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DEPLOYMENT EVALUATION METHODOLOGY FOR THE ELECTROMETALLURGICAL TREATMENT OF DOE-EM SPENT NUCLEAR FUEL

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ABSTRACT

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). The NSNFP, conducted by Lockheed Martin Idaho Technology Co. (LMITCO) at the Idaho National Engineering and Environmental Laboratory (INEEL), is evaluating final disposition of SNF in the DOE complex. While direct repository disposal of the SNF is the preferred disposition option, some DOE SNF may need treatment to meet acceptance criteria at various disposition sites. Evaluations of treatment needs and options have been previously prepared, and further evaluations are ongoing activities in the DOE-EM NSNFP. The treatments may range from electrometallurgical treatment (EMT) and chemical dissolution to engineering controls. 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. The current planning option for treating this SNF, pending completion of development work and National Environmental Policy Act (NEPA) analysis, is the EMT process under development by Argonne National Laboratory - West (ANL-W). A decision on the deployment of the EMT is pending completion of an engineering scale demonstration currently in progress at ANL-W.

Treatment options and treatment locations will depend on fuel type and location of the fuel. One of the first steps associated with selecting one or more sites for treating SNF in the DOE complex is to determine the cost of each option. An economic analysis will assist in determining which fuel treatment alternative attains the optimum disposition of SNF at the lowest possible cost to the government and the public. 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.

For this study, a set of questions was developed for the EMT process for fuels at several locations. The set of questions addresses all issues associated with design, construction, and operation of a production facility. A matrix table was developed to determine questions applicable to various fuel treatment options. A work breakdown structure (WBS) was developed to identify a treatment process and costs from initial design to shipment of treatment products to

final disposition. Costs were applied to determine the life-cycle cost of each option. This technique can also be applied to other treatment techniques for treating SNF.

INTRODUCTION

The NSNFP has the mission of safely, reliably, and efficiently managing DOE-owned SNF and preparing it for disposal. The NSNFP assists EM in this mission through the active development of disposal strategies, coordination, and integration with other DOE sites, the Repository Program, and management of NSNFP issues. It is unlikely that all SNF will be suitable for final direct disposal without treatment. Preliminary work on this evaluation was presented as a poster session at the Waste Management 98 Conference.(1)

One treatment option for a portion of the SNF, being evaluated by ANL-W, is the EMT process.(2,3,4) For this process, fuel pieces are dissolved in a molten salt electrolyte. The uranium is electrochemically deposited on a cathode. The uranium-loaded cathode is removed from the electrorefiner. The uranium is removed and blended with depleted uranium to produce a low-enriched ingot. Cladding hulls, which may contain a small quantity of the less reactive fission products, are also removed for waste treatment. Most fission products and the transuranic elements accumulate in the salt through repeated electrorefining cycles. The salt can be pumped out of the electrorefiner for treatment.

Because significant quantities and types of SNF may require some type of treatment before final disposal, a comparative cost matrix was developed by the NSNFP to aid in the evaluation of treatment processes/treatment site for several fuel types. Treatment is assumed to be any production process required to process interim storage SNF for final disposal. This includes storage, pretreatment, treatment, transportation, and disposal costs. NSNFP personnel developed a set of questions that incorporate requirements specified in the SNF Program Requirements Documents.(5) Then, a cost matrix incorporating an economic analysis was developed. 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.

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. Deployment of the process for the treatment of the SNF requires evaluation to determine the NSNFP need for treatment and compatibility of the SNF with the process. The evaluation is influenced by many factors including economics of treatment, programmatic need for treatment, technical feasibility, 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.

TREATMENT 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 option. This is accomplished by:

- The issues associated with fabrication (if applicable) and operation of a production facility are articulated by a list of specific treatment questions intended to ensure that all issues and costs associated with each option are identified. 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.

- A WBS is developed to provide the basis for capturing life-cycle cost. For each fuel type, a cost for each activity is applied to a WBS matrix, developed for this study, to derive a cost/unit for a fuel to go to final storage. The WBS structure is proposed to gather life-cycle cost information to allow evaluation of alternative siting strategies on a similar basis.

