SYSTEMS STUDY OF BACK END OF NUCLEAR FUEL CYCLE INCORPORATING A PEER REVIEW GROUP

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ABSTRACT

The purpose of this paper is to describe the results of a program, performed for the DOE, to evaluate metal cask systems for the packaging, handling, storage, transportation and disposal of spent nuclear fuel. This program has developed tools and demonstrated the methodology for efficient analyses of the economics, radiological, and institutional aspects of very complex nuclear waste management systems. These analyses and the data accumulated in conducting the program provide the DOE with a great deal of insight into the direction that future DOE programs should take.

BACKGROUND

As background (Fig. 1), the DOE issued a Program Research and Development Announcement (PRDA) for a nuclear waste packaging and handling design initiative in May 1984. In response to the PRDA, Westinghouse proposed a systems evaluation of metal cask systems for spent fuel management from the reactor to the repository. The project scope included technical, economic and institutional evaluations of the cask systems in a variety of spent fuel management systems.

- In May, 1984, the DOE issued a Program Research and Development Announcement (PRDA) for a Nuclear Waste Packaging and Handling Design Initiative.
- In response, Westinghouse proposed a systems evaluation of metallic cask systems for spent fuel management from the reactor to the repository.
- The project scope encompassed both technical and economic evaluations of the cask systems in a variety of spent fuel management systems.

Fig. 1. Background

INTRODUCTION

The comparative evaluation of metallic cask systems for use in the spent fuel management system depends on all the interested parties reaching a compromise between potentially conflicting technical, institutional, environmental, economic, political, and social concerns and considerations. The interested parties are those whose acceptance, if not support, will be necessary to the implementation of the chosen system. A combination of traditional systems engineering and multi-attribute decision analysis methodologies was used in conjunction with input from a Peer Advisory Group which was representative of the various interests for this study. Decision analysis methodology was also employed to provide a framework in which values, information, and alternatives are structured to portray the relationships between decisions, uncertainties, and outcomes. This paper describes the methodology used in the evaluation along with the results and conclusions.

There are numerous concerns to consider in the evaluation of metallic cask systems for spent fuel management such as health and safety, economic cost, and political implications. In order to conduct a comparative analysis of alternative metallic cask systems, it is necessary to specify a single set of value criteria against which each alternative can be evaluated.

If this set of value criteria is judged to be inappropriate or inadequate by industry executives, governmental regulators, legislators, or public interest groups, the credibility of the analysis will suffer greatly, and the results of the analysis may be practically meaningless. Recognizing these circumstances, this study documents an initial effort to develop a comprehensive set of value criteria for evaluating metallic cask systems.

The approach was to use a panel of peers representing the various interest groups to help define the problem, identify alternatives to be considered, establish value criteria by which the alternatives can be judged, and participate in performing tradeoffs among conflicting objectives. It was important to first perform the technical support work necessary to ensure that the systems under consideration would meet the necessary functional requirements, quantify the measurable attributes of the alternatives to permit comparison, and facilitate the implementation of the overall process. The underlying premise was that decisions must balance the needs and values of the interested parties in making choices leading to a mutually acceptable outcome. Multiple-attribute decision analysis provided a means to identify objectives and value criteria of each interest group, quantify the ability of the alternatives to meet the criteria, and provide a basis for evaluation of the alternatives. The methodology also helped to develop clear relationships between decisions, uncertainties, and outcomes. These relationships are essential to resolution of complex problems of this type. It permitted taking into account uncertainties and helped to resolve differences in opinion through the use of probabilities which recognize that many things are possible, but some are more likely than others.

Each objective for metallic cask systems specifies both a value criterion and an orientation of preference with respect to that criterion. For instance, one objective would be to minimize economic cost. The associated value criterion is "economic cost" and the preference orientation is to minimize that cost. Another objective would be to minimize health impacts to the public from radiation exposure. The associated value criterion in this case would be "public health impacts from radiation exposure" and the preference orientation is, again, minimization. With each value criterion, there is a need to identify a measure and to indicate the degree to which the associated objective is achieved.

It is natural to structure a set of value criteria into a hierarchy. Such a hierarchy is sometimes referred to as an objectives hierarchy, a hierarchy of values, or a value tree. Whether one thinks of such a hierarchy as a hierarchy of objectives or of value criteria is not important since there is a direct correspondence of objectives and value criteria.

