Conf-910435--41

SAND--90-2147C

DE91 006640

EVALUATION OF STORAGE/TRANSPORTATION OPTIONS TO SUPPORT CRITERIA DEVELOPMENT FOR THE PHASE I MRS[a]

K. B. SORENSON, N. N. BROWN, P. C. BENNETT
Transportation System Development
Department
Sandia National Laboratories[b]
Albuquerque, NM 87185
(505) 845-8431, 845-9099, 845-8777

W. LAKE
U. S. Department of Energy
Office of Civilian Radioactive
Waste Management
Forrestal Building (RW-33)
1000 Independence Ave. S.W.
Washington, D.C. 20585
(301) 896-5100

ABSTRACT

The Department of Energy's (DOE) Office of Civilian Waste Mangagement (OCRWM) plans to develop an interim storage facility to enable acceptance of spent fuel in 1998. It is estimated that this interim storage facility would be needed for about two years. A Monitored Retrievable Storage (MRS) facility is anticipated in 2000 and a repository in 2010. Acceptance and transport of spent fuel by DOE/OCRWM in 1998 will require an operating transportation system. Because this interim storage facility is not yet defined, development of an optimally compatible transportation system is not a certainty. In order to assure a transport capability for 1998 acceptance of spent fuel, it was decided that the OCRWM transportation program had to identify likely options for an interim storage facility, including identification of the components needed for compatibility between likely interim storage facility options and transportation. Primary attention was given to existing hardware, although conceptual designs were also considered. A systems-based probabilistic decision model was suggested by Sandia National Laboratories and accepted by DOE/OCRWM's transportation program. Performance of the evaluation task involved several elements of the transportation program. This paper describes the decision model developed to accomplish this task, along with some of the results and conclusions.

INTRODUCTION

The U.S. Department of Energy/Office of Civilian Radioactive Waste Management (DOE/OCRWM) is legislated to begin accepting spent nuclear fuel (SNF) from civilian nuclear reactors in 1998. Because the permanent respository is not scheduled to open until 2010, OCRWM plans to interim store the SNF at a Monitored Retrievable Storage (MRS) facility. The current schedule calls for the MRS to be operational in the year 2000.

In order to bridge the two-year gap between 1998 and 2000, the DOE plans to operate a Phase I MRS facility that will be designed to handle a limited amount of fuel which will be discharged to the DOE in 1998 and 1999. The criteria for designing the Phase I MRS are:

1. It should be built with hardware that is licensed (when possible).
2. It should be compatible with a majority of the discharged fuel and the transportation casks.
3. It must have fuel recovery capability.
4. The selected hardware must be deliverable in sufficient quantities to accommodate the 1998 schedule.

The challenge for DOE/OCRWM is to create an effective selection process to best configure the Phase I MRS and procure the appropriate hardware. Issues that impact this selection process include at-reactor out-of-pool storage, reactor facility limitations, transportation options, and MRS options. Currently, there are several licensed out-of-pool storage designs. Two examples are metal casks and multiple element sealed containers (MESC). Additionally,

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[a] This work performed at Sandia National Laboratories, Albuquerque, New Mexico, under the U.S. Department of Energy Contract DE-AC04-76DP00789.

[b] Sandia National Laboratories A U.S. Department of Energy Facility.

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DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED facility constraints such as crane capacity and dimensional limitations must be addressed to assure proper interface of hardware components. Transportation options such as the Cask Systems Development Program (CSDP) casks and existing licensed casks will also affect efficiency of fuel movement. Examples of MRS hardware options include metal casks, concrete casks, and concrete storage modules. To establish transportation requirements, a decision basis for configuring the Phase I MRS was developed using a systems-wide approach to evaluate hardware options for the envelope of SNF operations.

This paper describes the work performed by a DOE task group to develop a decision model for selecting hardware to configure the Phase I MRS. Operations are identified that could be implemented in a demonstration program that would provide a quantitative data base for final hardware selection.

