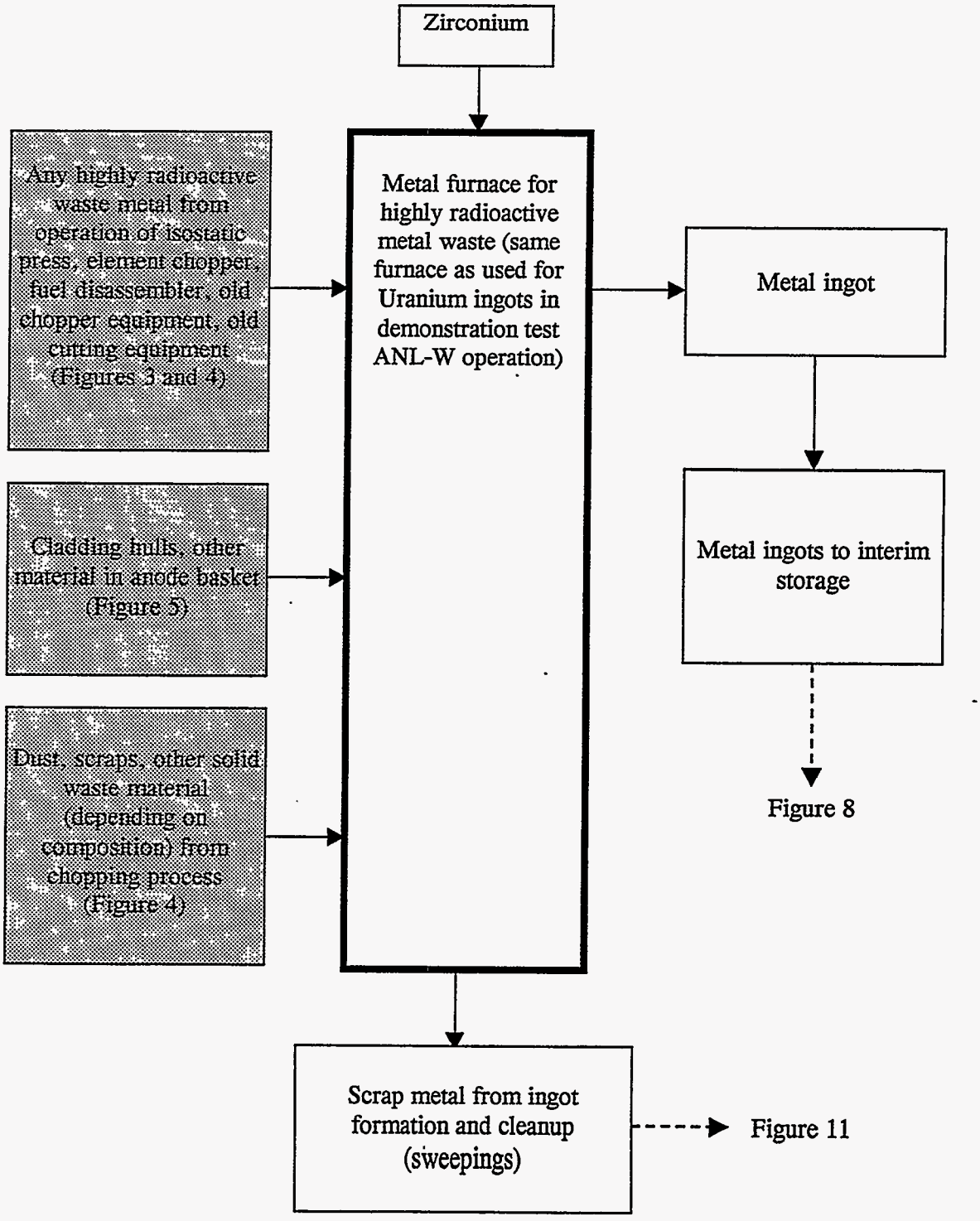


Figure 7. Metal waste furnace

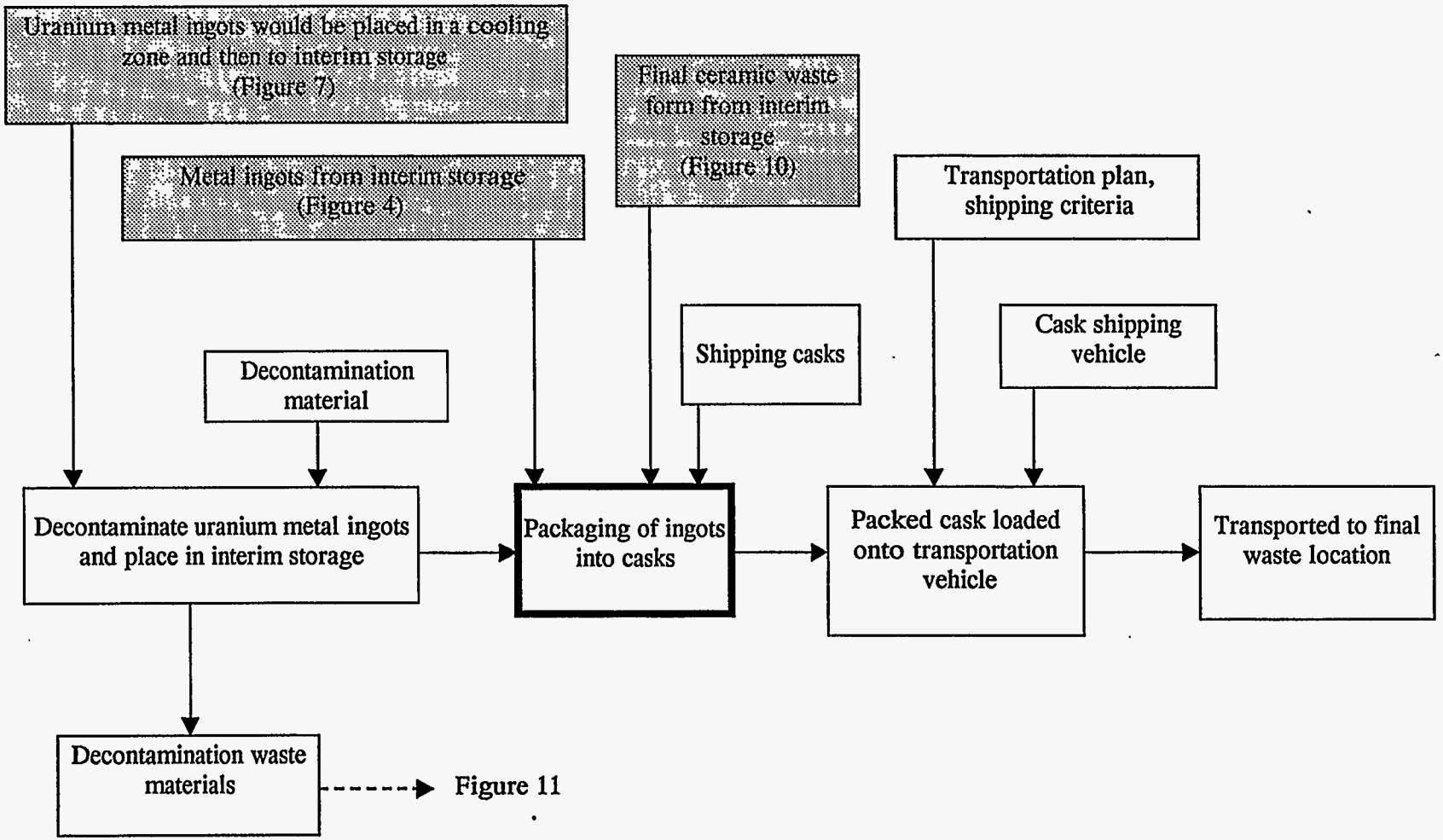


Figure 8. Packaging of ingots.

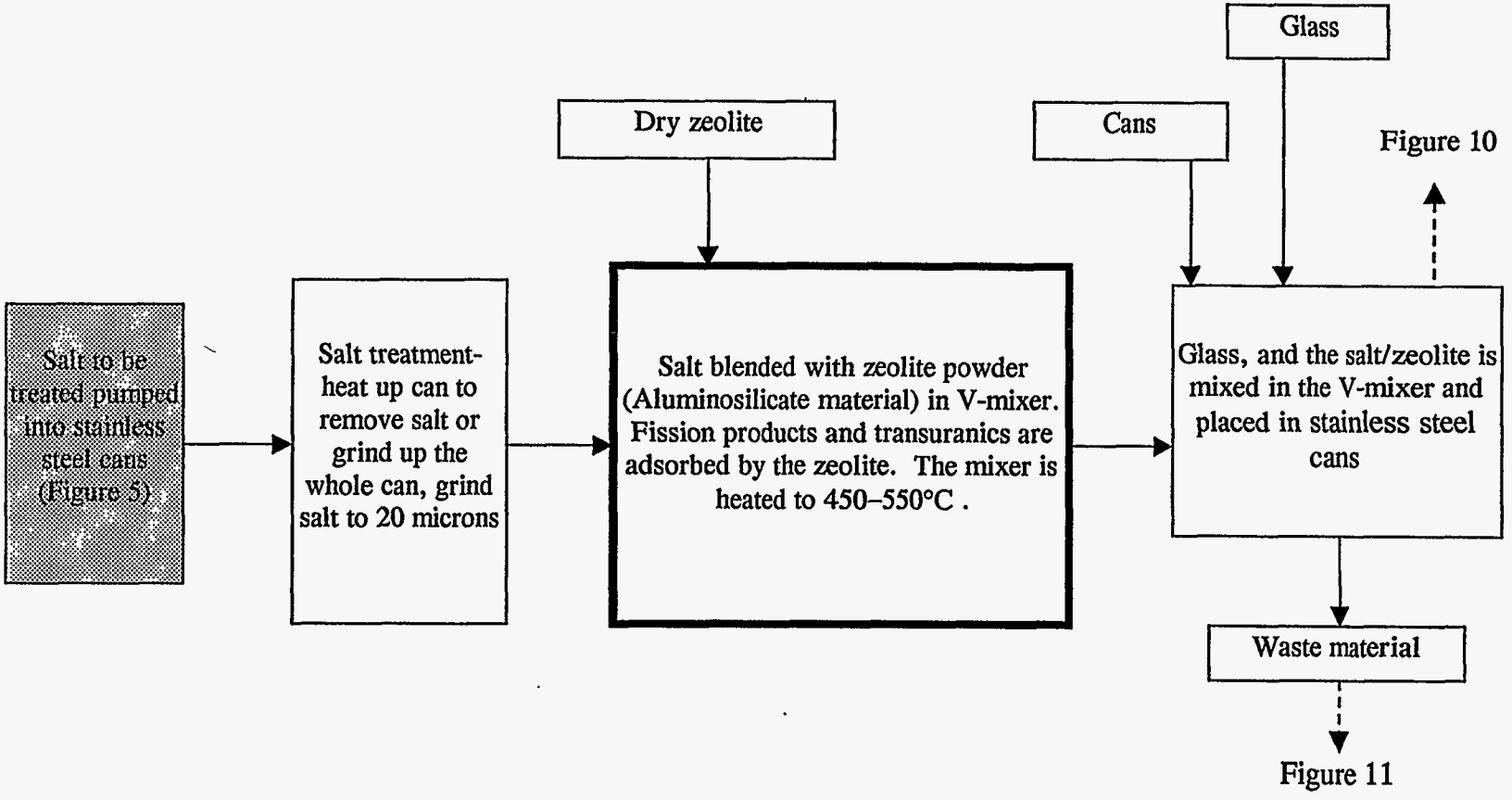


Figure 9. Salt treatment.

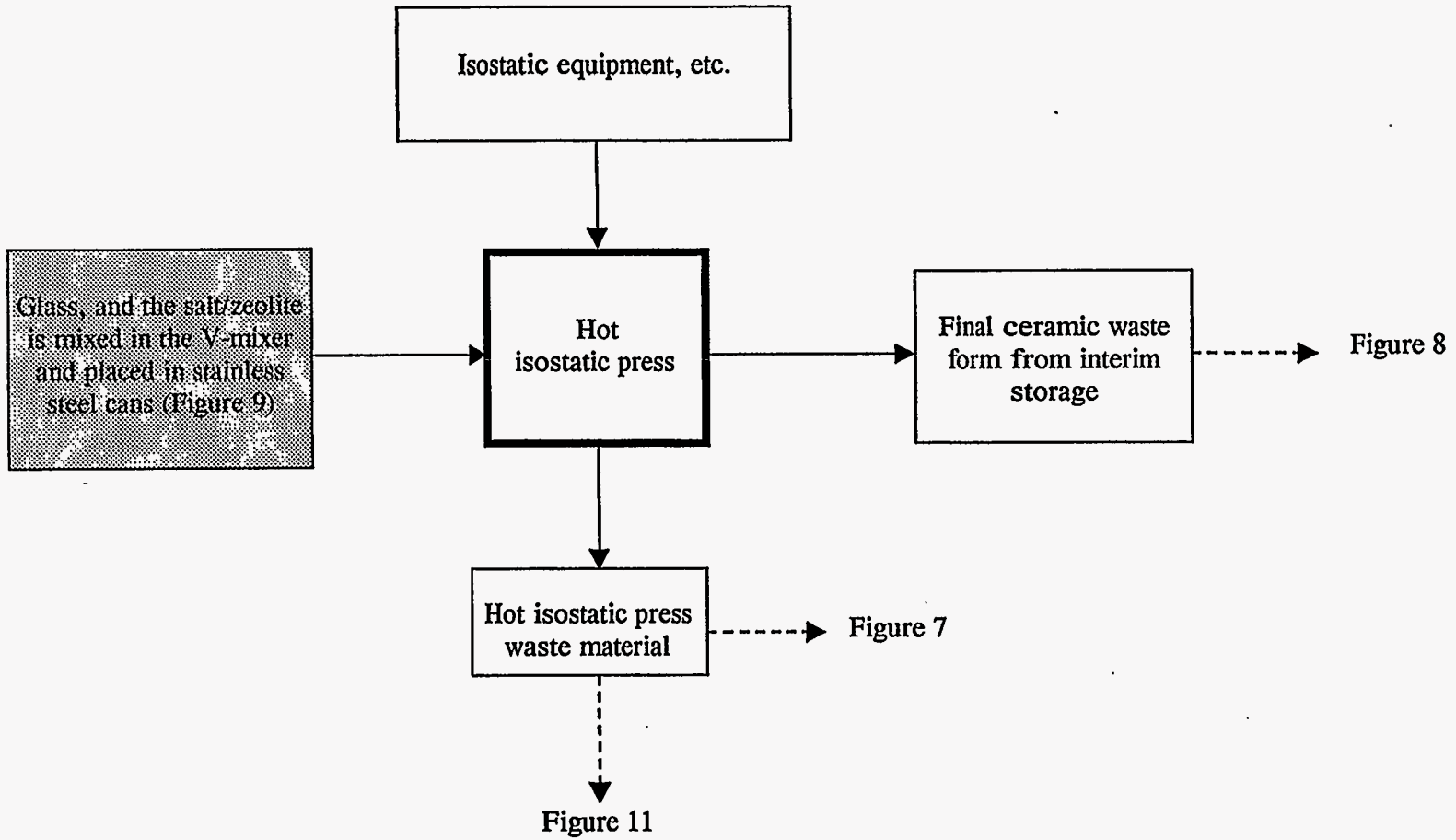


Figure 10. Hot isostatic press.