- The costs associated with the questions are estimated and summed through the WBS to determine total costs for each option. Second, an evaluation made of treating more than one type of fuel in a location, and evaluating the tradeoffs in the various scenarios.

During the evolution of these treatment 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 SNF Program Requirements Document.(5) This document presents top-level requirements for the NSNFP and is based on the SNF Strategic Plan.(6) 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 the SNF Program Requirements Document, 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.(7) The programmatic questions are those that address issues such as 1) What plans (transportation plans, safeguard and security plans, Quality Assurance plans, etc.) are required for the option?, 2) Is the work force adequate to operate the facility?, and 3) What are the decontamination and decommission and recycling issues?

Dividing the questions into three categories helps to ensure 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

The issues involved with siting a production facility are:

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

These issues were captured in five generic siting options. In addition, an option is listed to capture untreated disposal costs.

The siting options are:

A: Treat at current ANL-W pilot-plant—This option requires treating the fuel in the facility that is currently being used for the demonstration project (Mark-IV and Mark-V electrorefiners) at ANL-W.

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

B2: Treat at Current Fuel Storage Facility: New equipment in new building—This option requires building a new facility, fabricating new production-size equipment, and placing it in the facility, which will be located on the site where the fuel is currently located. Any fuel movement would not require a fuel transportation plan or an NRC licensed cask.

C1: Treat at new area away from storage facility: New equipment in existing building—This fuel treatment option requires installing new production-size 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 on a public transportation system (highway or railroad). A fuel transportation plan and an NRC licensed cask would be required.

C2: Treat at new area away from storage facility: New equipment in new building—This option requires building a new facility, fabricating new production-size 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 be transported offsite on a public transportation system (highway or railroad). A fuel transportation plan and an NRC licensed cask would be required.

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. 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 licensed cask.

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

Table I: Treatment Questions.

Technical	
1.	How much fuel can the process treat in a new facility or an existing facility? What is the processing rate? What rate will the current system handle? 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?
2.	Based on the performance assessment, will the untreated fuel meet repository acceptance criteria (chemical composition, Resource Conservation and Recovery Act [RCRA], can the fuel be stabilized enough by new engineering to assure fuel integrity for long-term storage)?
3.	Will the cask handling area accommodate the various fuel cask designs?
4.	Can off-specification/degraded fuel be transported in a cask? Will an off-specification cask be needed if the fuel needs to be treated somewhere before it is transported?
5.	Do new procedures need to be developed for the complete operation of the treatment process system?
6.	Will the treatment products (metal waste, ceramic waste, uranium ingot, etc.) from the process meet the acceptance criteria of the final storage facility?
7.	Does the treatment location have sufficient hot cell area for a new production facility?
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?

Table I: Treatment Questions.

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?
10.	What various 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, Molten Salt Reactor Experiment [MSRE] salt, 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-specification fuel can be treated in the process?
	Schedule
11.	What is the schedule for treating/handling the fuel? Can treatment of the fuel meet all schedule agreements (for example, the Idaho agreement [6-months turnaround])?
12.	Can building the new plant size facility (design, decontamination, constructing a new building, constructing and installing the plant equipment, potential RCRA permitting, Operational Readiness Review [ORR], training, etc.) meet all schedule requirements?
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 (state of Idaho, DOE commitments, etc.)?
	Programmatic
14.	Are there approved transport mechanisms (off site 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])?
15.	Will the safeguards and security requirements for the repository require changing if the fuel is untreated?
16.	What will the safeguards and security requirements be for treating the fuel in a new facility or an existing facility?
17.	Is there an adequate Quality Assurance plan?
18.	Will a new environmental impact statement (EIS), NEPA, or other government controls be required?

Table I: Treatment Questions.