DECISION MODEL

Evaluation of the storage/transportation (S/T) options available for configuring the Phase I MRS is complicated by the mix of quantitative and qualitative data. For example, several storage cask designs, which provide quantitative data with regard to fuel capacity, cost, licensability, etc., are already licensed. By contrast, dry fuel transfer hardware is largely conceptual in nature (qualitative data), which results in large uncertainties in the data. An analysis method had to be developed that could effectively evaluate this mix of data in a consistent manner. A design analysis was the method chosen for evaluating S/T options. This method can accommodate qualitative data with large uncertainties along with quantitative data. The product of this effort is a decision analysis model which, when combined with available data, results in a ranking of credible S/T options based on the odds of success that a specific S/T hardware configuration can be operational in 1998.

Figure 1 illustrates the steps taken in the development of the decision model. To perform the work needed in the four-month time-frame specified, a core group of experts was assembled. Representatives from DOE, Headquarters (Chair); DOE, Chicago; DOE, Idaho; Sandia National Laboratories; Edgerton, Germeshausen and Grier (EG&G); Roy F. Weston, Co.; Hazardous Materials Systems; and Science Applications International Corporation (SAIC) comprised the core group. This core group was responsible for developing and applying the analytic model, collecting data, and estimating the cost. This project was a team effort in all aspects of the model development.

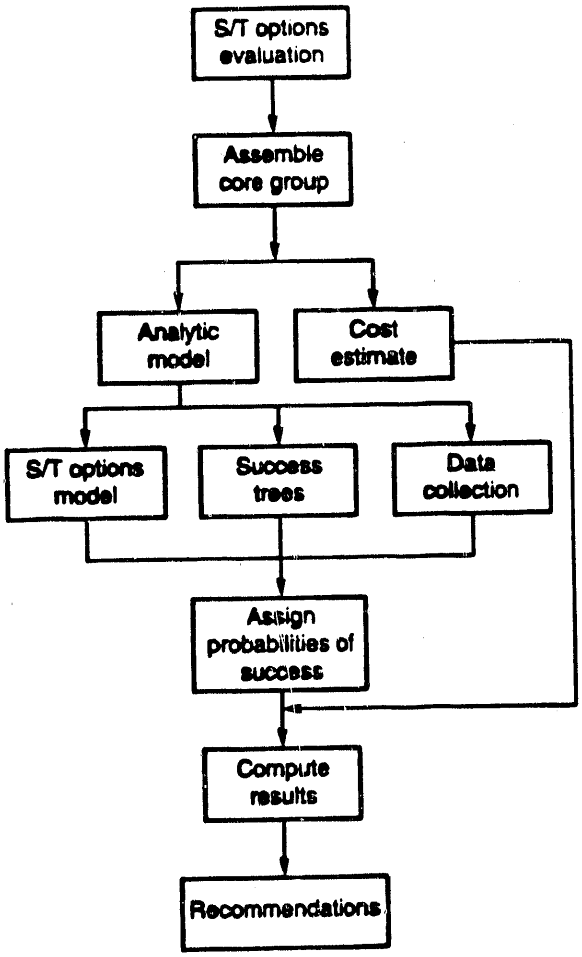


FIGURE 1 FLOW DIAGRAM OF EVALUATION PROCESS

The first step in developing the decision model was to identify credible S/T paths for managing transfer of SNF from the reactor site to the Phase I MRS. For the decision model, a credible S/T option is one that has a reasonable chance of being operational by 1998, given sufficient resources. Figure 2 illustrates the nine basic paths with associated hardware options available for each operational mode (at-reactor, transportation, and at-MRS). Each operational mode has several hardware choices (Fig. 2) which, when combined with the nine basic paths, yield 47 S/T options. For example, a path in Figure 2 illustrates shipment from a rail access reactor using a CSDP rail cask that has several hardware options under Phase I MRS operations. Selection of a single hardware option for fuel transfer hardware and storage results in one S/T option. Each path, then, has several S/T options based on hardware selection. Figure 2 provides 47 different combinations for shipping fuel from the reactor to the MRS. These 47 S/T options are considered a good envelope of hardware and technology combinations