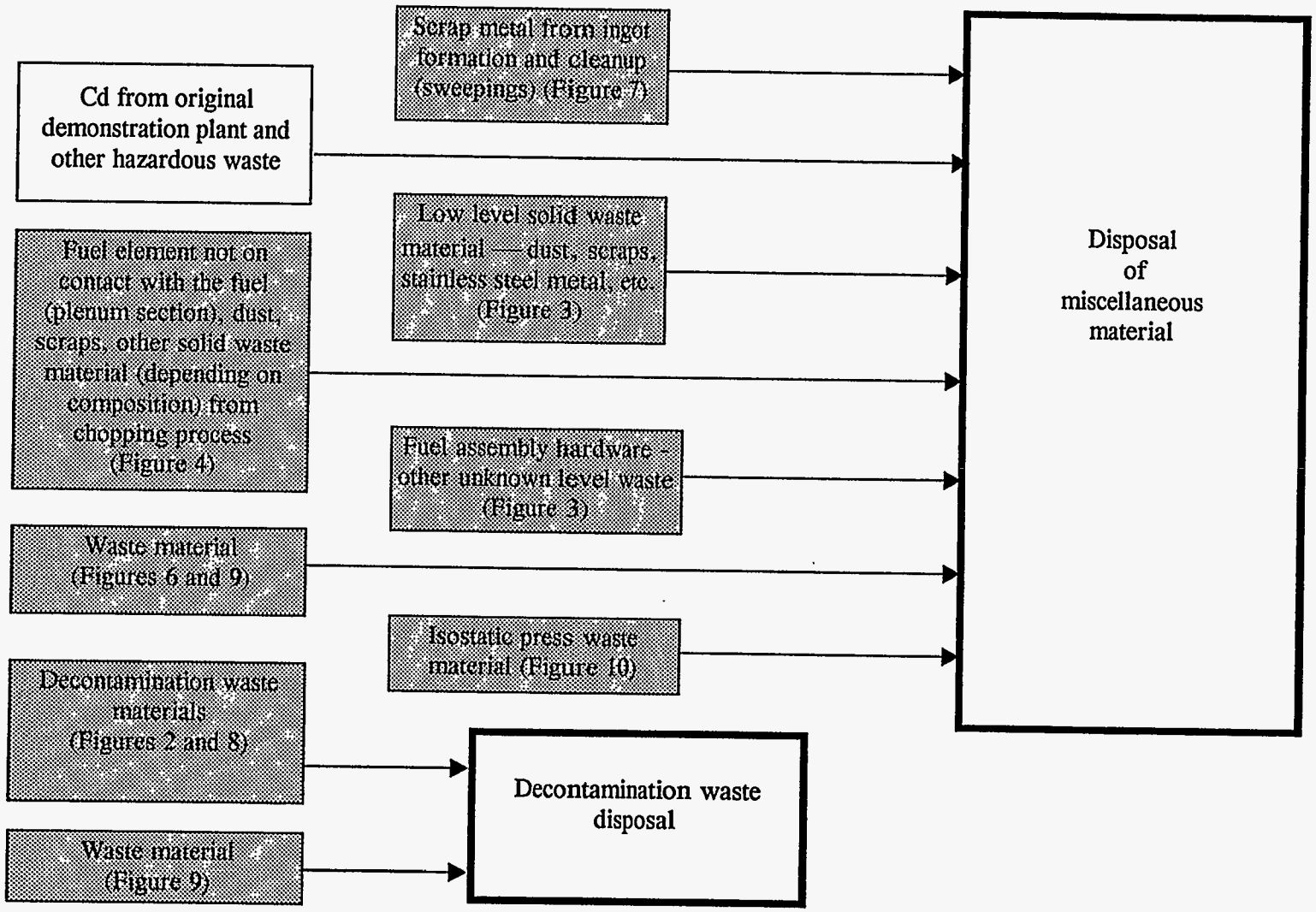


Figure 11. Other waste disposal.

The standard cask is placed in the transfer cart which has the capacity to handle casks up to 4,540 kg (10,000 lb). The cask is opened and the driver or blanket assembly is removed from the cask in an air atmosphere. Two assemblies of driver fuel (one batch) contain about 5.7 kg of stainless steel wire and cladding and 9.7 kg of fuel matrix [8.1 kg heavy metal (HM) of uranium, 5.1 kg of U^{235}]. The spent fuel assemblies are stored in the FCF air cell in square storage racks. After unloading, the empty casks are then sent to the cask storage area. The cask internals (spacing) stay with the cask.

The FCF and HFEF at ANL-W can handle several cask designs in addition to the HFEF-5. With facility modifications, the HFEF and FCF could handle additional designs.[5] Type B certified casks are currently handled at HFEF and FCF. These casks include the T2, T3, NRBK-41, WAPD-40, TRUPACT-II, B2, and TN/4 casks. The facility could handle casks with size and weight limitations with only minor facility modification. The cask would be less than 170 in. tall, 32 in. in diameter and weigh less than 25 tons. The minor facility modifications (arbitrarily defined at costing less than about $75K) assume a redesign of cask shield rings, cask cart upgrades, and interfacing equipment.

If larger casks were to be brought into the facility, major modifications to the facility would be required. Size and weight limitations for those casks using the existing high bay crane capacity include casks that are greater than 32 in. in diameter, 200 in. long, and weighing more than 40 tons. The major modifications (arbitrarily defined at costing more than about $75K) include modifications to cell penetrations, pits, trenches, cask cart, and cask-to-cask mating equipment. The HFEF is being modified to handle larger casks.

Production — The production facility may need to treat 23.5 metric tons (MT) of EBR-II fuel located at ANL-W and 2.0 MT of EBR-II fuel at the Idaho Nuclear Technology and Engineering Center (INTEC). The EMT process is being evaluated to treat other sodium-bonded fuel (Fermi Blanket fuel, sodium-bonded Fast Flux Test Facility (FFTF) fuel, et cetera). The process may also be considered for treatment of other SNF. An NRC-licensed shipping cask and a transportation plan will be required if the fuel must be transported over a public transportation system. Logistic plans will be required to address additional cask operation (procurement, maintenance, transportation, and scheduling). The entire process will require two cells. The cask unloading area will require one operating cell with an air atmosphere for handling intact fuel. The electrorefining operating area will require an argon atmosphere cell for handling exposed reactive materials (Figure 2).

Fuel Disassembler

Generic — A fuel disassembler area will be needed to remove as much non-SNF hardware from the fuel assemblies as possible. Each type of fuel assembly will need to be evaluated to determine the amount and method for removing non-SNF from the fuel. A fuel disassembler (Figure 3) separates the fuel assembly hardware from the fuel elements that contain uranium and other fission products. The assembly is cut and the fuel elements are physically separated. Manipulators are used to pull the elements apart. The section of fuel containing the uranium is chopped and treated in the electrorefiner. The rest of the fuel assembly that is highly radioactive is combined with the cladding hulls that are removed from the anode basket after electrorefining. The fuel assembly hardware that does not go to the electrorefiner is disposed in accordance with criteria at a specific disposition site. Options for disposition of this material are discussed in this report. The resulting waste may contain noble metals or some TRU components.

Demonstration Test — The fuel assemblies are stored in the air cell of the FCF in square storage racks. For EBR-II fuel, the assemblies are removed from interim storage racks one at a time, placed in the vertical assembler/disassembler (VAD), and disassembled. Only the bottom of the EBR-II elements contain uranium and sodium and will be placed in the EMT process.

The fuel assembly hardware that does not go to the electrorefiner will be placed in interim storage in the RSWF until guidance on how to dispose the material is provided by DOE. The total heat in a storage liner must be less than 500 watts.

The fuel disassembly process requires seven days per batch. The current system can accommodate two assemblies in about four days. Two assemblies (one batch) contain about 5.7 kg of stainless steel wire and cladding and 9.7 kg of fuel matrix (8.1 kg HM, 5.1 kg of U^{235}). Two assemblies provide enough uranium material for three magazines. The current fuel disassembly system has sufficient throughput capacity to provide material for two of the current Mark IV electrorefiners.

Production — Fuel disassembly will be different depending on the structures of the different fuels. The material removed from the fuel assemblies would need to be evaluated for appropriate handling and storage processing. In the fuel disassembly area, fuel assembly containers could be opened and the fuel elements removed. The containers may require cutting to remove the elements from the container. The fuel disassembly area will need to handle the large quantity of fuel to be disassembled as well as maintain fissile material accountability.

Element Chopper

Generic — The fuel containing the fission material is sent to a chopper to be reduced to an appropriate size for treatment in the electrorefiner (Figure 4). The portion of the element that contains no uranium is combined with the cladding hulls that are removed from the anode basket after electrorefining. These metals are melted to form the metal waste form.

Demonstration Test — Only the fuel containing the bottom of the EBR-II element will be placed in the anode basket in the electrorefiner. The element is placed in an element chopper magazine and is sent to the chopper. The element is converted into small sections to be placed in an anode basket. The basket is then placed in the electrorefiner. When chopped, two assemblies (one batch) provide enough material for three magazines. If the fuel is not to be refined immediately, the pins are placed in extra anode baskets in the argon cell of the FCF. The driver fuels tested so far have ¼-in. diameter elements. The blanket fuel is in ½-in. diameter elements and a new chopper is being implemented for the larger elements and for increased throughput. The fuel elements are placed into a container for transfer to the argon cell.

Process and equipment modification and improvements in the second-generation electrorefiners are expected to increase throughput 2 to 4 times. Therefore, the current mechanical fuel-handling step (cask unloading/fuel disassembly/fuel chopping system) could handle twice the current throughput through the Mark IV electrorefiner. The current disassembly system probably will handle the throughput through the second-generation (Mark V) electrorefiners. Modifications may be necessary if second-generation electrorefiners increase capacity above a factor of two.

Production — For a production scale plant, the chopping process needs to be designed to chop sufficient fuel to maintain the production throughput. The fuel disassembly area will need to handle the large quantity of fuel to be chopped as well as maintain fissile material accountability. Cleanup and waste disposal will need to be addressed.

Gas Recovery

Generic — During chopping and electrorefining of the fuel, fission gases are released; therefore, recovery of these gases was evaluated. During traditional processing operations, the INTEC would recover most of these gases. The recovery process could collect 20,000–30,000 curies per year during a

fuel processing campaign. The rare gas was sent to isotope sales in Oak Ridge, Tennessee. Rare gas recovery could be performed on the treatment of this SNF.

Demonstration Test — The demonstration test was not designed for rare gas recovery. These gases are vented to the atmosphere in accordance with the air permit issued by the State of Idaho.

Production — For a production size facility, the amounts of rare gases need to be evaluated to see if recovery of the gas would be economically favorable. Recovering the gas would require building a new system, conducting operational readiness reviews (ORR), training operators, etc.

Electrorefiner

Generic — In the electrorefiner (Figure 5), primarily the uranium is separated from the other components of the chopped fuel. The electrorefiner contains molten salt (a mixture of LiCl and KCl) that is maintained at 450–500°C. The elevated temperature is required for process operation. Electrical heating coils around the electrorefiner provide the heat source. The anode basket containing the chopped fuel is lowered into the molten process salt. Upon application of an electric voltage between the anodes and cathodes, the uranium, transuranics, most of the fission products, and the sodium would dissolve into the salt, forming chlorides of the various elements. The uranium is transferred by the current from the anode basket to form a dendrite crystal structure on the cathode.

