SYSTEMS ENGINEERING APPROACH TO U.S. DEPARTMENT OF ENERGY'S COMMERCIAL NUCLEAR WASTE TRANSPORTATION PROGRAM

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ABSTRACT

The U.S. Department of Energy (DOE) has been given the responsibility of developing a program to transport commercially produced spent nuclear fuel and high-level radioactive wastes to disposal sites or storage facilities safely and cost-effectively. To accomplish this task it is desirable to plan, perform, and document all technical activities based on systems engineering principles. This paper presents an overview of the systems engineering approach being developed by Battelle for consideration by DOE, specifically the early identification of the required technical activities and approaches to technical management and decision making. The program should support the development of an integrated, well-documented transportation system acceptable to regulatory agencies and the public.

INTRODUCTION

The Nuclear Waste Policy Act of 1982 (NWPA) assigns to the U.S. Department of Energy (DOE) Office of Civilian Radioactive Waste Management (OCRWM) the responsibility for safely transporting spent nuclear fuel and high-level radioactive wastes (HLW) from commercial power plants or other facilities to disposal sites or storage facilities.(1) Shipments of spent fuel to a Monitored Retrievable Storage (MRS) facility may begin as early as 1998 if Congress approves construction of the MRS; shipments to a geologic repository are scheduled to begin in 2003.

Transportation of nuclear waste is, by its nature, a complex, multidisciplinary undertaking that will grow in magnitude with time and requires an integrated approach, using carefully structured thinking. To obtain the desired integration, it is necessary that all technical activities should be planned, performed, and documented on the basis of systems engineering principles. This application of the systems engineering process will be utilized in support of system analysis-related activities of the DOE Waste Management Transportation program. This approach satisfies the DOE programmatic requirement for application of systems engineering to major projects; it also leads to efficient management and makes good fiscal sense. The systems engineering approach described in this paper is based upon an initial systematic analysis of program objectives and constraints, and the application of formalized systems engineering tools. While systems engineering can be described in complex terms, the approach presented here is based on the concept that systems engineering is actually only applied common sense, applied in a documented, auditable fashion to yield an integrated technical program.

In essence, systems engineering has been developed to prevent designing a transportation program by the process that Slovic and Fischhoff have called "muddling through". To quote those authors,

> "By far the most common approach toward setting risk policies, nuclear or otherwise, is 'muddling through,' making somewhat arbitrary initial decisions and then letting them be molded into generally accepted standards by the pressure of political and economic forces. While this process may employ analytic arguments, it is essentially nonanalytic. It relies upon the internal structure of participating organizations, their interaction with one another, and the varied feedback provided by their environment to produce satisfactory decisions."(2)

BACKGROUND

The US DOE-OCRWM has established the Office of Storage and Transportation Systems (OSTS) with the responsibility for the establishment and operation of a safe transportation system for spent nuclear fuel and high-level nuclear wastes. The OSTS has in turn established a programmatic structure, shown in Fig. 1, to accomplish this responsibility. Each of the DOE offices has contracted with various organizations to assist in the accomplishment of its responsibilities. US DOE-Chicago, through its Transportation Program Office (TPO), has contracted with the Battelle Project Management Division to establish an Office of Transportation Systems and Planning (OTSP) as their primary technical contractor.

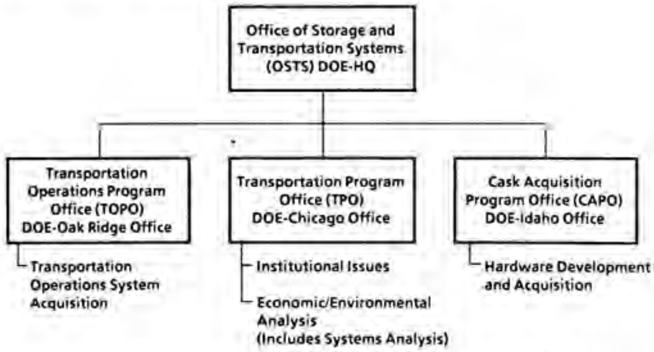

Fig. 1. Programmatic Structure of the National Nuclear Waste Transportation Activity.