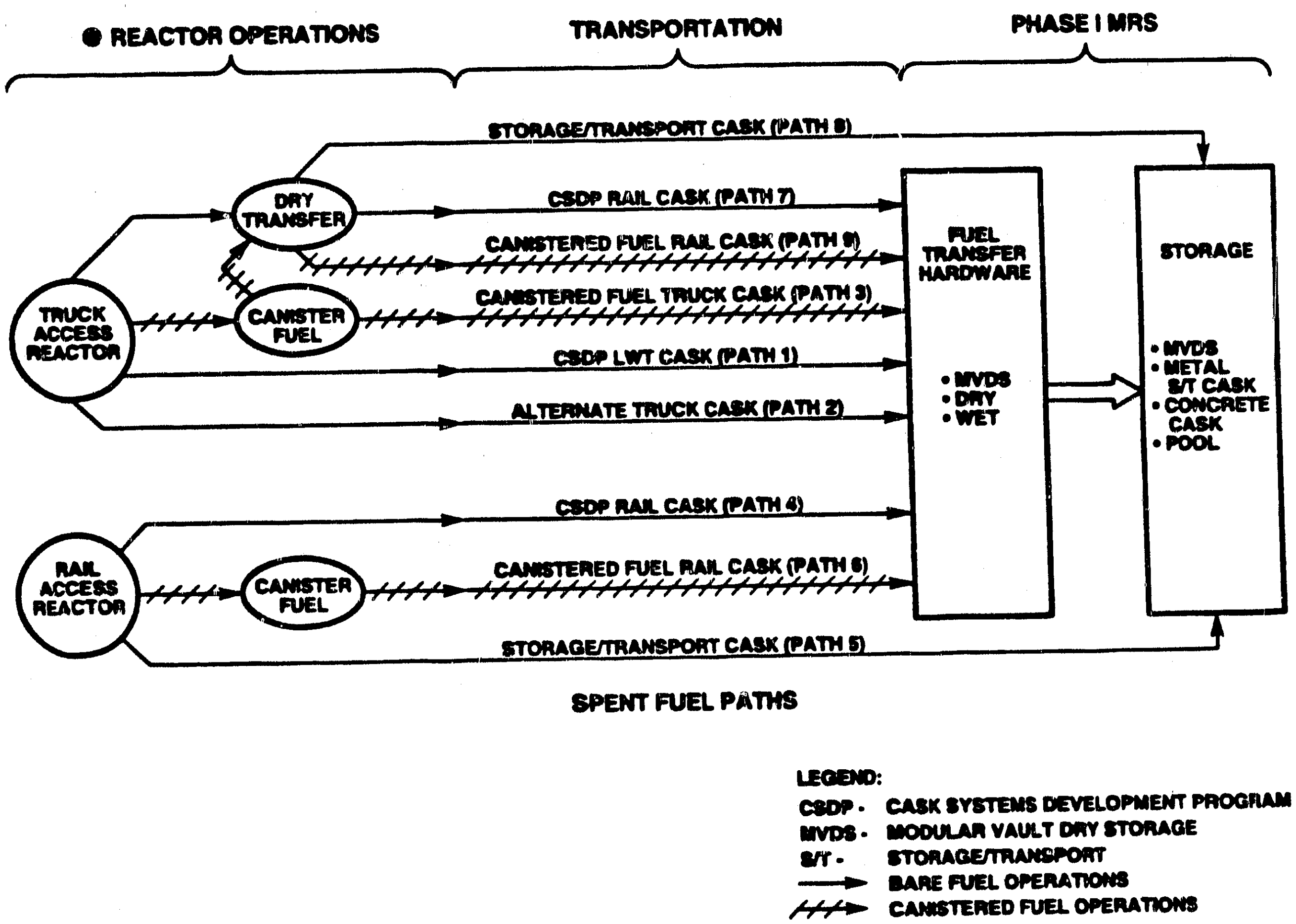


FIGURE 2 NINE BASIC SPENT FUEL PATHS WHICH DEFINE THE SYSTEMS MODEL

that must be evaluated to give DOE a firm decision basis for configuring the Phase I MRS.