When sufficient uranium has accumulated on the cathode, the cathode containing the uranium dendrite and residual salt is raised in the gas space of the electrorefiner to allow molten salt to drain away from the cathode. The cathode is transferred to an electrorefiner support station where the uranium is removed from the cathode. A scraper shaped like two half circles is squeezed together over the top of the uranium attached to the cathode. The circle is then pulled down, physically removing the uranium dendrite and the salt mixture adhering to it from the cathode. The uranium dendrite and adhering salt mixture falls into a graphite crucible. The dendrite uranium in the graphite crucible is treated in the cathode processor. The graphite crucible is located on the top of the cathode processor while a stainless steel crucible is located on the bottom of the cathode processor.

Demonstration Test — For the EBR-II fuel, about 10 kg of the chopped fuel is placed in four baskets which make up the anode basket. For operation of the electrorefiner, about 10 kg of uranium can accumulate on the cathode before the cathode needs to be removed. The entire electrorefining operation takes 24–72 hours but the operation time may decrease as a result of process and equipment improvements.

The material remaining in the anode basket is mostly stainless steel cladding hulls with some residual salt. The basket is spun to remove some of the residual salt. The remaining hulls and salt are placed in a stainless steel crucible for salt removal in the cathode processor. The stainless steel remains in the crucible and the salt is collected in the condensate crucible. The stainless steel cladding hulls are sent to the metal furnace.

The initial operation of the process required about 400 kg of Cd metal in the Mark IV electrorefiner to collect uranium not collected on the cathode. Process modifications are expected to eliminate the requirement for the Cd metal in the Mark V electrorefiner. The Cd metal will be retained in the Mark IV electrorefiner until the Mark IV is ready for decommissioning and decontamination (D&D). The Cd from the Mark IV will be disposed as mixed waste.

Production — Several of the processing steps throughput rates (fuel disassembly, cathode processor, etc.) will need to be increased for production operation. This can be accomplished by using more equipment or by improving flowsheet operation. For example, the throughput in the Mark V electrorefiner will need to be greater than the throughput for the Mark IV electorefiner to adequately treat all of the EBR-II fuel. Larger equipment could be used; however, additional criticality concerns exist when using larger volume vessels because fissile material is present in the process. For a larger facility, the salt can be refined and recycled back to the electrorefiner with replacement salt (as needed). Increased throughput will also be needed in the operation of other process steps (fuel disassembly, cutting, etc.).

Cathode Processor and Uranium Metal Furnace

Generic — The graphite crucible is located on the top of the cathode processor while a stainless steel crucible is located on the bottom of the cathode processor. The temperature of the graphite crucible is increased and the system is evacuated, volatizing chloride salts while the uranium stays in the graphite crucible. The volatized salts and fission products are collected in a condensate crucible to be returned to the electrorefiner. The purified uranium in the graphite crucible is placed in the casting furnace to form ingots. Highly enriched uranium can be combined with depleted uranium to produce low-enriched uranium ingots.

Demonstration Test — After the uranium dendrite and adhering salt mixture are placed in the graphite crucible, the crucible is placed in a cathode processor. The temperature of the graphite crucible is increased and the crucible is evacuated, volatizing chloride salts while the uranium stays in the graphite crucible. The volatized salts and fission products are collected in a condensate crucible and recycled to the electrorefiner. The purified uranium in the graphite crucible is placed in the furnace and melted with depleted uranium to form ingots. It takes about one day to process one batch of uranium in the cathode processor. The uranium and metal waste are melted in the same furnace for the demonstration tests. Highly enriched uranium from driver assemblies is combined with depleted uranium to produce low-enriched uranium ingots. It takes about a day to cool a batch of uranium ingots. The ingots stay in the FCF for interim storage. They are transported to the Zero Power Physics Reactor (ZPPR) Storage Complex for secondary interim storage until a final disposal decision has been reached. The uranium metal ingots may be temporarily stored at ANL-W.

Production — For the production facility, the uranium and metal probably will not be cast in the same furnace. Highly enriched uranium will be combined with depleted uranium, the ingot will be removed from the uranium furnace and cooled over a period of time in an ingot-cooling zone. Hot ingots will be placed in the cooling area as cooled ingots are removed. The ingots will then be placed in interim storage.

Metal Waste Furnace

Generic — The highly radioactive metal waste is sent to the metal furnace (Figure 7). Only the part of the element containing uranium is placed in the anode basket, the rest of the element is waste cladding and is combined with the cladding that remains in the anode basket after removing the uranium (the cladding hulls). The cladding hulls require a salt removal step before combining with other stainless steel. The metal is melted in the casting furnace and then cooled to form the metal waste form.

Demonstration Test — One 6-kg ingot is produced for every batch (two assemblies) of fuel. The metal is melted at 1600–1625°C for two hours under a vacuum in the casting furnace. For the demonstration test, the casting furnace is also used to melt the uranium from the cathode that is combined

with depleted uranium to produce low-enriched uranium ingots. The stainless steel cladding hulls are sent to the metal furnace from the cathode processor. The resulting metal ingots are treated as highly radioactive metal waste since much of the noble metal fission products stay with the cladding. Highly radioactive metal waste ingots would be stored in FCF until being transferred to the RSWF for interim storage. The metal ingots may be shipped to Hanford for long-range storage.

Production — Any metal removed from the fuel during disassembly not sent to the electrorefiner is waste cladding material and is combined with the cladding hulls that are removed from the anode basket after removing the uranium. For the production facility, a dedicated furnace will be used for forming the metal ingots. One furnace for the uranium ingots and the metal ingots could cross contaminate the ingots with material not desired for the metal or uranium ingot. Depending on the waste criteria, the metal ingots may be shipped to Hanford or to the repository for long-range storage.

Packaging of Treatment Products

Generic — The major treatment product from the process will be packaged into casks and sent for final disposal (Figure 8). Composition of the treatment products will determine the final disposal site. The EMT products may require additional treatment before final disposal. Other wastes will be disposed appropriately.

Demonstration Test — The uranium ingots are brought from interim storage in FCF, FASB, or RSWF to the loading area. The fuel assembly hardware that does not go to the electrorefiner is disposed in accordance with criteria at a specific disposition site. This material will be placed in interim storage in the RSWF until guidance on how to dispose the material is provided by DOE. The metal treatment ingots in the RSWF are loaded in the loading area. Ceramic waste will be moved from the RSWF into the loading area. The waste material will be decontaminated and packed into casks. A transportation plan will be developed to transfer the material from ANL-W to final disposal.

Production — The treatment wastes will be placed in interim storage. The material will then be placed in casks for shipment to final disposal or handling. A transportation plan will be developed for the transfer of the treatment products to final disposal or for additional treatment.

Salt Treatment

Generic — The salt used in the electrorefiner is a mixture of LiCl and KCl. Only about 5,000 kg of HM can be processed per batch (600–700 kg/batch) of salt. The salt used in the electrorefiner must then be renewed. The salt can be disposed and replaced or recycled (Figure 9).[a]

The used salt will be removed from the electrorefiner. The salt is passed through an ion exchange column loaded with zeolite pellets or the salt is blended with zeolite powder (alumino silicate material). The zeolite is dried before it is used to remove water. The salt is ground and mixed with the dry zeolite in a V-mixer. The zeolite mixture (crystalline form) in the V-mixer adsorbs fission products and TRU elements. The zeolite and salt are heated in the V-mixer. Then, the glass frit is mixed with the zeolite and salt that were contacted in the V-mixer. About 5 kg of salt will produce 50 kg of ceramic waste (salt, zeolite, glass frit, etc.). The resulting powder (glass with salt-loaded zeolite) is put in a stainless steel can

a. M. Simpson, Argonne National Laboratory-West, letter to R. J. Ramer, Staff Engineer, Lockheed Martin Idaho Technologies Company, "Ceramic Waste Process Parameters," (March 14, 1997).

and sent to a hot isostatic press to be processed into the final ceramic waste form. The system is sampled after each process step.

Demonstration Test — The salt and then the cadmium are pumped out of the electrorefiner into stainless steel cans. The cans of salt (highly radioactive) are shipped to the HFEF for treatment. The salt composition associated with both the Mark IV and Mark V batch tests in the demonstration test will be similar. According to the Environmental Assessment (EA) for the demonstration test, approximately 600–700 kg of salt will be used per batch in the electrorefiner. About 5,000 kg of HM can be processed per batch of salt. Only a portion of the salt will be used during the demonstration tests. The salt will not be recycled for the demonstration test.

To treat the salt, the salt will be removed from the can in the HFEF. The salt is ground to about 20 microns and mixed with the dry zeolite in a 5-ft^3 V-mixer. The zeolite and salt are heated in the V-mixer to 450–550°C. The zeolite is dried (450–550°C) before it is used. Then, glass (final glass type is under evaluation) is mixed with the zeolite and salt that were contacted in the V-mixer. The V-mixer system can treat about 5 kg of salt per day. The 5 kg of salt will produce about 50 kg of ceramic waste (salt, zeolite, glass frit, etc.) per day.

Production — Small SNF treatment batches will be approximately 10 kg of SNF and large SNF treatment batches will be approximately 160 kg of SNF. The batch sizes of the full production-sized facility would be capable of treating up to 800-kg uranium batches. About 3–4 batches of the salt (600–700 kg/batch) will be needed to treat 20 MT of fuel. It may be advantageous to recycle the salt used to treat N-Reactor fuel or some other fuels. For these systems, the salt may be continuously treated. A side stream of salt could be removed from the electrorefiner and pumped through columns and then the cleaned salt is sent back continuously to the electrorefiner. The final volume of ceramic product produced may be reduced by a factor of four or more if the salt was treated and recycled.

Hot Isostatic Press

Generic — The glass/zeolite mixture, containing fission products and TRU, in stainless steel cans is sent to a hot isostatic press (Figure 10). The cans are heated to a final temperature, which is a function of the material in the can. The cans are compacted with high pressure. The heat and pressure result in a volumetric reduction of the can by about 50%.

Demonstration test — The hot isostatic press is in the HFEF. The salt is transported to the HFEF for treatment. About 5 kg of salt will produce 50 kg of ceramic waste. For the hot isostatic press, the cans are heated and their temperatures raised 5–20°C/min until a final temperature of 800 to 1,000°C is reached. The final temperature is a function of the material in the can. The demonstration tests call for the cans to be heated to 850°C. The cans are compacted with a pressure of 10,000 to 25,000 psig. The pressure ramps up and down at the same rate. The hot isostatic press reduces the dimensions of a can from about 8.2 in. long and 4.5 in. diameter (2.14 L volume) to 4.8 in. long and about 4 in. diameter (0.99 L volume)—a 50% volume reduction. The time required for the operation from loading to unloading the can takes 7–8 hours. The final density of the material in the can is about 2.45 gm/cc. The cans are sent to interim storage in the RSWF.

Production — For processing fuel other than the demonstration tests, a larger hot isostatic press would be installed in the facility. A new system, being evaluated, may use 19 in. diameter cans and reduce a can from 40 in. to 20 in. long. To treat 5,000 kg of HM, 650 kg of salt will be required and 5 kg of salt will result in 50 kg of waste. The final density of the material after isostatic pressing is 2.45 gm/cc. For example, the final volume of ceramic waste from treating 25,350 kg HM of EBR-II fuel will be about 13.5 m^3 (470 ft^3).

Other Waste Disposal

Generic — Operational wastes in addition to treatment products (uranium ingot, ceramic waste, and metal waste) will need to be disposed from the process (Figure 11). The operational process wastes include pumps, valves, wrenches, piping, other metal waste, gloves, and shoe covers. The operational process wastes are decontaminated if possible. Decontamination solutions will need to be evaporated and disposed. Disposition and treatment of these materials will depend on facility deployment. After the fuel treatment campaign has been completed, operating equipment and possibly a facility D&D will be required.

Demonstration Test — For the ANL-W demonstration test, the additional waste material will be sent to the Radioactive Waste Management Complex (RWMC) at the Idaho National Engineering and Environmental Laboratory (INEEL). Materials sent to the RWMC must have a thermal output of less than 500 watts/m.[3] If the materials can not go to the RWMC, the material may be sent to Hanford. The standard evaporation process will treat the decontamination solution and other liquid waste material. Any resultant solid waste will be disposed as radioactive Low-level waste (LLW) or TRU waste. The cadmium used in the initial EMT tests will need to be disposed appropriately.

Production — The production campaign will require disposal of more material than the demonstration tests. The final D&D of the equipment used for the fuel treatment and the facility will also be required.

Criticality Safety

Generic — Because fissile material is present in the SNF, criticality control is required to protect the worker and public from a criticality accident. A safety analysis and criticality evaluation is required for treating the SNF. A safety analysis must be completed to assure the safety of the operating area because of the fuels and quantities of fuels treated in a facility.

Demonstration Test — For the ANL-W demonstration tests, the Criticality Hazards Control Statement (CHCS) provides the limits, boundaries, and conditions established by nuclear analyses, and the specific rules under which activities involving fissionable materials are carried out.[6,7,8] Criticality safety in the area is maintained by moderator exclusion and fissile mass limit criticality controls.

The fuel is weighed before it is chopped and then again after it is chopped. It is chopped so that the fuel falls into the anode basket or falls into the container surrounding the basket. At ANL-W, strict control of all movement of fissionable material into and out of the facility, as well as within the facility, is maintained. The facility is divided into criticality hazards controls zones with limits on the amount and type of material within each zone. The limits on each zone are specific to the work being performed in that zone as to the form, type, mass, and other characteristics of the materials pertinent to criticality. Analyses have been performed to examine the consequences of an inadvertent violation of the rules. Separation of the zones limits interaction between zones, and the limits within each zone aids criticality safety. All movements into and out of a zone follow written approved procedures and are logged at the sending and receiving zones. The weight difference is determined and a record is kept. The area is operated until a hold-up limit is reached. The operating limit is less than the hold-up limit, which is less than the criticality limit. Moderator limits are also set for the zone. For example, the chopping zone can have up to 500 grams of moderator. All potential moderator material brought into the area is determined by the criticality engineer to be either a moderator (such as liquids, wet paper towels) or not a moderator (tools, etc.). There are checks and double checks on the material entered as a moderator in the log.