In structuring the value criteria, two important concepts are used repeatedly. One concept is the separation of means and ends to the extent possible. For example, one objective to evaluate metallic cask systems might be to minimize the transportation of casks with spent fuel. For this or any other stated objective, the question should always be asked "Why is this objective important?" The answer in this case might be that with less transportation, there would be fewer transportation accidents and that it is important to minimize transportation accidents. Again, the question would be asked "Why is that important?" The response might be that with fewer accidents, there would be less public exposure to radiation. The reason that it is important to minimize radiation exposure is to minimize the health impacts of radiation. When asked "Why is it important to minimize the health impacts from radiation?", the response may be that it simply is important. This would indicate that this latter value criterion of the health impacts to the public due to radiation exposure is an ends to the means in the process leading to this criterion. When the ends can be identified, the hierarchy of value criteria should include only the ends and not the means, as this would lead to double counting in evaluation. This clearly does not indicate that the means are not important, but rather that they are important for their effects on the ends. It is recognized that a particular means could affect more than one end. For example, transportation accidents could have health and safety consequences, economic consequences, environmental consequences, and political consequences.

Another important concept in structuring values is that of specification of value criteria. For instance, one objective for the evaluation of metallic cask systems might be to minimize environmental impacts to the natural environment. However, it may be useful to make this more specific in order to evaluate metallic cask system alternatives. Thus, the question is asked, "What environmental impacts should be minimized?." The response, which may be simply one specific environmental impact or many, would result in a clarification of the concern and a better specification of appropriate value criteria.

APPROACH TO ESTABLISHING VALUE CRITERIA

The overall approach involved the elicitation of sets of value criteria from three panels composed of from ten to fifteen individuals each. These panels were referred to as the technical, governmental, and public interest panels. The technical interest panel was composed of individuals from utility firms and other firms in the nuclear industry. The governmental interest panel included individuals from various federal agencies, legislative aides, and representatives of state governments. The public interest panel included individuals in environmental groups, consumer groups, and universities.

A brief outline of the task was presented collectively to the panels in order to clarify the overall problem and to present guidelines for proceeding further. The objective was to provide a preliminary set of value criteria which would be a basis for feedback, modification, and improvement for this process. It was important to assure individuals that criteria would not be weighted at the meeting and hence the relative importance of the value criteria was not an issue. Furthermore, the individuals were there to represent themselves and not necessarily their organizations.

With this background, the separate sessions with each individual panel were short and straightforward. It was stated that two general guidelines would be repeatedly used to help structure the concerns of panel members into a hierarchy of value criteria. One guideline was that they would strive toward the ends from the means. The manner that this would be done was to always ask why a value criterion was relevant. This was followed up by asking "why?" to the answers until it was simply stated that a value criterion was important in itself, that it was an end. The second guideline was regarding specification of the value criteria. Whenever an end objective was identified, the question was asked, "What does that mean?" or "Due to what?" or "With respect to what?" In an example presented involving safety, where the objective may have been to minimize safety in the transport with regard to the metal casks, the question was, "What safety is of concern?"

Finally, individuals were asked to write down value criteria that they felt would be important, prior to starting the open discussion.

ESTABLISHMENT OF VALUE CRITERIA

As a result of the panel discussions, numerous suggestions of appropriate value criteria were obtained from each panel. The results of these discussions were utilized to structure the preliminary hierarchies of value criteria. The hierarchy of value criteria was first developed for each panel and then these were combined to provide an overall value structure for this group. This value criteria structure is presented in Table I.

TABLE I

Value Criteria

• Health and Safety	• Social
• Economic	• Fairness
• Environmental	• Scheduling
• Political	• Flexibility

MEASURES FOR VALUE CRITERIA

The list of value criteria, presented in Table I, represents the set of concerns required to adequately evaluate the relative desirability of different metallic cask systems. In order to use these value criteria, it was necessary to develop measures to indicate the degree to which the different metallic cask systems met the concerns represented by the respective criteria. For instance, with the value criteria of health effects due to radiation exposure to the public, the concern was related to possible health effects to members of the public. This could be measured directly by the number of health effects induced over the time period of dealing with the spent fuel disposal problem, or it could be measured by the proxy of cumulative public radiation dose. Such proxy relates to the mechanism by which the health effects would be induced, but it does not directly measure the primary concern (i.e., health effects) itself. The next step in the process was therefore to identify quantifiable actual or proxy measures for the value criteria. Some measures are readily apparent while others are difficult to identify. Some of the value criteria were combined resulting in 20 separate criteria distributed among the 8 primary categories. Before results of the detailed analysis were available, the project team arrived at very rough estimates of the indicated range of the parameters for the alternatives being considered, permitting a preliminary assessment of the project team weighting factors. The relative weights on concerns and on value criteria within concerns for three individuals from the project team are provided in Table II.