For each of the 47 S/T options, critical events were identified that define a particular option in terms of fuel transfer, shipping, and storage operations. Based on these critical events, a decision model was developed as shown in Figure 3A.

Odds of success for each critical event along a pathway are determined using a fault tree technique. The fault trees are termed "success trees" in this analysis, because the resulting probabilities define the relative success of the particular event. For example, to determine whether using a CSDP legal weight truck (LWT) cask is feasible at a non-rail/barge nuclear facility, the success tree in Figure 3B is used. Figure 3B illustrates the probability analysis approach. The construction of the success trees impact the results. For example, as the number of "and" gates increases for a given process, the probability of success decreases. From an engineering standpoint, as more steps are added to a process, reliability decreases. Conversely, as the number of "or" gates increases, the probability of success increases. In other words, as the number of alternative success options increases for this program, the likelihood of success (i.e., of being ready in 1998) increases.

For the success tree in Figure 3B, either the GA 4/9 cask OR the Westinghouse Titan cask must be feasible. To be feasible, a cask must satisfy all basic conditions outlined in the success tree (i.e., the fuel must be compatible with the casks AND the casks must be available at the appropriate time in sufficient quantities to meet transportation needs AND the casks must maintain Nuclear Regulatory Commission certification). To obtain the odds of success for a specific S/T option, the probability of success is computed for each success tree that is related to a critical event. (The triangle under each event in Figure 3A refers to a unique success tree.) The series of critical events for the specific S/T options are then linked through a series of "and" gates. In this manner, a probability of success for each of the 47 S/T options is obtained. For example, the computed probability of success for Path 1 in Figure 3a. is obtained by:

$$P_{s(1)} = P_b * P_g * P_h \qquad (1)$$

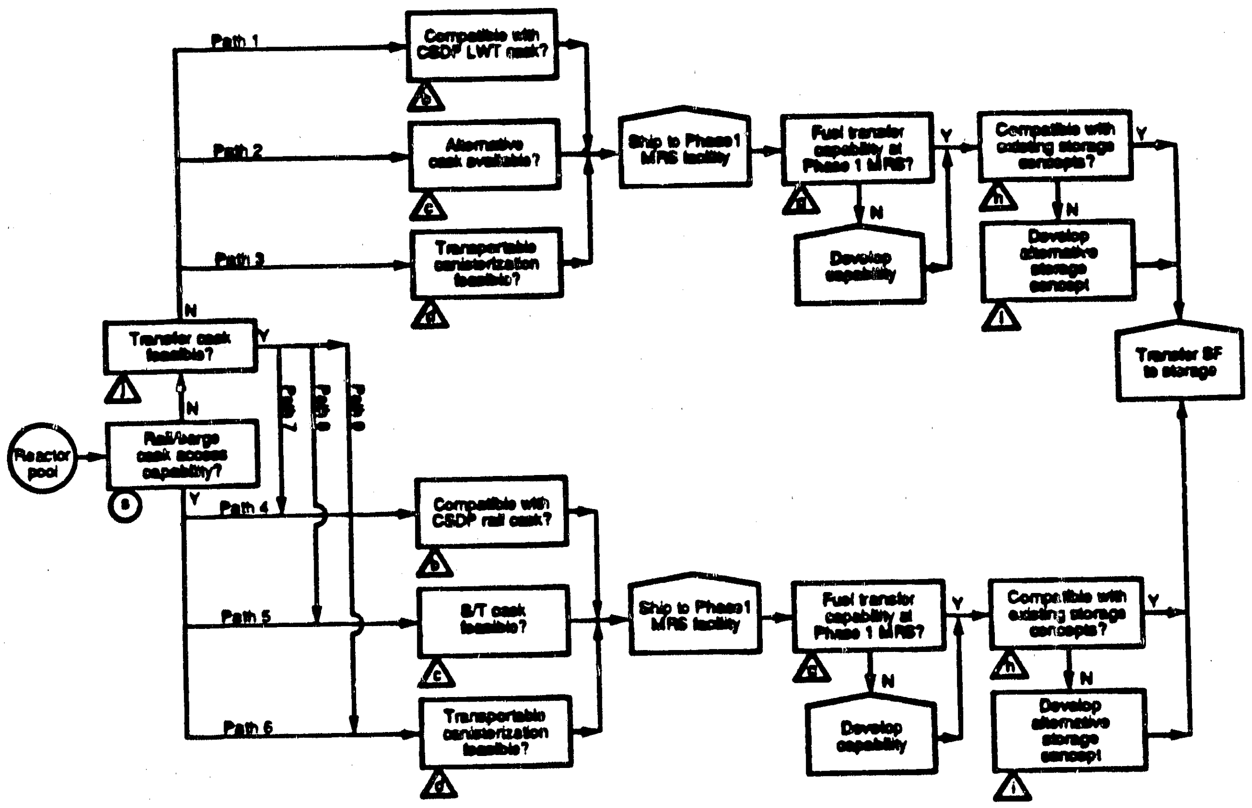


FIGURE 3A DECISION MODEL FOR MOVING SPENT FUEL FROM A REACTOR POOL TO A CENTRAL STORAGE FACILITY

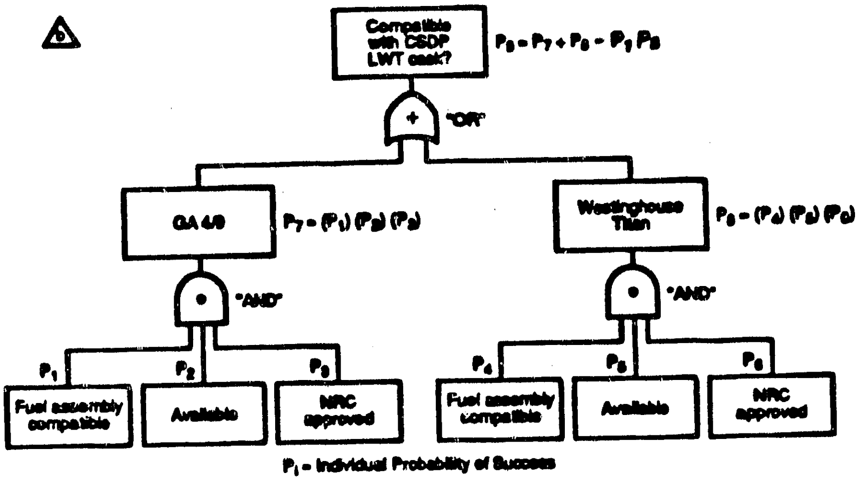


FIGURE 3B SUCCESS TREE

where:

$P_{s(1)}$ - probability of success for Path 1
P_i - probability of success for individual events

The Delphi approach is often employed when concrete data is unavailable or difficult to measure. Based on Bayesian technique premises, any unknown quantity is considered a random variable, to which an analyst can apply expert knowledge about the variable in the form of a probability density function. This assigned function in turn serves as a quantitative basis for future decisions. The Delphi approach typically surveys individual experts who submit their views (anonymously) for comment and criticism by other members of a chosen panel. The information is compiled, refined, and resubmitted for further comment until a consensus is reached. The decision model used in this analysis was similar to the Delphi approach in that a group of experts was used to assign probabilities. However, because of significant time constraints, interactive panel (core group) discussion was allowed on several occasions. The approach used by the core group to assign probabilities to the success trees is therefore termed a modified Delphi approach.

The assignments made by the core group are based on a consensus formed from the qualitative judgments of the individual experts. These assignments are subjective probabilities. Basically, the probabilities of success of individual components of an option were constrained to the discrete values 0, 0.1, 0.3, 0.5, 0.7, 0.9, and 1.0. This approach results in qualitatively-based probabilities. To focus attention away from the absolute probabilities and toward the relative ranking of options, these qualitative probability estimates are normalized to the average probability of success of the collection of options. This provides a relative scale for comparing one option to another. Thus the ranking provides relative "odds of success" for individual options.