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? 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 on site?
20.	Will the treatment products (metal waste, ceramic waste, uranium ingot, etc.) from the process meet the handling criteria (chemical composition, hydrogen, etc.) to transfer the material to a final storage facility?
21.	Is there a sufficient work force to handle the treatment load? Some of the items are training personnel, conduct of operations evaluations, operators, radiological control technicians, analytical support, mechanics, welders, etc.
22.	Is a new safety analysis (criticality evaluation, operational safety, etc.) required for the treatment load?
23.	Is a new safety analysis (criticality evaluation, operational safety, etc.) required for the interim storage of the treatment products?
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.?
25.	Have decontamination and decommissioning concerns been addressed?
26.	Does the process adequately address recycling of process materials (salt, cadmium, etc.)?
27.	Are past facility missions and the facility organizational structure receptive to new plant start-up and operation?
28.	Will any of the treatment products be acceptable for various nondisposal uses?
29.	What are the costs associated with final disposal?
30.	What are the procedures and costs for the preliminary fuel transfer from the current storage location to the cask loading area?
31.	Can the treatment products be returned to the “home” facility after treatment?

VIABILITY TESTS

Two basic economic tests are available to determine the economic viability of an investment, program, or project.

The most common of the economic tests is cost-effectiveness. Cost-effectiveness has the primary objective of ensuring all requirements are met at the lowest possible cost. Cost-effectiveness is the most 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 performance requirements have been previously agreed to and are well established. Cost-effectiveness has been determined by the Office of Management and Budget to be the preferred economic test for promoting the efficient allocation of limited federal government funding.(8)

The second economic test is cost efficiency. Cost efficiency has the primary objective of maximizing return on investments; thus, costs and benefits must be evaluated. 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 modulate more and are often compromised to optimize efficiency objectives. This tends make it much more difficult to optimize return on investment. Typically, businesses use efficiency tests to maximize return on ownership equity.

Because environmental laws and regulations often prescribe minimum standards of performance, cost-effectiveness 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 of 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 previously spent should not be included. The previously spent costs are also known as sunk costs and are irretrievable. 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 STRUCTURES

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. The elements at the work level, having been identified, can now have costs assigned to them. Thus, the summation of all WBS activity costs at any given level is the total project cost.

WBS components may be products or services. Either 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 1. This WBS was constructed solely for purposes of this evaluation and is not intended as a replacement for any program WBS currently in existence. Using this WBS, process information is easily leveraged into identifiable costs for this project. This parallel cost effort is often referred to as a cost breakdown structure.

COST MODEL

After the treatment questions were clarified and the WBS developed, an economic analysis can be performed. From the analysis of each fuel type, costs will be applied to the WBS matrix to determine the cost/kg to process fuel from current to final storage. A computerized cost model was developed as a generic modeling tool. This generic format was established as a modeling requirement. The generic format permits broad and flexible analysis for anticipated and unforeseen treatment/deployment options. Additionally, the model was developed to accommodate many deployment solutions (depending on the fuel type). The deployment solutions may be combined to evaluate the whole NSNFP's effort.

For each fuel type, cost data are inserted into the WBS matrix for each treatment scenario to derive total life-cycle costs, unit cost (total life-cycle cost/metric ton of heavy metal [MTHM]), etc. Treatment options may also be evaluated according to facility location.

For example, if a fuel is transported offsite for treatment at an existing facility, building costs maybe minimized but require additional transportation costs. Thus, tradeoffs in treatment activities are captured in the economic analysis.

RESULTS

For this paper, this methodology model was evaluated with three scenarios treating sodium-bonded fuel at ANL-W. The three scenarios for Option A are as follows:

1. Experimental Breeder Reactor II [EBR-II] blanket SNF currently being stored at ANL-W
2. EBR-II SNF currently being stored at the Idaho Nuclear Technology and Engineering Center (INTEC)
3. Fermi SNF currently being stored at the INTEC

The life-cycle costs for this evaluation are based on initial estimates. The preliminary scenarios will be used to check the adequacy of the methodology model. These three preliminary scenarios are assumed to be independent of each other. The evaluation assumes the equipment currently in the ANL-W facility will be used to treat the fuel. The flow rates assumed to calculate the ratios for this paper are based on the ANL-W planning basis rates for the process.