The mass of uranium entering and exiting the zone is measured to keep uranium from accumulating. Each zone is assigned a mass number. The zone is monitored for mass.

There is a decontamination area in the basement. A piece of material (equipment or other material) moved into a zone would have a mass assigned to it by criticality personnel. If the material is decontaminated, the decontamination solution goes into a poisoned sump with a fissile material limit.

Production — A safety analysis and criticality evaluation will be required for a production facility handling the larger quantities of EBR-II fuel or other SNF.

EMT TREATMENT PRODUCTS AND LIFE-CYCLE DISPOSITION

One of the major issues associated with treatment of SNF is final disposition of the treatment products and associated waste streams. During treatment of SNF, various chemicals are added to the fuel, increasing the mass of product and waste streams that have to be handled, stored, and, eventually, disposed. Thus, when assessing whether or not to treat SNF, the costs associated with final disposition must be determined, in addition to the technical issues and costs associated with the treatment process, itself.

For example, if all of the products and waste streams will eventually be shipped to the repository, the storage costs may increase over those associated with shipping the untreated SNF directly to the repository. However, if some of the products or waste streams can be shipped to a LLW site, final storage and disposition costs may actually be less than those associated with disposition of untreated SNF in the repository. These cost savings can be used to offset the costs associated with the treatment process and provide an economic advantage for treatment, independent of the technical reasons for treating the SNF.

Five principal treatment streams are associated with the EMT process:

1. The fuel assembly hardware (most of the fuel assembly mass except for the fuel pins) is removed from the fuel pins and discarded. The fuel assembly hardware does not contain any spent fuel, except for possible surface contamination, but does contain activation products, as a result of being irradiated by the neutrons in the reactor vessel during burnup. This hardware comprises the first treatment stream.

2. When the fuel elements are chopped into small pieces, prior to being placed into the electrorefiner, fission gases (primarily tritium and krypton) are released. More of these gases are also released when the fuel is dissolved in the electrorefiner. These gases comprise the second treatment stream.

3. The uranium is separated from the rest of the SNF and cast into ingots. This comprises the third treatment stream.

4. The residual cladding hulls and noble metal fission products remain in the anode basket. These are melted and cast into ingots, forming a metallic waste stream and the fourth treatment stream.

5. The chemically active fission products are trapped in the electrolyte, along with most of the actinides, other than uranium. These are formed into a ceramic and comprise the fifth treatment stream.

In addition to the principal treatment streams, the EMT process will generate some ancillary waste streams. Disposition of these waste streams will also have to be considered. These are indirect process liquid waste, indirect process solid wastes, nonradioactive wastes, and decommissioning wastes.

Each of the EMT treatment streams has different radioactive and material characteristics and each needs to be considered separately. Final disposition options for each treatment stream are presented in this section. Since characterization of the product streams is currently being determined in the demonstration, the discussion on disposition options is preliminary and could change, as more experimental data become available. In addition, the acceptance criteria for the repository are not yet finalized and changes in these criteria could also affect the disposition options.

Fuel Assembly Hardware

The first step in the treatment of SNF using the EMT process is to remove all non-SNF hardware from the fuel. The function of the fuel disassembler to separate the fuel assembly hardware from the fuel pins that contain the spent fuel and fission products. The fuel assembly hardware represents a significant fraction of the total fuel assembly mass. For example, the fuel assembly hardware comprises approximately 60% of the total mass of an EBR-II fuel assembly.[4] Thus, disposition of this waste stream in a facility other than the repository could significantly reduce the costs associated with final disposition of SNF, compared to shipment of the SNF, untreated, to the repository.

Since the principal radioactivity associated with the fuel assembly hardware is due to activation products and not fission products, it is expected that this waste stream is a candidate for disposition in a LLW site. The hardware could be encapsulated and shipped to the LLW site as is or could be melted into ingot form and then encapsulated and shipped to the LLW site. This product may exceed Class C criteria and, thus, may not be acceptable for disposal in a LLW site. Independent of this issue, DOE is currently evaluating the order governing the operation of the LLW site. The independent evaluation should also include the resolution of this issue.

Gaseous Fission Products

When the plenum end of the fuel element is sheared, some fission product gases (primarily tritium and krypton) are released. The shearing procedure takes place in the argon hot cell during the demonstration test and the fission gases are released to the argon atmosphere. Then, when the chopped fuel pins are placed into the hot electrolyte, more of the gaseous fission products are released. Gaseous fission products are scrubbed from the argon and eventually vented to the atmosphere, in conformance with the air permit. The semi-volatile fission products form salts in the electrorefiner.

The potential for collecting these gases and marketing them was considered. However, the costs associated with this option are expected to exceed the potential income from this treatment stream. For example, the gases associated with all of the EBR-II SNF at ANL-W are summarized in Table 1. As shown, the total radioactive gas content is less than 16,000 Ci. Consequently, venting these gases to the atmosphere may be the disposition option of choice for the EMT treatment process. However, this should be reevaluated when more details are available regarding which specific SNF types will be treated and whether a new EMT facility will be constructed.

Table 1. Estimate of gaseous isotopes for the total EBR-II inventory at ANL-W.

Gaseous Isotope	EBR-II Ci Content	Percent of Total
^{85}Kr	14,600	93.4
^{3}H	1,030	6.6
Total, Ci	15,630	100.0

a. Approximately 10% of the residue tritium (100 Ci) is released during the chopping operation. The rest of the residue tritium is bound within the sodium metal and is released during the electrorefining operation. Most of the residue tritium in the fuel diffuses out of the cladding during reactor operation.

Uranium

There are two basic categories of uranium resulting from the EMT process, depending on the type of fuel assembly being processed. Blanket fuel assemblies result in depleted or natural enrichment uranium ingots and driver core assemblies result in enriched uranium ingots. The enrichment of the resulting ingot can vary but for safeguards and security purposes will be less than 20% (higher enriched uranium will be diluted to below 20% enrichment in the casting furnace).

There are three potential disposition options for the depleted or natural enrichment uranium ingots. First, these could be placed in canisters and shipped to the repository. Second, they could be shipped to the LLW site. One of the most important characteristics that could influence the decision is contamination of the ingots with TRU waste products, such as Pu. The EMT process is designed to separate the uranium from any other actinides. However, the contamination level at which a given waste product is considered to be TRU waste is so low that it is not yet determined whether or not the uranium ingots will be TRU. If they are considered to be TRU waste, the LLW site would not be an option and they would probably have to be shipped to the repository. It is possible that they could be shipped to the Waste Isolation Pilot Plant (WIPP). However, at this time only defense-related TRU waste is designated for this facility. In addition to these options, there is a third disposal option for the enriched uranium ingots. They could be included in the disposition of off-specification enriched uranium, which involves having them formed into new fuel elements and used in commercial reactors.

All of these options are currently being investigated as part of the NSNFP charter to dispose the DOE-EM SNF.

Metal Waste Product

The fourth treatment stream from the EMT of SNF is the metal waste form. This is principally comprised of the cladding hulls plus noble metal fission products. In addition, the fuel element plenum sections (that part of the fuel element located above the fuel) will be added to this treatment stream. There is also the possibility of actinide contamination due to chemical interaction between fuel and cladding or recoil of the fuel constituents onto the inner cladding surface as a result of the fission process.

These constituents are placed into a furnace and melted to form ingots, which are the metal waste product. Since this waste form contains substantial amounts of fission products, it should be relatively highly radioactive—much more so than the previously discussed three treatment streams. The most probable disposition is to treat it as high-level waste (HLW) and package and ship it to the repository.

Ceramic Waste Form

The fission product laden salt from the electrorefiner is pumped into stainless steel cans for temporary storage in the hot cell. The solid salt is removed from the cans and ground to a fine powder. Zeolite powder (alumino silicate) and glass frit are added to the salt in a large V-mixer. The resultant powder is loaded into special cans and then converted to a ceramic by exposure to high pressure and temperature in a hot isostatic press, forming the ceramic waste form.

Of all the treatment streams emanating from EMT of SNF, this one most closely meets the legal definition of HLW. That is, it is the solid waste form made from the processing "liquid" (molten salt) that comes into contact with the spent fuel and contains most of the radioactive fission products. Additionally, this waste form will contain most of the plutonium and other actinides, other than uranium. It is, therefore, highly radioactive TRU waste. The most likely disposition option for the ceramic waste form is to treat it as HLW and package and ship it to the repository.

Ancillary Waste Streams

Indirect Process Liquid Waste

The indirect process liquid wastes are water used to wash residual sodium from fuel assemblies (for treatment of sodium-contaminated SNF) and fluids from the decontamination spray chamber used to remove radioactive material from equipment/material removed from the operation area. It is anticipated that these wastes will be directed to a drain where they will be collected and evaporated to form a solid LLW form.

Indirect Process Solid Waste

The indirect process solid wastes are the plastics, tools, and equipment that result from the routine operation of the hot cell that are anticipated to be shipped to a LLW site.

Nonradioactive Waste

Nonradioactive wastes consist of sanitary sewage, industrial sewage, normal solid wastes, and excess unused chemicals. These will be disposed using standard industrial waste disposal practices which will be conducted in accordance with all appropriate waste management regulations.

Decommissioning Waste

The decommissioning wastes are from the decontamination of the facility and disposing of equipment and chemicals after the operations have been completed. Radioactive components are expected to be LLW and will be disposed as such. The other wastes will be disposed using standard industrial waste disposal practices which will be conducted in accordance with all appropriate waste management regulations.

SNF AMOUNTS AND LOCATIONS

Several categories of SNF within the DOE complex may require treatment prior to final disposal. The reasons for this are diverse and include concerns about the SNF matrix composition and cladding condition. The repository acceptance criteria are not yet final, so engineering judgment was employed to select candidate SNF for treatment. The candidate SNF is that for which there is a reasonable expectation

that the SNF may require treatment before final disposal. It should be noted that inclusion of these SNF types in this report as candidates for treatment does not represent a binding determination from DOE that these fuels do or do not require treatment. As more information becomes available regarding specific SNF type characterization or disposition facility acceptance criteria, this list of candidate fuels for treatment will be modified.

Evaluations of disposition strategies and conditioning alternatives for the identified SNF have been conducted by DOE task teams consisting of knowledgeable DOE and contractor personnel from the affected sites.[1,2] The discussions in this paper include the evaluation results from the task team reports and further discussions with knowledgeable site personnel.

Sodium-Bonded SNF

Although DOE-EM SNF is not waste and therefore Resource Conservation and Recovery Act (RCRA) solid waste regulations do not currently apply, an eventual waste determination by DOE would require evaluation for applicability of RCRA hazardous waste regulations. Certain fuels within the DOE-EM inventory may potentially exhibit a 10 CFR 60.135[9] hazardous characteristic. Preliminary evaluations indicate that the primary characteristic of concern is potential chemical reactivity caused by the presence of metallic sodium bonds used to thermally bond the fuel to the cladding in some SNF types.

Further evaluations of the sodium-bonded SNF and whether it actually exhibits the 10 CFR 60.135 characteristic of reactivity are required. Although this SNF may be determined to not be 10 CFR 60.135 reactive, it may still be chemically reactive enough to require stabilization prior to repository disposal in accordance with the regulations governing repository disposal.

There are multiple individual entries in the National Spent Nuclear Fuel (NSNF) Database[b] that involve sodium-bonded SNF. The fuels comprise 100 MT total mass, 60 MTHM, and 50 m^3 of SNF with a total of 2.4 MT of fissile mass. Included in this category are fuels with metallic uranium, uranium/zirconium, UO_2, PuO_2/UO_2, Pu/U-carbide, Pu/U-alloy, U-5 fissium, U-Mo, and U-Pu-Zr fuel matrices. (Note: The current version of the NSNFP Database lists several entries as sodium-bonded oxide fuels. However, these fuels may contain sodium, but are not sodium-bonded. The sodium-bonded fuel is principally metallic.) All of these SNF categories have either stainless steel or stainless steel-tantalum cladding. A detailed listing of these fuels is included in Appendix A.

N-Reactor SNF

The second category of SNF that may require treatment prior to disposal is that which was irradiated in the N-Reactor at the Hanford Site. There are 3,525 MT of mass (total mass) of this SNF (2,100 MTHM, 25 MT fissile mass), by far the dominant portion of the DOE-EM SNF inventory. N-Reactor fuel is composed of metallic uranium SNF with zircalloy-2 cladding. This SNF may require treatment because some of the cladding is in relatively poor condition and exposure of the metallic uranium in the SNF matrix to water in the storage pool has resulted in the formation of UH_3, which, under some conditions, can chemically react when exposed to air. The magnitude of this reaction and potential

---

b. The NSNF Database is comprised of information on SNF submitted by the site contractors where the spent fuel is currently being stored. Information in the database includes isotopic inventories, masses, fuel matrix composition, cladding composition, cladding condition, etc. This information has been inserted into a computer-database. The database is continuously being refined and listed values are subject to change. The data in this report are derived from the June 1997 release of the database.

impacts to repository disposition are currently being investigated but until resolution of the issue is achieved, it is prudent to maintain the EMT process as a possible treatment option.