The model assumes that each critical event is independent of the others for calculational purposes. Given the compressed schedule there was not sufficient time to evaluate interdependencies.

Assignment of probabilities and evaluation of the data were based on several fundamental assumptions:

1. Fuel acceptance rates are 400 MTU (metric tons of uranium) for 1998, 800 MTU for 1999, and 1200 MTU for 2000. These rates were selected as representative of DOE's ability to process the quantities of fuel involved.

2. Reactor fuel delivery rights are based on the Oldest Fuel First (OFF) criterion defined in 10 CFR 961.

3. To identify reactors that may need to be serviced, but which do not show up as a result of the first two assumptions, a bounding case of 1200 MTU for 1998 was considered. In addition, a full core reserve (FCR) case, comprised of reactors which may run out of FCR prior to 1998, was considered. Such reactors that need to be serviced may arrange to use delivery rights of other utilites, thereby imposing additional constraints on the system.

4. A DOE site will be available and the time schedule and resources will be provided so that a Phase I MRS will be operational by 1998.

5. The probability scores selected by the core group were based on the time schedule for developing the Phase I MRS as defined by DOE/OCRWM. Meeting this time schedule depends on appointment of an MRS negotiator, selection of an MRS site, and completion of the approval process for acquiring site certification. The success or failure of some options is relatively sensitive to this schedule.

Data collection was performed in parallel with the decision model development. Identification of specific reactors that will need to be serviced, types and quantities of fuel that will be discharged, fuel transfer concepts, and transportation and storage options were all included in the data gathering. Reactor data included eligible reactors identified from 10 CFR 961 considerations,[1] cask access limitations, and crane capacity. The reactor data was assembled largely from the ongoing Facility Interface Compatibility Assessment (FICA) Study sponsored by DOE.

Data for transportation operations came largely from the Cask Systems Development Program (CSDP). The CSDP casks are likely candidates for shipping SNF to the Phase I MRS. For reactors which cannot accommodate CSDP casks, existing licensed casks were evaluated.

Data for dry storage at the MRS and for dry fuel transfer was compiled from operating histories at demonstration projects and reactor sites and from the literature. Development work for dry storage is ongoing in both the private and government sectors. As utilities reach capacities in their pools, various out-of-pool dry storage concepts are being developed. Additionally, DOE is involved in several dry storage cooperative demonstration programs. All of these technologies were included in the evaluation process. Examples of MRS dry storage technologies include metal storage casks, concrete casks, MESCs, and modular vault dry storage (MVDS).

The compilation of this data allowed the construction of an S/T options decision model that depicts movement of SNF from the reactor to the Phase I MRS. By construction of the S/T options in this manner, system constraints can be identified more readily and compatibility of the Phase I MRS with the transportation hardware and the fuel configuration can be optimized.

For the 47 S/T options considered, first-order cost estimates were performed. The cost estimating covered capital and operating costs for the 1998 and 1999 Phase I MRS. These estimates included Phase I MRS facility costs and two-year operating costs. The level of detail for the cost estimation was coarse for two principal reasons. First, the schedule for this evaluation was compressed and did not allow for detailed estimation of all options. Second, because much of the data is qualitative, it was difficult at best to estimate costs for hardware that in some cases is not yet designed and will not be procured for several years.

For these reasons, cost comparisons between the various S/T options evaluated serve as a discriminator secondary to the ranking of the odds of success. The cost estimation is meant to identify options that may be significantly more or less expensive than the other options.

It is important to note that the expected hardware requirements are sensitive to the assumed acceptance rate. Different acceptance rate assumptions result not only in larger quantities of fuel, but also in different mixes of reactors which may significantly alter hardware requirements and costs (e.g., pressurized water or boiling water reactors and rail access or truck access reactors). The assumed acceptance rates were chosen by the core group as representative of DOE's ability to handle the specified amount of fuel.