The complex nature of the problem, the large number of organizations responsible for specific activities, and their physical separation all support the need for a systems engineering approach. Recognition of this need has recently led to an assignment for TPO with assistance from OTSP to consider how to implement a systems engineering process for the overall commercial nuclear waste transportation program under DOE-OSTS. While the formal systems engineering approach is still being developed for the transportation program, it is possible to describe in this paper the approach being considered.

A major goal of the DOE is reaching consensus among the many affected parties on how the program should be implemented. To this end, the Institutional component of the program is closely coordinated with systems engineering and is structured to accomplish the following:

- Develop and disseminate program information on behalf of DOE,
- Encourage and support public participation in all aspects of developing the transportation system,
- Review and analyze public comments and concerns on key transportation issues,
- Provide for the efficient management of complex, contentious transportation issues over a long time frame, and
- Develop strategies and policies to address and resolve transportation issues.

APPROACH TO SYSTEMS ENGINEERING IN THE PROGRAM

The general concept of systems engineering under consideration by DOE in the transportation program is: structuring the problem and its associated activities, identifying objectives and alternatives, analyzing and comparing the alternatives, presenting information in a suitable framework to aid decision making and developing the required system. The key aspect is that of decision making, whether it be on technical program content or policy issues. Within the transportation program, the classic elements of systems engineering are utilized to fulfill five major objectives:

- Work within OSTS technical requirements to identify transportation initiatives required to satisfy data needs and resolve issues,
- Provide technical consistency for all OSTS transportation activities,
- Conduct interdisciplinary technical analyses for the transportation program,
- Provide OSTS with decision support, and
- Reach a consensus among the affected parties on program implementation through the systematic identification and resolution of program issues.

Each of these objectives is discussed in subsequent sections.

Identify Transportation Initiatives

TPO and OTSP will be working with other components of the OSTS transportation program in the development of key systems engineering documents such as the Systems Engineering Management Plan (SEMP), Systems Engineering Program Plan (SEPP), Systems Requirements and Description Document (SRD), Issue and Data Hierarchies, activity logic networks, and a consistent technical baseline for the program. From these documents (described briefly below) are being derived the technical initiatives for the program.

- The SEMP is the policy document that describes the application of systems engineering in the program. As such, it supplies the justification, the general process, organizational responsibilities, management procedures, and required documentation for systems engineering.
- The SEPP will describe in detail the systems engineering approach and activities required to implement the directives established by the SEMP.
- The SRD is fairly well understood in systems engineering and its application to nuclear waste management has been discussed elsewhere.(3) More detail of this document will be given later.
- The Issue and Data Hierarchies develop and document the technical activities required of the program, establish their priorities, and illustrate interdependencies. These documents along with the SRD are usually the most difficult to develop and require intense interactions among program participants and numerous iterations for their successful completion.

- The Activity Logic Networks are pictorial representations of the interrelationships among activities and milestones necessary to achieve the ultimate goal of a safe operational system. Their development and use are the key project control activities.

- The Technical Baseline is the documented and approved list of all assumptions, key data, and other critical technical information to be used by all programmatic participants.

Provide Technical Consistency

A significant ingredient in a complex technical program is the consistent use of common assumptions, data, and analytical tools. A major concern is to establish baselined parameters and assumptions of the program under a change control process and thereby improve the documentation, traceability, comparability, credibility, and accuracy of analytical results. Finally, since the baseline used by transportation must interface and be consistent with all other OCRWM technical activities, it is a responsibility of systems engineering to integrate and coordinate these functions with the other components of OCRWM.

Consistency is maintained by establishing a technical baseline and configuration management procedure. Configuration management provides consistent direction, control, and surveillance to a developing system, and it uses a controlled baseline for identifying, describing, and maintaining the system under development and the applicable development tasks. This baseline serves as a point of departure for consistent technical project coordination and permits control of subsequent changes from that baseline. The existence of an authorized baseline provides all project participants with the same ground rules. Configuration management procedures ensure that when the defined baseline is to be updated changes are assessed and approved by a process that provides adequate consideration of overall program impact.