Small-Lot SNF

Much SNF was placed in interim storage with the intent to reprocess the material prior to the cessation of reprocessing activities within the United States. The information available for this SNF was sufficient for the intended reprocessing. The information for this SNF, in some cases, is not as extensive as that generally required for repository disposal. These are small lot SNF categories, which represent SNF and SNF parts (e.g., from nuclear fuel tests) from various test reactors and which have been in storage for various periods of time. It may be very difficult and expensive to characterize these fuels, particularly in containers containing miscellaneous mixed SNF materials for direct repository disposal. It may be more cost-effective to condition this SNF, generating known, qualified, process products for disposition.

The first group of these small-lot SNF categories is currently being stored at the INEEL, not including ANL-W or the naval facilities. They are summarized in Table 2. The summary includes the SNF type, sub-type (if applicable), treatment priority, and whether or not they should be assessed against the EMT process. The information in this table is based on data extracted from the NSNF database and conversations with INEEL SNF Program personnel.[c] Masses and volumes of the specific small-lot SNF categories are listed in Appendix A.

The first small-lot SNF type is disrupted, low-enriched uranium oxide fuel. This type of SNF has six subtypes:

- SNF that is particulate in nature. The treatment priority is high since it probably will not meet repository acceptance criteria and it is not as stable a matrix as ceramic SNF.

- Samples from irradiated SNF metallurgical mounts, analytical analyses, and associated scrap. It has a high treatment priority and should be evaluated against the EMT process (with the possible exception of the metallurgical mounts). The reasons for the high treatment priority are the presence of organic materials (from the mounting epoxy), relatively poor characterization data, wide diversity of physical properties, and small quantities of SNF, which could be very costly to characterize.

- SNF from the TORY reactor. The treatment priority is medium and is based on the ceramic SNF form, which is relatively stable. While this does not currently meet repository acceptance criteria, it is expected that some type of containerization will overcome this. This SNF may not be amenable to existing treatment processes, including the EMT process, due to its ceramic form. The relatively small quantity of this SNF may make development of a treatment process prohibitively expensive.

c. Private communication between D. L. Fillmore (INEEL), L. C. Lewis (INEEL), and J. P. Adams (INEEL) on July 1, 1997.

Table 2. INEEL small-lot SNF to be assessed against the EMT process.

Number	Fuel Type	Sub-type	Treatment Priority	Assess against EMT
1	Disrupted, low-enriched uranium oxide fuels			
		Particles	H	YES
		Metallurgical Mounts/Analytical Waste/scrap	H	YES (except metallurgical mounts)
		TORY	M	NO
		Left-Over	M	YES
		TMI	L	NO[b]
		MOX	L	NO[b]
2	Disrupted high-enriched uranium oxide		M	YES
3	Low-enriched, U-metallic and U-alloy		M	YES
4	High-enriched, U-metallic and U-alloy		M	YES
5	Low integrity high-enriched, U-carbide SNF		M	NO[a]
6	High integrity, high-enriched, U-carbide SNF		L	NO[a,b]
7	U-Zr-H fuels		L	NO[b]

a An appropriate headend process does not exist for carbide fuels.
b. Currently, there is a low probability that these SNF fuels would require treatment prior to shipment to the geologic repository. If the criteria changes, their candidacy for treatment will be reevaluated.

- Disrupted low-enriched oxide SNF that is not included in the other subtypes and is labeled "left-over." The treatment priority is medium since it is somewhat better characterized than some of the other subtypes but is still poorly known. Also, the small quantities of the SNF could make it very expensive to fully characterize.

- TMI-degraded SNF. This subtype has a low treatment priority since it contains no volatile materials, is very well characterized (due to the extensive post-accident evaluation program conducted by the DOE, NRC, Three Mile Island (TMI) operating utility, and INEEL), and represents no major challenge for disposition. Although there are several metric tons of these fuel types, they are listed with the INEEL Small Lot SNF for convenience. Currently, there is a low probability that these SNF fuels would require treatment prior to shipment to the geologic repository. If the criteria change, their candidacy for treatment will be reevaluated.

- Mixed oxide (MOX) fuels. While there is none of this material currently at the INEEL, it is expected that some may be shipped there in the future. However, the treatment priority is low. Currently, there is a low probability that these SNF fuels would require treatment prior to shipment to the geologic repository. If the criterion changes, their candidacy for treatment will be reevaluated.

The second type of SNF is disrupted, high-enriched uranium oxide. The treatment priority is medium, based on the lack of characterization data, presence of PuO_2, and criticality concerns. This SNF requires demonstration of a headend process using actual SNF.

The third SNF type is low-enriched, metallic uranium and uranium alloy SNF. Again, the treatment priority is medium, based on the uncertainty associated with the acceptability of metallic SNF in the repository. The same argument is used as the basis for the treatment of the fourth SNF type, high-enriched, metallic uranium and uranium alloy SNF.

The fifth and sixth SNF types are low- and high-integrity, high-enriched, uranium carbide SNF. The low-integrity SNF has a medium treatment priority due to the poor condition of the particle coating, which may result in release of fission products during storage. There is also uncertainty associated with potential reactivity concerns for the uranium-carbide fuel matrix. The same reactivity concerns exist for the high-integrity SNF but the treatment priority is low due to better particle coating condition. Currently, there is a low probability that these SNF fuels would require treatment prior to shipment to the geologic repository. If the criteria change, their candidacy for treatment will be reevaluated.

The seventh SNF type is uranium-zirconium-hydride SNF, which has a low treatment priority. The reason for the low treatment priority is due to the relatively stable fuel matrix, which is not expected to easily release the fission product inventory during storage. Currently, there is a low probability that these SNF fuels would require treatment prior to shipment to the geologic repository. If the criteria change, their candidacy for treatment will be reevaluated.

Candidate SNF for the EMT

The specific SNF types that are judged, by the NSNFP, to be candidates for treatment using the EMT process are identified in Table 3. This table includes the SNF type, current location, total mass, mass of heavy metal, and SNF volume. All data were extracted from the most current version (June 1997) of the NSNF database.

This listing is still in development since the final information concerning small-lot fuels from other sites (other than INEEL) is continuously being upgraded. When this additional information has been received, it will be included in the evaluation.

Environmental Considerations

If no new EMT facility is built and all processing takes place in the current facility, many of the environmental concerns may already be covered by existing permits and procedures. Of course, these permits and procedures would have to be reviewed to determine whether they will support treatment of the SNF on the schedule required by the program. If they do not, they would have to be revised and resubmitted for approval to the appropriate agency, either federal or state, that has jurisdiction.

Table 3. Candidate SNF for the EMT process.

Fuel	Current Location	Total Mass	Mass, Heavy Metal	SNF Volume
INEEL SODIUM-BONDED FUEL				
EBR-II*	ANL-W	31.5 MT	23.5 MT	3.05 m^3
FFTF fuel	ANL-W	37.2 kg	19.0 kg	0.01 m^3
EBR-II	INTEC	2.2 MT	2.0 MT	4.83 m^3
Fermi-I	INTEC	63.6 MT	34.2 MT	18.58 m^3
NON-INEEL SODIUM-BONDED FUEL				
FFTF	Hanford	22.6 kg	230.0 kg	6.67 m^3
PNL fuel	SNL	350.0 kg	34.0 kg	0.40 m^3
OTHER FUELS				
N-Reactor Fuel	Hanford	3,524.9 MT	2,100.3 MT	204.24 m^3
SMALL LOT FUELS				
Various fuels	Small lots that may be treated in the process.	TBD	TBD	TBD

* Demonstration test will account for 1.6 MT

HM = heavy metal MT = metric ton = 1,000 kg

The following sections provide a cursory summary of the environmental impact requirements that would need to be followed for construction and operation of a new production facility based on the EMT process. While some of these requirements are specific to a facility constructed and operated at the INEEL, they are judged to be sufficiently general, in scope, to provide a guideline for construction and operation elsewhere as well. The top-level documents governing compliance with environmental law are listed, such as the National Environmental Policy Act (NEPA). The details associated with compliance will require an extensive interpretation of the governing laws. These details will be developed if and when it is decided that a production facility should be constructed and operated.

National Environmental Policy Act

Guidance for compliance with NEPA at the INEEL has been established.[10] This report provides guidance in environmental impact requirements for compliance with the NEPA for construction and operation of any major federal action at the INEEL. Similar requirements are expected to apply to federal actions at other DOE sites.

The INEEL NEPA guidance lists five regulations that apply to major federal actions:

- NEPA as amended[11] requires preparation of new environmental documentation or the review of existing documentation. This documentation must assess the environmental impacts of

the action, propose and assess alternatives to the action, if any, and state any irreversible and irretrievable commitments of resources involved in the proposed action. Also required is consultation with federal, state, and local agencies with jurisdiction over or an interest in the action.

- The Council on Environmental Quality (CEQ) regulations provide general guidelines for the preparation of environmental impact statements, environmental assessments, and categorical exclusions.[12]

- DOE NEPA implementing regulations apply the general guidance in the CEQ regulations to substantive DOE projects and tasks.[13]

- DOE orders 5400.1 and 5400.1E identify the assignments and responsibilities for DOE officials and departments.[14,15]

- Department of Energy-Idaho (DOE-ID) supplemental directive 5440.1 provides additional guidance for DOE-ID officials and departments.[16]

In addition to these regulations, six guidance documents are also summarized for use by the contractor environmental organization in interpreting the regulations.[17,18,19,20,21,22]

Air Permits

The discussion in this section is based on air quality emission standards specific to the State of Idaho. However, similar, though not necessarily identical, standards are expected to exist in other states as well and it is judged that similar procedures will be required. If either the regulating agency or the operating contractor determines that construction and operation of a new production facility require either a new or modified air permit, one will be requested. The Rules and Regulations for the Control of Air Pollution in Idaho[23] set the standards for air pollution administration and enforcement. Idaho issues two types of permits, the Permit to Construct, which implements the federal new source review program for the construction of new facilities, and the Operating Permit, which is required for all facilities.

A Permit to Construct may be required for any construction or modification of a facility that emits an air pollutant, including radioactive emissions. If a facility is expected to emit air pollutants in excess of certain regulatory limits, a Prevention of Significant Deterioration Permit to Construct is required, which results in a more extensive analysis of the air pollutant emission impacts.

The National Emission Standards for Hazardous Air Pollutants is a federal program that could potentially affect permitting of a new EMT facility. The Region X Office of the Environmental Protection Agency (EPA) administers this program. The interaction between this program and the corresponding state air quality programs is subject to change.

Radionuclide emissions from DOE facilities are regulated under 40 Code of Federal Regulations (CFR) 61 Subpart H.[24] This standard limits the exposure to any member of the public to less than 10 mrem per year. Specific emission monitoring and test procedures, compliance reporting and record keeping procedures are listed in the standard. This regulation also stipulates that if a facility is expected to result in an exposure to the public exceeding 0.1 mrem per year, the EPA must approve the construction. If the expected exposure is less than 0.1 mrem per year, EPA approval is not required.

There are a series of source term calculations and dose determinations required by this standard. First, the effective dose equivalent is calculated, using worst case assumptions (such as if the material is heated to above 100°C, all radionuclides are assumed to escape, unabated, to the atmosphere). This establishes the status of the project relative to requiring EPA approval of the construction permit. If the subsequent calculated offsite public dose does not exceed 0.1 mrem per year, then the project is considered to be exempt from EPA approval, assuming the site where the facility is to be located is in compliance. The construction permit can then be submitted directly to the state for approval as part of the Permit to Construct process. For the state submittal, the expected source term and dose are recalculated using process knowledge and emission controls efficiencies.

If the worst-case calculated offsite public dose does exceed 0.1 mrem per year, an EPA approval must be obtained in accordance with paragraph 61.96 of 40 CFR 61.[24] The source term and dose are then recalculated, using process knowledge and emission controls efficiencies as well as known radionuclide behavior and the best-estimate calculations are included as part of the EPA approval request.

Water Regulations

Although water is not an integral part of the EMT process, water will probably be used during cleanup, maintenance operations, and D&D. An overview of groundwater and surface water standards pertinent to the INEEL is presented in reference form.[25] These standards are designed to prevent releases of wastes, such as radioactive wastes, into the environment and to require some measure of cleanup or isolation if contamination does occur.

The key DOE order regarding groundwater and surface water monitoring, management, and protection is DOE Order 5400.1.[14] This order includes specific requirements related to monitoring, waste management, corrective actions, hydrogeologic investigations, quality assurance, and quality control. In addition, the order requires preparation of groundwater monitoring and protection management plans. The order also requires adherence to all applicable state and local standards, on a site-specific basis.

DOE Order 5400.5[26] includes groundwater and surface water protection provisions established to address radiation protection control standards and practices for DOE operations. DOE's objective is to operate facilities and conduct activities while minimizing radiation exposures to the public and the environment.

RCRA Permit Applications

Treatment, storage, and disposal of hazardous and nonhazardous solid waste is regulated under the Solid Waste Disposal Act[27] as amended by RCRA[28] and the Hazardous and Solid Waste Amendments of 1984.[29]

Due to the changes in U.S. defense policy, the DOE has determined that reprocessing of SNF for the purpose of reclaiming special nuclear materials should cease. Thus, the emphasis has shifted from production and reprocessing to storage, cleanup, and eventual permanent disposal of SNF. This had resulted in some uncertainty associated with the regulation of these nuclear materials in relation to RCRA.