RESULTS

Figure 4 represents the primary results of the evaluation in terms of hardware options, odds of success, and cost. Odds of success are normalized to the average odds of success for all 47 S/T options. The quantified rankings of these options are therefore tied to the average odds of success. The 14 options in Figure 4 depict the basic operational mode hardware requirements. The option rankings are plotted along with the associated costs for development, procurement, and two years of operation for each option.

The primary results of this evaluation are as follows:

1. There is no obvious "winner" that stands out in terms of odds of success or cost. Given the qualitative data base and the first order cost estimation, small differences in ranking and cost are not effective discriminators.

2. The 14 S/T options shown in Figure 4 can be grouped as shown by the dotted lines. As previously discussed, reducing the number of critical operational steps in any given procedure increases the odds of success. In Figure 4, S/T options with relatively few steps (Paths 1,2,4, and 5) have higher odds of success than the S/T options that require at-reactor operations.

3. The dual purpose cask option with wet or dry transfer capability has the highest probability for successful implementation of 1998 Phase I MRS operation, followed by the metal storage cask, MVDS, the concrete cask, and the MESC options.

An additional significant result is the construction of the decision model with the associated success trees. The results obtained are a function of the available data. As hardware concepts mature and new technologies emerge, the results can be refined using the same basic model with the additional data.