The objective functions derived for the evaluation are technically referred to as measurable value functions. The main property of these value functions is that alternatives which score higher should be preferred to alternatives that score lower. However, in addition, a measurable value function has the property that the difference in value between alternatives evaluated as 0.2 and 0.4 is the same as the difference between alternatives evaluated as 0.4 and 0.6. A measurable value function can be constructed on any arbitrary scale, as is the case with temperature measurement scales.

In this study, the additive measurable value function was established to be the most appropriate. Thus,

$$v(x_1, \ldots, x_{20}) = \sum_{i=1}^{20} w_i v_i(x_i), \qquad (1)$$

where v is the value function scaled from 0 to 1, v_i is a value function over measure X_i scaled from 0 to 1, x_i is a specific level of X_i, w_i is a weight representing the relative importance of X_i. As the range of any given measure increases, the relative weight on that measure would necessarily increase since the weight refers to the importance of going from the worst level of the range to the best level of the range relative to that same change for the other measures.

RESULTS OF PEER ADVISORY GROUP EVALUATION

The evaluation of the different alternatives with the measurable value functions in Eq. (1) was

TABLE II

Relative Weights on Concerns and on Value Criteria Within Concerns Using Measurable Value Function (2)

	Concern K for				Within Concern k_i for		
Concern	Ind. 1	Ind. 2	Ind. 3	Measure	Ind. 1	Ind. 2	Ind. 3
Health & Safety	.006	0	.152	X_1	.387	.176	.048
				X_2	.240	.131	.261
				X_3	.026	.039	.017
				X_4	.150	.157	.086
				X_5	.197	.497	.588
Economics	.231	.139	.348	X_6	.102	.150	.102
				X_7	.796	.700	.796
				X_8	.102	.150	.102
Environmental	≈0	≈0	≈0	X_9	.100	.950	.154
				X_{10}	.900	.005	.846
Political	.144	.581	.014	X_{11}	.840	.952	.144
				X_{12}	.160	.048	.856
Social	.037	.029	.022	X_{13}	.985	.954	.101
				X_{14}	.015	.046	.899
Fairness	.019	.001	.040	X_{15}	1.0	1.0	1.0
Scheduling	.087	.072	.233	X_{16}	.748	.584	.510
				X_{17}	.252	.416	.490
Flexibility	.484	.178	.191	X_{18}	.006	.110	.064
				X_{19}	.058	.011	.104
				X_{20}	.936	.879	.832

found to be straightforward. A description of each of the alternatives in terms of vector (x_1, ..., x_{20}) is substituted into Eq. (1). This results in a measurable value being assigned to each alternative. Alternatives with greater values were preferred to those with lesser values. However, these evaluations did not replace the vectors (x_1, ..., x_{20}) which also provide insight about the relative desirability of the alternatives.

There appears to be a great deal of uncertainty in the radiological transportation indices for truck and rail which are used to determine the radiological exposures during the transportation of the fuel. Sandia National Laboratories is currently evaluating this issue with the use of unit trains. After discussions with Sandia personnel on the appropriate indices to use for this program, it was decided to use the same radiological transportation index for truck and rail. The overall ranking of each concept was determined with respect to where consolidation was performed, if at all, and with the repositories completed on-time or delayed eight (8) years. The system rankings obtained from using these attribute values, the component and value criteria weights and Eq. (1) are provided in Table III. The results of this evaluation indicate that the preferred choices are to consolidate at the integrated MRS or at the reactor and to use the Conventional Cask System, the Dual Purpose Cask System, and the USSWP System in that order. The technical and economic evaluations selected the same three concepts but the order of preference was different.

TABLE III.

Results of Peer Advisory Group Evaluation

Rank	System	Place of Consolidation
1.	Conventional Cask	MRS
2.	Conventional Cask	Reactor
3.	Dual Purpose Cask	MRS
4.	Conventional Cask	Repositories
5.	USSWP	Reactor