Initially, DOE's position was that RCRA only applied to certain mixtures of radioactive and hazardous wastes related to indirect process waste streams. This was based on Section 1004(27) of the RCRA, which excludes source, special nuclear, and byproduct material from the definition of solid waste and therefore excludes them from regulation under RCRA. This position was modified by a memorandum of understanding on February 22, 1984, which established a hazardous and mixed waste management program — though it was recognized that a more precise clarification was needed regarding

RCRA exclusions. The clarification was made when the DOE issued its Byproduct Rule[30] on May 1, 1987, stating that "only the actual radionuclides in DOE waste streams will be considered byproduct material" and, therefore, excluded from regulation under RCRA. Therefore, other spent fuel constituents may not be excluded from RCRA regulation. This is an area of current investigation.

DOE has initiated discussions with the Environmental Protection Agency regarding the potential application of the RCRA requirements to SNF. In addition, DOE is currently holding discussions with regional offices of the Environmental Protection Agency and corresponding state agencies to develop a strategy for meeting any RCRA requirements that may apply.

One of the tasks assigned to the NSNFP is to determine which, if any, of the SNF types could come under the Subtitle C, Hazardous Waste requirements of RCRA if SNF were determined to be waste. The concern is that if a specific SNF type contained any RCRA hazardous materials, it potentially would not be acceptable for disposal in the repository. Thus, it would have to be treated, to remove the hazardous materials prior to final storage. The working group in charge of researching this issue published an interim report which draws the following conclusion:[31]

> For evaluation of both regulatory applicability and management technologies, the various types of DOE-owned SNF have been divided into 55 categories based on fuel type, matrix type and material, cladding type, uranium-235 enrichment, burnup, potential hazardous materials, and characteristics, and actinide content. Current preliminary process knowledge and analyses indicate that 47 of the categories would not be subject to RCRA regulation if SNF is determined to be a solid waste. Only sodium-bonded and disrupted fuels, representing 8 SNF categories, require further evaluation before a more definitive position regarding RCRA applicability can be established.
>
> Extensive evaluation of the sodium-bonded SNF concern is required. Evaluation will involve determination of the extent of reactivity of the metallic sodium bonding. The sodium-bonded SNF is present in six categories representing approximately 3% of DOE-owned SNF by mass in MTHM ... or 19% by volume. The metallic sodium-bonded fuels appear to be the most likely to exhibit a RCRA characteristic.

Some mixed hazardous waste streams may result from the process. This conclusion is based on an assessment summarized in the EA.[4] In this summary, mixed waste streams were identified and treatment of these streams was indicated under a Generator Treatment Plan, corresponding to 40 CFR Part 268.7(a)(4) and Idaho Administrative Procedures Act (IDAPA) Section 16.01.5011. After this treatment, these mixed waste products will be shipped offsite for final disposal, depending on the level of radioactivity and RCRA waste concentrations. In the evaluation for the production facility, potential mixed waste streams will be evaluated and appropriate treatment/disposal costs will be included.

The Emergency Planning and Community Right-to-Know Act[32] (EPCRA) was extended to federal facilities by Executive Order 12856.[33] The executive order states that federal agencies are "...encouraged to comply with all state and local right-to-know and pollution prevention requirements to the extent that compliance with such laws and requirements is not otherwise already mandated." Thus, emergency planning procedures for a new facility would need to address this order. This act has four major aspects:

- Emergency planning — provides one-time notice and ongoing information for local planning.

- Emergency notification — provides immediate notification about chemical release events.

- Community right-to-know reporting — establishes guidelines for use of Material Safety Data Sheets and for the inventory of onsite chemicals.

- Toxic chemical release inventories — requires annual report of total releases and offsite transfers of chemicals.

While the EPCRA establishes the law, guidelines on interpretation of the law are not yet complete.

The Pollution Prevention Act of 1990[34] establishes a national policy for waste management and pollution control and was also extended to federal facilities by Executive Order 12856.[33] The Pollution Prevention Act (PPA) was enacted by Congress and put under EPA jurisdiction. The PPA sets general guidelines for reducing or preventing pollution. The EPA has focused on source reduction as the primary method in pollution prevention. This method entails reducing hazardous waste generation at the source, before the wastes have been introduced into the environmental. The PAA, as the EPA has interpreted it, does not include recycling as a means of pollution prevention. If a material needs to be sent offsite to be recycled, it has not been prevented. However, recycling within a process at the facility (in-process recycling) is an exception to this and is considered a form of pollution prevention. The act establishes national policy of source reduction using a hierarchical list of guidelines:

- Pollution should be prevented or reduced at the source

- Waste should be recycled or reused in an environmentally safe manner

- Waste should be treated in an environmentally safe manner

- As a last resort, waste should be disposed or released to the environment.

The act defines recycling and energy recovery (as part of waste management) to be part of the problem since it is not prevented at the source. The PPA specifies that source reduction is more desirable than waste management and pollution, yet opportunities for source reduction are often not realized. The Act mandates a national policy creating a hierarchy of preferred waste management approaches: source reduction, recycling treatment, and disposal, all to be conducted in an environmentally safe manner.

In addition, the PPA requires that owners and operators of facilities subject to the annual toxic chemical release filing requirements of the Emergency Planning and Community Right-to-Know (EPCRA) section 313, to file a Toxics Release Inventory Report. These facilities must include with that filing a toxic chemical source reduction and recycling report for the preceding calendar year. This report must address: the amounts of chemicals released and recycled, source reduction practices aimed at the reported chemicals, methodologies used to identify source reduction opportunities, and future chemical production estimates.

Also in response to the provisions of the PPA, the DOE committed to participation in the Superfund Amendments and Reauthorization Act.[35,36] Existing facilities, such as Electrometallurgical demonstration test at ANL-W, were committed to EPA's 33/50 Program of reducing the release of 17 high priority toxic chemicals to the environment. The 33/50 Program was a voluntary pollution reduction initiative that promoted a reduction in the amount of the 17 high priority toxic chemicals released or transferred offsite from that of a baseline established in 1993.

In keeping with the 33/50 Program's goal to dramatically reduce if not prevent pollution, new facilities are to maximize the first three waste management techniques (source reduction, in-process recycling, and treatment) so as to minimize waste disposal and related impacts to the environment.

Criteria Questions

One of the first steps associated with selecting one or more sites for treating the SNF in the DOE complex is to determine the cost for each of the options discussed in the preceding section. This is accomplished by:

- Articulating the issues associated with fabrication (if applicable) and operation of a production facility by a list of specific questions. The intent of these questions is to ensure that all issues and costs associated with each option are identified.

- Developing a work breakdown structure (WBS) to provide the basis for capturing life-cycle cost.

- Estimating the costs associated with the questions and summing these costs through the WBS to determine total costs for each option.

Although the principal focus to this work has been the EMT process, the cost determination methodology is judged to be sufficiently general for application to other treatment processes.

During the evolution of these questions, care was taken to ensure that all issues associated with fabrication and operation of a production facility were included. This was accomplished, in part, by basing the questions on the relevant sections of the Spent Nuclear Fuel Program Requirements Document.[37] This document presents top-level requirements for the NSNFP and is based on the SNF Strategic Plan.[38] The purpose of the document is to clearly describe the requirements, which, if met, will accomplish the goals of the SNF program mission. A systems engineering approach was used to integrate the overall SNF program planning with specific programmatic needs, stakeholder participation, safety, environmental protection, quality, safeguards and security, and facilities design and operation. Thus, it is judged that if the questions associated with the various options adequately address the requirements of SNF Program Requirements Document,[36] fabrication and operation of the production facility will meet the objectives of the NSNFP. This approach will also maximize the probability that all significant costs associated with fabrication and operation of such a facility will be identified.

The questions have been divided into three generic types to address technical, schedule, and programmatic issues. Technical questions are those that specifically address technical issues such as 1) Will the treatment process require modification in order to treat the specific fuel type?, 2) What will the treatment products be and will they meet final disposal facility criteria?, and 3) Do approved cask designs exist for transportation of the SNF? The schedule questions are those that specifically address whether or not the SNF can be treated in time to meet existing schedules such as the Idaho agreement. The programmatic questions are those that address issues such as 1) What plans are required (transportation plans, safeguard and security plans, Quality Assurance (QA) plans, etc.) for the option?, 2) Is the work force adequate to operate the facility?, and 3) What are the D&D and recycling issues?

The distribution of the questions among the three categories helps in ensuring completeness, though it is somewhat arbitrary and some of the questions could fit in more than one category. This is not a problem since costs associated with each option will be summed and it is the total cost that will be used to determine the best path-forward for each specific fuel type.

GENERIC TREATMENT SCENARIO OPTIONS

There are several generic issues involved with siting of a production facility. These are:

- SNF location
- SNF transport
- Use of current facilities compared to new construction
- Centralized versus distributed facilities.

These issues were captured in five generic siting options. An additional option to ship untreated SNF to the geologic repository is listed as a baseline.

The deployment options are:

A1: Treat at Current ANL-W pilot plant — This option requires treating the fuel in the facility that is currently being used for the demonstration test at ANL-W. The Mark IV and Mark V electrorefiners are being used for the demonstration tests and are included in this category.

B1: Treat at Current Fuel Storage Facility — New equipment in existing building — This option requires fabricating and installing new production-sized equipment in an existing facility in an argon atmosphere located on the site where the fuel is currently stored. Movement of the SNF to the processing location would not require transportation offsite or on a public transportation system — highway or railroad — and thus would not require a fuel transportation plan or NRC-approved cask.

B2: Treat at Current Fuel Storage Facility — New equipment in new building — This option requires building a new facility, fabricating new production-sized equipment, and placing it in an argon atmosphere in the facility, which will be located on the site where the fuel is currently located. Any fuel movement would not involve transportation offsite or on a public system nor would it require use of an NRC-approved cask.

C1: Treat at new area away from storage facility — New equipment in existing building — This fuel treatment option requires installing new production-sized equipment in a current facility on a site different from where the fuel is currently located. To be treated, the fuel would have to be transported offsite. Travel on a public transportation system (highway, railroad) is involved. Any such fuel movement would require a fuel transportation plan and an NRC-approved cask.

C2: Treat at new area away from storage facility — New equipment in new building — This option requires building a new facility, fabricating new production-sized equipment, and placing it in the facility, which will be located at a site other than where the fuel is currently stored. To be treated, the fuel would have to travel offsite and travel on a public transportation system (highway, railroad). Any fuel movement would require a fuel transportation plan and an NRC-approved cask.

D: Ship fuel untreated to repository — This option assumes the SNF can be shipped to and accepted by the repository and, thus, does not involve treatment of the fuel. The fuel would be shipped directly to the final disposal area. Where technically and politically acceptable, this is the

preferred option for DOE SNF. The fuel may require physical controls (spacing, containment, etc.) in the disposal area, but would not require treatment prior to shipment to the repository. The fuel would be transported offsite on a public transportation system — highway or railroad. The fuel movement would require a fuel transportation plan and an NRC-approved cask.

The specific questions are listed in Table 4.

Each question was examined to determine whether or not it is applicable for each of the specific deployment options discussed. For example, for Treatment Option D, none of the questions regarding fabrication and operation of a production facility were applicable. Transport of the fuel to the production facility is not applicable for Options B1 and B2, since they involve onsite treatment of the SNF.

Table 5 is an example of an options table, which was set up to provide a visual representation of the questions for treating various fuels. This specific table is based on some of the sodium-bonded SNF currently stored at the INEEL. The questions in this table refer to the questions in Table 4. The distribution of the questions among the three categories (technical, schedule, and programmatic) is the same in both tables.

In Table 5, the questions, as they apply to the treatment options for the specific fuel type, are either: Applicable, Not Applicable, or Applicable and Addressed. For example, any questions regarding treatment of the SNF type are "Not Applicable" for Option D since this option involves shipping the SNF, untreated, to the repository. Obviously, the only questions that are "Applicable and Addressed" are some of those associated with treatment of SNF in the existing ANL-W facility as part of the demonstration test. This category is included for tracking purposes after a decision is made regarding application of the EMT process for specific SNF types.

Table 4. Master list of questions.

Number	Question
	Technical
1	How much fuel can the process treat in a new or an existing facility? What is the processing rate? What rate will the current system handle? (5.1.2)[a]
	EMT process-specific: How much fuel can the EMT components (electrorefiner, casting furnace, chopper, hot isostatic press, Zeolite columns) treat? How fast can ANL-W treat the increased load. Are separate casting furnaces required for the ingots and the metal waste? (4.7.1)
2	Based on the performance assessment, will the untreated fuel meet repository acceptance criteria (chemical composition, RCRA, can the fuel be stabilized by new engineering to assure fuel integrity for long-term storage)? (4.1.2, 4.8, 5.3)
3	Will the cask handling area accommodate the various fuel cask designs? (4.7.1, 5.1)
4	Can off-spec/degraded fuel be transported in a cask? (4.2) Will an off-spec cask be needed if the fuel needs to be treated somewhere before it is transported? (4.2, 5.1.4, 5.1.5)
5	Do new procedures need to be developed for the complete operation of the treatment process system? (4.7.4, 5.2)
6	Will the treatment products (metal waste, ceramic waste, uranium ingot, etc.) from the process meet the acceptance criteria of the final storage facility? (4.1.2, 4.8, 5.3)
7	Does the treatment location have sufficient hot cell area for a new production facility? (4.2.6, 4.2.7, 4.7.4, 5.1.2)
8	Will a pilot-plant be needed to test the proposed treatment process? If so, will a scale-up study be required to treat the fuel in the production size plant after evaluation in a pilot plant process? If a pilot-plant is not needed, will a scale-up study be required to treat the fuel in the production size plant after evaluation in a laboratory process? (4.1.1)
9	Does the proposed site have adequate support systems (off-gas, off-gas filtration, power supply, water, sewage, roads, maintenance, etc.) to handle the proposed treatment load? (4.7.1, 5.1.2)
10	What types of fuels (requiring treatment) will the process handle? If a modified process were used requiring a different head-end process or different materials (salt eutectic, etc.), would this require significant additional equipment or a new facility? Would the overall production rate decrease unacceptably? If the fuel is off-specification, are there accurate and adequate fuel characterization data to evaluate whether the off-spec fuel can be treated in the process? (4.1.1, 4.1.2, 4.1.5, 4.4, 4.7, 5.1.4)
	Schedule
11	What is the schedule for treating/handling the fuel? (4.1.1) Can treatment of the fuel meet all schedule agreements (e.g., the Idaho agreement [6-months turnaround])? (4.7.1)
12	Can building the new plant size facility (design, decontamination, constructing a new building, constructing and installing the plant equipment, potential RCRA permitting, ORR, training, etc.) meet all schedule requirements? (4.1, 4.5, 4.7)

Table 4. (continued.)