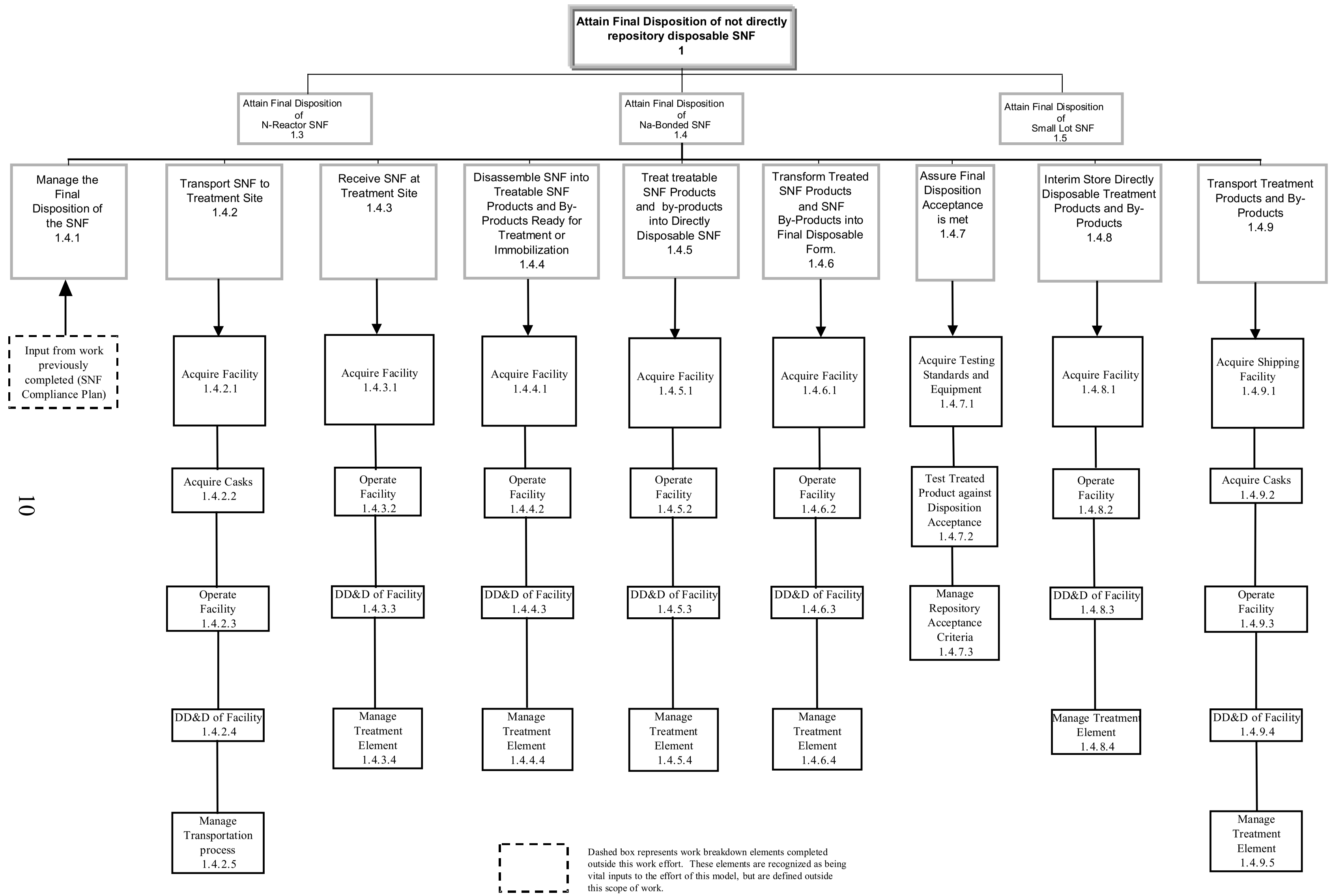

Figure 1. WBS diagram for the treatment of sodium-bonded fuel.