Conduct Technical Analyses

The conduct of diverse technical analyses, commonly designated as systems studies, is a key ingredient of systems engineering.

Systems studies will be carried out to evaluate technical alternatives, to support systems evaluation and systems optimization activities, and to balance the allocation of performance and design goals for each system element. The identification of required systems studies will be maintained in a Systems Study Register. The register will identify the following information:

- What decision, alternative, or level of uncertainty the study supports,

- When the study results are needed,

- Which OSTS component prepared the study, and

- The scope of work for the study.

The register will also include a list and description of systems studies that have been completed. These studies may be either scoping or detailed in nature, as appropriate to the topic and the timing required. Often systems studies are used to gain a preliminary insight into a technical problem which has many aspects, with detailed analyses conducted later by the traditional engineering group. The tools employed for these technical analyses may vary widely, including trade studies, risk assessment, preliminary design calculations, simulation models, optimization analyses, parametric studies, cost-benefit studies, etc.

Provide Decision Support to DOE

In a complex and far-flung program, the ability of decision makers to reach timely and proper judgments based upon many and varied inputs is put to an extreme test. The large volume of data, the uncertainty in many considerations, the difficulty in quantifying many variables in a commonly agreed to and understood lexicon without explicitly agreed-to value judgments, and the extreme public visibility and controversy of the program all combine to complicate the decision making process. The goal of this activity of systems engineering is to simplify the decision process by organizing and presenting information, along with recommendations and possible alternatives, in a manner that facilitates the process. The process must allow for consideration of technical/non-technical (quantifiable and non-quantifiable) factors, utilize output from the systems studies mentioned previously and be consistent with higher level OCRWM decision processes, as well as with the decisions to be made. The selection of tools to be used will be based upon the decision at hand and the data available. Thus any decision methodology, from simple ranking (e.g., on the basis of costs) to more formal approaches such as multi-attribute decision theory, will be used as appropriate.

A specific tool being developed by OTSP to support DOE decision making incorporates life-time transportation risks and costs as the basic decision variables. It is a network optimization model that can be used to evaluate policy, system, equipment and scheduling alternatives, subject to the applicable constraints, in terms of lowest achievable risk and cost. The model can be used to compute optimum solutions for alternative policies, given a set of system assumptions and constraints. These solutions can then be compared and used as the basis for selecting between alternatives. It is important to recognize, however, that a solution yielded by any tool is not a prescription for action. It only provides a capability to compare and evaluate broad policy, system, and equipment alternatives in a logical and defensible manner.

Identify Technical Issues and Resolve Them

DOE recognizes its responsibility to resolve valid issues within budget and time constraints, and to allay related fears. A formalized process of technical issue identification and prioritization is being considered for incorporation into the planning of the transportation program. The process is consistent with the DOE-OCRWM intent for the establishment of an "issues hierarchy" in its major programs. This hierarchy states the questions that must be resolved to permit system operation by demonstrating conformity to all appropriate objectives, regulations, and constraints. In the issues hierarchy, as described previously, the "key" or dominant issues that the program must resolve comprise the top tier. Below these few "key issues" are subsets of issues in more detail that expand on the "key issue" that they are derived from. The final, or lower, layer of the hierarchy consists of information needs that are requirements for technical information and data which the program must collect and analyze to address the issues.

If adopted, the subsequent step in the approach will be the preparation of a documented strategy for the resolution of each issue. The process being considered, illustrated in Fig. 2, would lead to a comprehensive, structured understanding of all of the issues, and it also can be utilized to define the data needs which will permit issue resolution and the approach necessary to reach and document the resolution of the issues. A brief discussion of the process shown in Fig. 2 follows.