Number	Question
13	Will the modification in 1) acceptance criteria/cask availability or 2) additional government controls for the repository or other final storage allow meeting the schedule (Idaho, DOE commitments, etc.)? (4.1.1, 4.8)
	Programmatic
14	Are there approved transport mechanisms (offsite casks) and transportation plans for shipping (includes shipping the fuel to the treatment facility and shipping the treatment products to the final disposal site[s])? (4.1.1, 4.2)
15	Will the safeguards and security requirements for the repository require changing if the fuel is untreated? (4.6.1)
16	What will the safeguards and security requirements be for treating the fuel in a new facility or an existing facility? (4.5.4, 4.6.1)
17	Is there an adequate QA plan? (4.3, 4.4)
18	Will a new environmental impact statement (EIS), NEPA, other government controls, etc., be required? (4.2, 4.3, 4.8)
19	Can the existing site waste storage facilities hold the treatment products for interim storage from all of the fuel to be processed at this site? (5.1) If the SNF is to be stored for long-term at the site, are there adequate long-term storage facilities for all of the fuel onsite? (5.2)
20	Will the treatment products (metal waste, ceramic waste, uranium ingot, etc.) from the process meet the handling criteria (chemical composition, hydrogen, etc.) for transfer to the final storage facility? (4.1.2, 4.8, 5.3)
21	Is there a sufficient work force to handle the treatment load? (4.7) Some of the items are training personnel, conduct of operations evaluations, operators, Radiological Control Technicians, analytical support, mechanics, welders, etc. (4.7)
22	Is a new safety analysis (criticality evaluation, operational safety, etc.) required for the treatment load? (4.2.8)
23	Is a new safety analysis (criticality evaluation, operational safety, etc.) required for the interim storage of the treatment products? (4.2.8)
24	What are the stakeholders' concerns regarding transportation of the fuel and/or treatment products? Will these concerns result in transportation restrictions (i.e., prohibition against transportation through heavily populated regions, a specific state etc.) and if so, what will the impact be on schedule, cost, etc? (4.1.1, 4.2)
25	Have decontamination and decommissioning (D&D) concerns been addressed? (5.2.10)
26	Does the process adequately address recycling of process materials (salt, Cd, etc.)? (4.3.5)
27	Are past facility missions and the facility organizational structure receptive to new plant startup and operation? (4.7)
28	Will any of the treatment products be acceptable for various nondisposal uses? (4.1.2)
29	What are the costs associated with final disposal? (5.3)

Table 4. (continued.)

Number	Question
30	What are the procedures and costs for the preliminary fuel transfer from the current storage location to the cask loading area? (4.2)
31	Can the treatment products be returned to the "home" facility after treatment? (5.1.2)

a. The number in parenthesis refers to the specific section(s) of the Nuclear Fuel Program Requirements Document.[36]

Table 5. Example options table for INEEL sodium-bonded fuel.

HM = heavy metal (U) MT=metric ton=1000 kg		INEEL SODIUM-BONDED FUEL EBR-II at INTEC (1.98 MTHM – 2.24 MT total mass) 4.83 m^3					
Question	Demonstration Test	A	B1	B2	C1	C2	D
Technical							
1							
2							
3							
4							
5							
6	✓						
7							
8							
9							
10	✓						
Schedule							
11							
12							
13	✓						
Programmatic							
14							
15							
16							
17	✓						
18							
19	✓						
20	✓						
21	✓						
22							
23							
24	✓						
25	✓						
26	✓						
27							
28	✓						
29							
30	✓						
31							

Applicable Not Applicable ✓ Applicable and Addressed

A Treat at current ANL-W pilot plant.

B.1 Treat at INTEC Storage Facility: New equipment in existing area.

B.2 Treat at INTEC Storage Facility: New area with new equipment.

C.1 Treat at new area away from storage facility: New equipment in existing area building.

C.2 Treat at new area away from storage facility: New facility with new equipment.

D Ship fuel untreated to repository.

Economic Analysis

Viability Tests

Two economic tests are available to determine the economic viability of an investment, program, or project. The first and most common economic test is cost-effectiveness. Cost-effectiveness has the primary objective of ensuring all requirements are met at the lowest possible cost. The cost-effectiveness test is simple because only total costs are evaluated, not benefits. This test assumes the minimum standard of performance has been met. Because only cost information must be determined, this test is less expensive to perform. For most individuals, businesses, and the government, cost-effectiveness is the preferred test since the minimum goal and performance requirements are agreed to and well established. Cost-effectiveness has been determined to be the preferred economic test for promoting the efficient allocation of limited federal government funding.[39]

The second economic test is cost-efficiency. Cost-efficiency has the primary objective of maximizing return on investments. This test is used less often because significantly more information requiring both cost and benefit analysis is used to maximize return on investment. Additionally, performance standards tend to modulate more and are compromised more often, thus making it much more difficult to optimize return on investment. Typically, only business uses this economic test.

Because environmental laws and regulations often prescribe minimum standards of performance, cost-effectiveness and its accompanying cost-minimization is the desired test of economic viability for deployment of the EMT process. For this reason, the objective of this economic analysis is to determine which deployment alternative attains the program goals for the SNF disposition at the lowest possible cost to the government and public.

Methodology

Although many modeling techniques are available to test for cost-effectiveness, the most common and acceptable technique is life-cycle analysis (LCA). Also known as cradle-to-grave analysis, LCA accounts for all of the economic activities necessary for the project, program, or investment beginning with the preoperational activities of planning, permitting, and conceptual design through the postoperational activities of project close-out, decommissioning, and long-term monitoring. Costs that are not included are any costs previously spent, also known as sunk costs. By definition, the LCA method will evaluate all competing alternatives expressed in present value or discounted terms. As defined by the selected evaluation methodology, the alternative with the lowest LCA is the preferred option.

Work Breakdown Structure

From the questions discussed earlier, a WBS was developed for a generic fuel type. A WBS is a tree of product-oriented components that organize individual work activities of a project using a hierarchical process. Almost always, the WBS is determined by decomposing work elements from the highest level to a lower, more manageable work element level. By definition, an integrated WBS will identify all work activities that must be performed to complete the project. Thus, the summation of all WBS activity costs at any given level is the total project costs.

WBS components may be products or services. Components can be broken into smaller sub-components, depending on the complexity and the level of detail required to properly manage the project.

The WBS for sodium-bonded SNF disposal with the EMT is shown in Figure 12. This WBS was constructed solely for purposes of this evaluation and is not intended as a replacement for any program WBS currently in existence. The WBS dictionary describes each WBS element.[40] Using a WBS leverages process information into an easily identifiable cost analysis of a project. This parallel cost effort is often referred to as a cost breakdown structure.

Cost Model

A computerized cost model has been developed as a generic modeling tool. This generic format was established as a modeling requirement. The generic format permits broad and flexible analysis of the anticipated and any unforeseen treatment/deployment options. Additionally, the model was developed to accommodate the analysis requirement that many possible deployment solutions exist (depending on the fuel type). The deployment solutions may be combined to evaluate the whole SNF Program's effort. Results from the model are not yet available, pending application of the methodology described in this report.

For each fuel type, cost data can be inserted into the WBS matrix to derive a unit cost (i.e., cost/kg of HM or cost/kg total fuel mass) for each treatment step. Treatment options will also be evaluated according to facility location. For example, if a fuel is transported to an offsite location for treatment at an existing facility, building costs are minimized. However, transportation costs are increased. Thus, tradeoffs in treatment activities are captured in the economic analysis.

Scheduling Considerations

Along with the other parameters discussed in this report, the suitability of any potential treatment technology for use with DOE-EM SNF is the ability of the proposed treatment method to support the overall programmatic schedule. Schedule drivers for the SNF currently include key milestone dates for the operation of the national repository, legal dates, such as those contained in the Idaho Settlement Agreement, and milestone dates for operations at the local SNF sites. All of these dates are extracted and maintained into the NSNFP Master Logic Schedule, which is a roll-up schedule of individual site schedules and the National Program Schedule. The dates for activities and required milestones are tracked and updated regularly. Using the Master Logic Schedule in this manner defines the required performance to meet overall goals. These dates are used as targets to estimate required throughput and estimate the treatment process ability to support the schedule.

QUALITY ASSURANCE

This document has been evaluated in accordance with Program Management Procedure 2.05, "Determination of Quality Program Applicability," and 6.02, "Preparation of Technical Documents." This report was not produced under a quality assurance program that satisfies the requirements of the NSNFP and DOE/RW-0333P, Office of Civilian Radioactive Waste Management Quality Assurance Requirements Description. Therefore, the data in the report are not considered qualified and are not to be relied upon to address safety and waste isolation issues until an accepted qualification process has been completed.

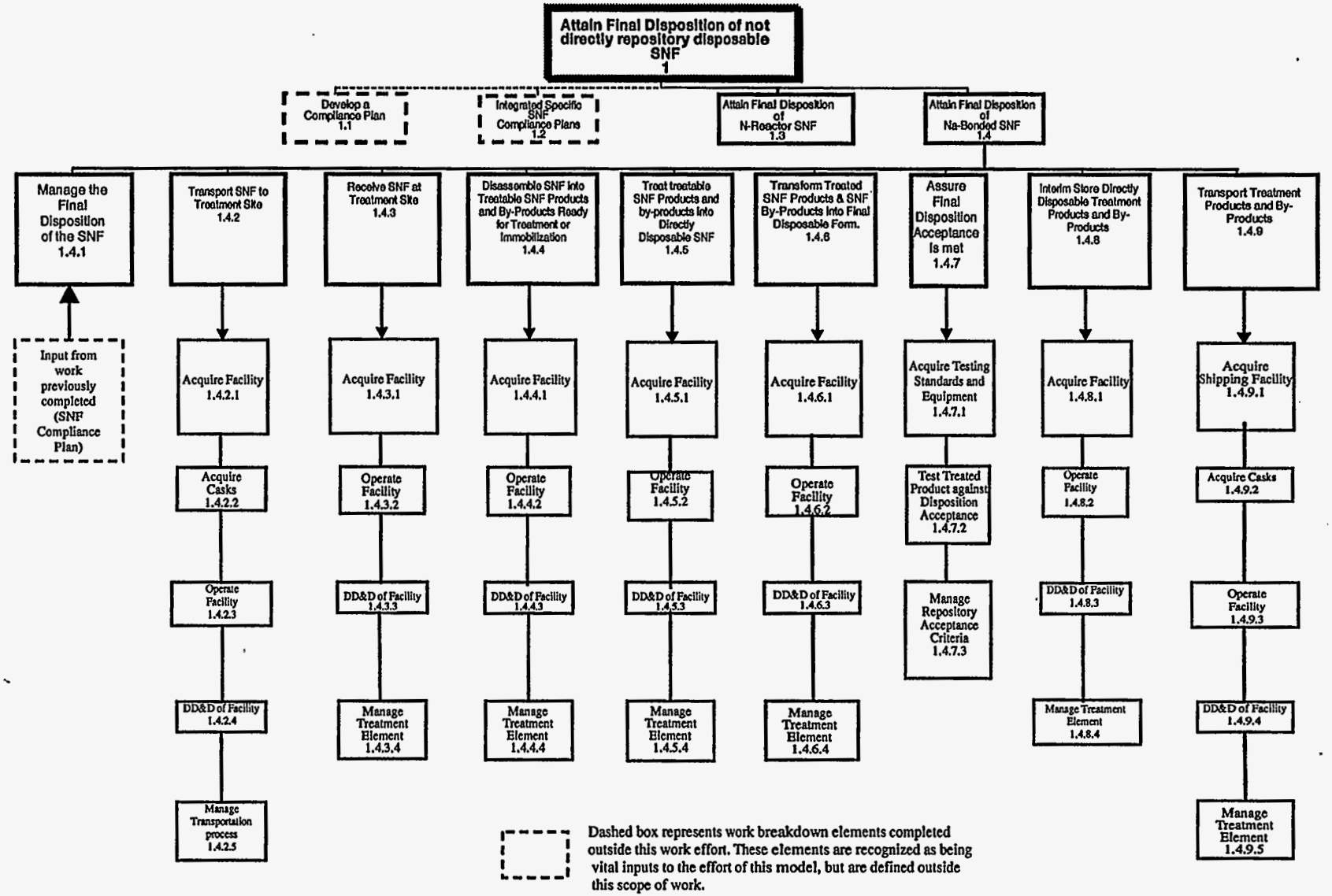


Figure 12. WBS diagram for the treatment of sodium-bonded fuel.