A demonstration test is currently underway to verify the flow rate. The cost numbers may change with updated information. The results of the evaluation are shown in Table II.

The table provides information on the three scenarios. For each scenario, information is specified on 1) the location of the fuel, 2) the amount of fuel (MTHM) to be treated, 3) the number of casks needed to be fabricated, and 4) the time needed to process the fuel assuming the planning basis rate.

Scenario 1 was used as the baseline scenario; it assumes that 22.5 MTHM fuel will be treated through the Mark V electrorefiner. As expected, the annual rates of operation for the three scenarios are similar to the baseline scenario. Scenarios 2 and 3 are slightly larger than the baseline scenario (0.4% and 0.6 %) because of the need to ship the fuel.

Table II. Life-cycle costs ratios for SNF treatment scenarios.

Scenario: fuel location	Available fuel (MTHM)	Casks to fabricate	Projected processing time -year	Annual operations discounted cost ratio
1) EBR-II at ANL-W	22.50	0	5.35	1.000
2) EBR-II at INTEC	1.96	1	0.5	1.004
3) Fermi at INTEC	34.20	1	8.14	1.006

	Unit cost ratio	Total discounted impact cost of cask ratio	Total operations cost ratio	Total life-cycle cost ratio
1) EBR-II at ANL-W	1.000	0	0.990	1.000
2) EBR-II at INTEC	3.709	0.191 (60%)	0.100 (31%)	0.323
3) Fermi at INTEC	1.094	0.194 (13%)	1.448 (87%)	1.662

The ratio for treating the fuel based on unit cost for the fuel is also shown in Table II. To determine the unit cost ratios, the unit cost of treating the fuel (total life-cycle cost/MTHM) was calculated. The unit costs are divided by the unit cost of Scenario 1 (baseline scenario) to obtain the unit cost ratio. For Scenario 2, the unit cost is 3.7 times more than the baseline scenario. For Scenario 3, treating a larger quantity of fuel, the unit cost is about 9% more than the baseline scenario. The values show it could be costly to ship and treat small quantities of fuel to maintain the production rate of the system. Comparing the unit cost shows treating small quantities of fuel quickly results in a significant cost increase (3.7 times for Scenario 2 vs. Scenario 1) primarily from the cost of the cask. The preliminary results show that the cask fabrication cost could be a significant quantity of the fraction of treating SNF. If more than one cask is needed to ship a specific fuel, the cask costs could become a significant cost in treating the fuel.

The total discounted impact cost of the cask was determined for Scenarios 2 and 3. The total operations cost and the total life-cycle costs were determined for the three scenarios. To obtain the rations in Table II, the values for each scenario were divided by the total life-cycle cost of the baseline scenario. For Scenario 2 and 3, it is assumed a new cask will be designed, fabricated, and licensed to transport the fuel. The new cask cost is about 60% and 13 % of the total life-cycle costs for Scenario 2 and 3, respectively. The costs to design, build, and license casks to maintain the flow rate of the system can be considerable. The unit cost ration and the percent of the total life-cycle cost ration indicate a need to evaluate different scenarios to incorporate the smaller quantity fuel in with the lager quantity fuel treatments.

The transportation and processing rate issues will be analyzed in future evaluations. Again, the assumptions on flow rates for the scenarios are based on the ANL-W planning basis rates for the process. The model can be easily upgraded to reflect operating changes when testing is completed.

CONCLUSION

This matrix analysis tool provides a mechanism to aid in determining a final siting alternative for the disposition of SNF at the lowest possible cost to the government and the public. The model can be used to evaluate optimal treatment options for disposition of SNF. The model has already shown that cask acquisition/transportation of the fuel can be a very large cost for some scenarios. Future work will continue to analyze deployment scenarios. Completion of the overall evaluation will include:

- Determine 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-W and factor those results into all evaluations.

The evaluation methodology, while created specifically for the EMT evaluation, has been presented so it could be applied to any potential treatment process that is a disposition option for SNF.

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