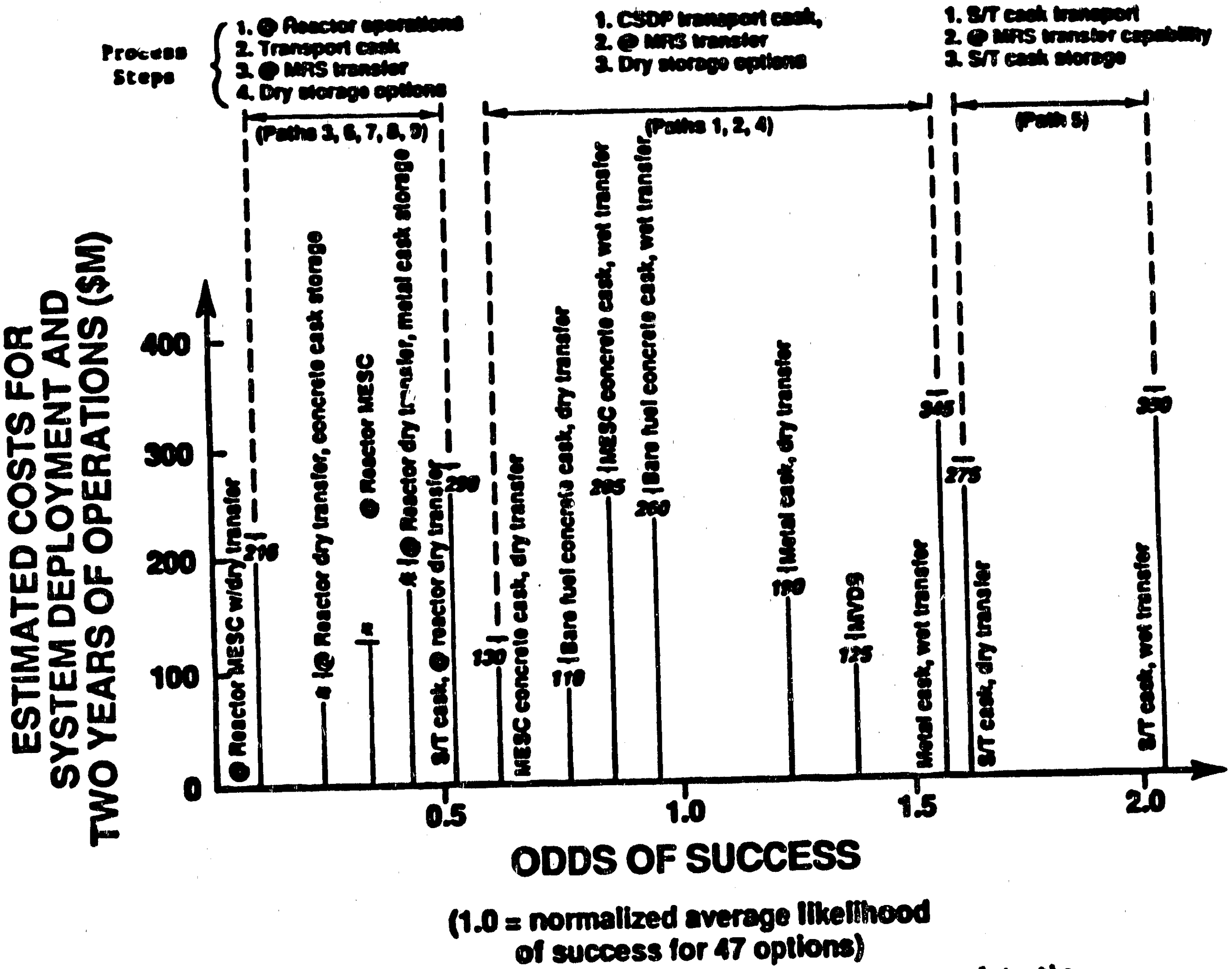
CONCLUSIONS

Because there is no clear "best" path for DOE to pursue, several S/T options could be pursued simultaneously to maintain system flexibility, respond to contingencies, and ensure that DOE can meet its 1998 obligation to accept spent fuel. Based on relative probabilities of success, system contraints, and costs, the following hardware development could be pursued to help assure 1998 DOE waste acceptance.

The S/T options that provide (for 1998 and 1999 operations) relatively low risk, economy, and system compatibility (accessibility to reactor sites) include the following hardware components:

* Dual purpose casks for transport and interim storage,
* Phase I MRS dry fuel tansfer capabilities, and
* Phase I MRS dry storage in concrete and metal casks. (Utilities are pursuing both concepts, which indicates that there is no clear cost winner at this time.)

Most hardware identified in these hardware options are licensed or far along in the development process. The exception, a dry fuel transfer facility, should be a high priority item for DOE hardware development. The utilities have recognized this need and have sponsored, through the Electric Power Research



[a] Costs for these options were not computed. Costs are set equal to the comparable hardware with at-MRS dry transfer.

FIGURE 4 RANKING OF S/T OPTIONS WITH ASSOCIATED ESTIMATED COSTS FOR HARDWARE DEPLOYMENT AND TWO YEARS OF OPERATION

Institute (EPRI), a dry fuel transfer criteria study.

These hardware options recognize that the MVDS has a high probability of success and low relative costs. However, the design of an MVDS facility is site-dependent. Therefore, establishment of MVDS design criteria must be delayed until the Phase I MRS site is selected and approved. Reliance on this option may result in a lack of DOE capability to accept spent fuel if the MRS site selection schedule is not met.

The core group felt that the MESC concept was disadvantaged due to the added step necessary (canistering the fuel either at the reactor site or at the Phase I MRS). The lower odds of success for the MESC option relative to the other options reflects this extra step.

For the MVDS and MESC options, private industry has taken the lead in developing both of these technologies. Because these hardware options are being privately developed, adding the MVDS and the MESC to the DOE program would be redundant. These technologies could still be evaluated with the above-described S/T options at the end of a DOE development program, when hardware options must be selected for configuring the Phase I MRS.

REFERENCES

1. "Standard Contract for Disposal of Spent Nuclear Fuel and/or High-Level Radioactive Waste," Title 10, Code of Federal Regulations, Part 961, January 1, 1989 Edition.

ACKNOWLEDGMENTS

This work is the product of numerous individual efforts. The following organizations had representatives in the core group that gathered the necessary data and served as the group of experts in the evaluation: DOE/OCRWM-323, DOE/ID, DOE/CH, Roy F. Weston Co., and Hazardous Materials Systems. In addition, representatives from DOE/HQ, EG&G/ID, and SAIC provided specific expertise toward the completion of the work. The authors would like to recognize and thank these representatives for their contributions to this work.

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