CONCLUSION

A methodology to evaluate the options for deployment of a treatment process for SNF has been constructed. This methodology captures elements of technical feasibility, economic considerations, and schedule considerations relevant to the NSNFP. This methodology now needs to be exercised to evaluate different deployment options for potential treatment of DOE-EM-owned SNF.

Future activity for this evaluation is, in general, related to the updating of information in this report and analysis of the scenarios identified including estimation of costs. To this end, the following activities need to be performed to complete this work:

- Estimate the costs for the WBS elements for each identified scenario, and compile these into an overall cost. Perform the indicated life-cycle evaluations, including factors of schedule and ability to meet the defined program need.
- Maintain an updated listings of fuels that may require treatment, based on the changing program need and further refinement of the repository acceptance criteria.
- Incorporate the technical results of the current demonstration run at ANL-W and factor those results into all evaluations.
- Complete evaluation of life-cycle disposition of the process products.
- Keep the evaluation current, incorporating all of the above analyses.
- Extend this methodology for other treatment processes proposed for the DOE-EM SNF.

REFERENCES

1. *Technical Strategy for the Management of INEEL Spent Nuclear Fuel*, March 1997.

2. *Technical Strategy for the Treatment, Packaging, and Disposal of Aluminum-Based Spent Nuclear Fuel*, June 1996.

3. National Research Council, "An Assessment of Continued R&D into an Electrometallurgical Approach for Treating DOE Spent Nuclear Fuel," Washington, D. C., 1995.

4. U.S. Department of Energy, "Electrometallurgical Treatment Research and Demonstration test in the Fuel Conditioning Facility at Argonne National Laboratory - West," DOE/EA-1148, Office of Nuclear Energy, *Science and Technology*, May 15, 1996.

5. E. M. Franklin, Argonne National Laboratory - West, letter to R. J. Ramer, Staff Engineer, Lockheed Martin Idaho Technologies Company (June 10, 1997).

6. R. M. Lell, to E. K. Fujita, "Nuclear Criticality Safety Analysis for Containers in the Fuel Cycle Facility (WBS 1.5.1.3, WBS 1.6.4.2)," IFR Document No. F5130-00340EK, Argonne National Laboratory, May 19, 1993.

7. *Criticality Hazards Control Statement for the Fuel Conditioning Facility*, F0000-0026-ES-04, July 1996.

8. *Criticality Hazards Control Statement for the Fuel Conditioning Facility*, F0000-0026-ES-05, July 1996.

9 10 CFR 60, Title 10, Energy, Part 60.135, "Disposal of High-Level Radioactive Wastes in Geologic Repositories, Design Criteria for the Waste Package," Washington, D.C., U.S. Government Printing Office.

10. B. M. Angle, et al., *Lockheed Idaho Technologies Company National Environmental Policy Act Guidance - A Model Process*, INEL-95/0134, April 1995.

11. 42 USC 4321-4347.

12. 40 CFR, "Environmental Protection 1500 Purpose, Policy and Mandate," October 1997.

13. 10 CFR, "Energy 1021 National Environmental Policy Act Implementing Procedures," October 1997.

14. DOE Order 5400.1, General Environmental Protection Program.

15. DOE Order 5400.1E.

16. "Implementation of the National Environmental Policy Act," DOE-ID Supplemental Directive 5440.1.

17. DOE-ID-10166, "Environmental Compliance Planning Manual at the Idaho National Engineering Laboratory," U.S. Department of Energy, Idaho Operations, Rev. 3, April 1993.

18. DOE NEPA Compliance Guide, Volumes I and II.

19. *Style, Content, and Format Guide for Preparing Environmental Assessments for the Department of Energy* - Draft, SAND94-0220.

20. *Recommendations for the Preparation of Environmental Assessments and Environmental Impact Statements*, DOE Office of NEPA Oversight, May 1993.

21. DOE Environmental Assessment Checklist (Appendix D).

22. *Effective Public Participation under the National Environmental Policy Act, DOE Office of NEPA Policy and Assistance*, December 1994.

23. *Rules and Regulations for the Control of Air Pollution in Idaho*, IDAPA 16.01.1000 et seq.

24. 40 CFR, "Environmental Protection 61 National Emission Standards for Hazardous Air Pollutants, Subpart H National Emission Standards for Emissions of Radionuclides Other Than Radon From Department of Energy Facilities," July 1997.

25. *Overview of Groundwater and Surface Water Standards Pertinent to the Idaho National Engineering Laboratory*, INEL-94/0012, Rev 3, September 1995.

26. DOE Order 5400.5.

27. Solid Waste Disposal Act.

28 40 CFR, Environmental Protection 261.4, "Identification and Listing of Hazardous Waste, Exclusions," July 1997.

29. Hazardous and Solid Waste Amendments of 1984.

30. 10 CFR 962(52 FR 15937), "DOE Byproduct Rule," May 1, 1987.

31. U.S. DOE, DOE/EIS-0203-F, April 1995.

32. 40 CFR 350, "Emergency Planning and Community Right-to-Know Act," October 17, 1986.

33. Executive Order 12856, 58 Federal Register 41981-7, August 3, 1993.

34. Pollution Prevention Act, Public Law 101-508, November 5, 1990.

35. U.S. Environmental Protection Agency 33/50 Pollution Prevention Program, Superfund Amendments and Reauthorization Act, Section 313.

36. Superfund Amendments and Reauthorization Act of 1986, Public Law Number 99-499, October 17, 1986.

37. *Spent Nuclear Fuel Program Requirements Document*, SNF-RD-PM-001, Rev 0, October 1994.

38. *DOE-Owned Spent Nuclear Fuel Strategic Plan*, DOE/SNF/PP-204, Rev 1, September 1996.

39. Office of Management and Budgets (OMB) Circular A-94, "Guidelines and Discount Rates for Benefit Cost Analysis of Federal Programs," October 29, 1992.

40. M. A. Rynearson, "An Economic Analysis for the Enhanced Siting Option of SNF," (Draft), July 1998.

Appendix A

Appendix A

Detailed Fuel Listing

This appendix contains a detailed listing describing the SNF that has been identified, as of this writing, to be candidates for consideration for EMT processing. The information, obtained from the Spent Fuel Database, is for the following SNF. The bracketed number following the SNF name is the database record number.

1. Sodium-Bonded SNF—This section provides a detailed listing of the specific SNF categories that are sodium-bonded. The specific data base entries have been grouped according to cladding, matrix material, and fuel type. Table A-1 contains a summary of the individual data base entries.

2. N-Reactor SNF—This section provides a detailed listing of the N-Reactor SNF. There are only two database entries and they are summarized in Table A-2.

3. Small-Lot SNF—This section provides a detailed listing of the specific SNF categories that include small-lot fuel entries in the database. The specific database entries have been grouped according to cladding, matrix material, and fuel type. Table A-3 contains a summary of the individual data base entries. Note: only those SNF categories that are being evaluated against the EMT process are included. Those small-lot SNF categories that will not be evaluated have been eliminated from the table.

Table A-1. Sodium-bonded SNF.*

SNF Name	Fuel Type	Cladding	Total Mass (kg)	U-Mass (kg)	Volume (m^3)
EBR-II [54]	U-5fissium	SST	1,323.09	1,161.61	2.86
EBR-II [55]	U-5fissium	SST	909.78	805.22	1.96
EBR-II (ANL-6 TEST) [58]	U-5fissium	SST	5.00	1.62	0.01
EBR-II MK-II/IIA [342]	U-5fissium	SST	13.60	7.97	0.00
EBR-II MK-II/IIA [360]	U-5fissium	SST	14.56	8.38	0.00
EBR-II AXIAL BLANKET [357]	Pu/U Alloy	SST	3,002.42	2,563.39	0.22
EBR-II RADIAL BLANKET [346]	Pu/U Alloy	SST	1,697.56	1,483.78	0.12
EBR-II RADIAL BLANKET [365]	Pu/U Alloy	SST	20,324.17	18,162.22	1.41
EBR-II METAL FUEL EXP [341]	Pu/U Alloy	SST	3,195.50	173.38	0.55
EBR-II METAL FUEL EXP [359]	Pu/U Alloy	SST	1,285.90	68.64	0.22
EBR-II MK-IIC/IICS [343]	U-10Zr	SST	63.62	33.31	0.02
EBR-II MK-IIC/IICS [361]	U-10Zr	SST	210.91	112.17	0.06
EBR-II MK-III/IIIA [344]	U-10Zr	SST	103.74	55.67	0.03
EBR-II MK-III/IIIA [362]	U-10Zr	SST	904.02	472.01	0.28
FFTF-TFA-MFF-2 THRU 6 [332]	U-10Zr	SST	902.70	182.45	0.28
FERMI I BLANKET [70]	U-Mo	SST	63,630.00	34,165.00	18.58
FFTF METAL FUEL EXPER. [348]	U-Pu-Zr	SST	37.20	17.68	0.01
FFTF-TFA-IFR-1 [328]	U-Pu-Zr	SST	21,666.00	35.28	6.39
PNL MIXED MAT'L EXP. D-10 [423]	UO_2	n/a	50.00	7.16	0.06
PNL MIXED MAT'L EXP. D-13 [424]	UO_2	n/a	50.00	6.46	0.06
PNL MIXED MAT'L EXP. D-2 [425]	UO_2	n/a	50.00	4.28	0.06
PNL MIXED MAT'L EXP. D-4 [426]	UO_2	n/a	50.00	3.21	0.06
PNL MIXED MAT'L EXP. D-5 [427]	UO_2	n/a	50.00	5.13	0.06
PNL MIXED MAT'L EXP. D-6 [428]	UO_2	n/a	50.00	4.28	0.06
PNL MIXED MAT'L EXP. D-9 [429]	UO_2	n/a	50.00	3.08	0.06
EBR-II (CAN 1) [56]	PuO_2-UO_2	none	63.00	2.10	0.30
EBR-II (CAN 2) [57]	PuO_2-UO_3	none	32.00	0.44	0.00
EBR-II CARBIDE FUEL EXP [358]	Pu/U Carbide	SST	140.40	33.35	0.04
EBR-II METAL FUEL EXPERIMENTS [723]	Pu/U Alloy	SST	2,684.20	16.10	0.05
EBR-II MK-III/IIIA [722]	U-10Zr	SST	119.30	62.40	0.04
EBR-II RADIAL BLANKET [724]	U Metal	SST	156.10	104.20	0.01
FFTF-TFA-ACN-1 [717]	Pu/U Carbide and PUO_2-UO_2	SST	8.30	3.60	0.00
FFTF-TFA-MFF-1 [716]	PuO_2-UO_2 and UO_2	SST	2.80	1.10	0.00

*The fuel in Table A-1 is not matrixed.

Table A-2. N-Reactor SNF.

SNF Name	Fuel Type	Cladding	Matrix Material	Total Mass (kg)	U-Mass (kg)	Volume (m^3)
N REACTOR [147]	U Metal	Zirc-2	None	1,723,358.00	1,143,635.11	99.85
N REACTOR [148]	U Metal	Zirc-3	None	1,801,524.00	952,385.17	104.38

Table A-3. INEEL small-lot SNF.

SNF Type	SNF Name	Total Mass (kg)	U-Mass (kg)	Volume (m^3)
A. High Treatment Priority				
Met Mounts/Analytical Waste/scrap	CANDU SCRAP [387]	15.0	2.66	0.01
	DRESDEN SCRAP [388]	30.0	18.64	0.01
	GAP CONDUCTANCE (GC) SCRAP [389]	285.0	11.49	0.01
	IRRADIATION EFFECTS (IE) SCRAP [392]	168.0	6.08	0.01
	LOFT (LP-FP-1) SCRAP [393]	13.0	0.01	0.01
	LOFT LEAD ROD SCRAP [394]	69.0	3.51	0.01
	LOSS OF COOLANT SCRAP [395]	139.0	7.78	0.01
	MAPI SCRAP [396]	35.0	22.97	0.01
	OPTRAN SCRAP [397]	30.0	19.68	0.01
	PBF SCRAP [398]	74.0	49.32	0.01
	PCM SCRAP [399]	20.0	5.40	0.01
	PEACH BOTTOM SCRAP [400]	168.0	9.32	0.01
	SAXTON SCRAP [402]	138.0	7.13	0.01
	SCRAP [403]	159.0	11.24	0.01
	SFD SCRAP [404]	61.5	40.09	0.01
	T.C. SCRAP [405]	46.0	4.08	0.02
Particles	GCRE CAN [94]	2.0	0.91	0.01
	GCRE PELLETS [95]	1.0	0.08	0.00
	GETR FILTERS [98]	400.0	4.42	0.19
B. Medium Treatment Priority				
Left Over	APPR (AGE-2) [6]	18.5	0.22	0.01
	SPSS (SPERT) [213]	6.0	0.59	0.01
	TEST TRAIN [227]	210.0	22.28	0.50
	EBR-II NITRIDE FUEL EXPER [363]	38.4	7.68	0.01
	MISCELLANEOUS FUEL [366]	6,240.0	4,160.82	0.58
	MISCELLANEOUS FUEL [369]	0.4	0.24	0.00
	RESIDUE FAILED PBF RODS [381]	3.0	1.11	0.00
Low-enriched, U-metallic and U-alloy	CORE FILTER [35]	230.0	218.50	0.03
	SPEC (ORME) [208]	8.0	2.39	0.00
High-enriched, U-metallic and U-alloy	SHIPPINGPORT PWR-C1-S4 [194]	90.9	2.02	0.09
	MISCELLANEOUS FUEL [350]	0.2	0.02	0.00