The Requirements to which a program must be responsive are primarily defined by an overall definition of the Mission. The foremost of these are the Nuclear Waste Policy Act of 1982 which represents the law of the land and the Transportation Mission Plan being formulated by DOE. Other forcing functions include External Directives which are documented statements of policy by recognized authorities, statutes and orders, regulations, DOE guidance, consultation and cooperation agreements, etc. (The DOE also recognizes its responsibility to resolve valid issues which have been identified through dialogue with a wide range of parties having an interest in the transportation of radioactive waste. This is being addressed and managed by the OCRWM Transportation Institutional Program.)

From this compilation of Requirements, a formalized process is employed to identify technical Issues which, when successfully resolved, will demonstrate compliance with the Requirements. Each Issue requires development of a Strategy which is a logical and preplanned sequence of events to be followed to resolve

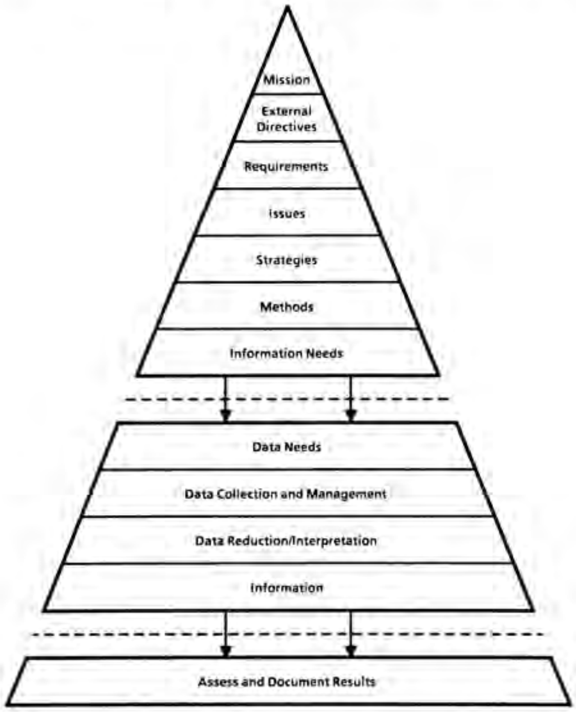

Fig. 2. Issue Identification and Resolution Process.

the Issue. The Strategy must include a detailed description of the Methods to be used in analyzing the Issue, as well as a description of the standard against which it is to be measured. These standards may be quantitative or qualitative. The Methods in turn identify the Information Needs which will be required for their application.

From a formal description of the Information Needs, which is led by systems engineering, technical specialists properly assume the responsibility for defining the Data Needs to supply the Information Needs, the Data Collection and Management Approach, and the Data Reduction/Interpretation process which yields the Information required in the final step of the process--Assess and Document Results.

Inherent with this approach is the need for a process or management tool that can prioritize the needs, identify data gaps or redundancies, and structure the process by which prioritization can ultimately be made. Several methodologies are being evaluated currently for this application.

PUTTING IT ALL TOGETHER

All the components of systems engineering previously discussed must come together as a process for technical integration of the transportation program. The process is summarized in Fig. 3, including its interface with the higher level DOE-OCRWM activities.

System Definition

This step is formalized by the preparation of a Systems Requirement and Description Document (SRD). The system description identifies the structure of the system and its subsystems and their components, and the interfaces and interactions among the subsystems and components. It first addresses "what the system should perform" and to do so must incorporate an identification of the anticipated roles of the system. Secondly it addresses "how the system should perform," and to do so addresses what equipment, facilities, personnel, etc. are needed to perform the required functions.

The requirements definition activity leads to the definition of functional requirements, performance criteria, and constraints on the system. Starting with the highest level objective of the system, a corresponding function is derived. Subsequently, functional analysis identifies the functions, requirements and specifications for each lower level of the system. The requirements of the higher levels are proportioned to the lower levels by trade studies or other methods. In this process, a requirement must be established to define the level of performance, or performance criteria, for each function. Similarly, constraints on the system performance, be they regulatory, design, or institutional, must be identified and documented.

Requirements Analysis and Information Needs Development

This step has been discussed in the context of technical baselining, development of an Issues Hierarchy and Issue Resolution Strategy, and establishment of logic networks for related activities.

System Development

During this step, the various functional components of the programmatic organization perform in the normal fashion to develop their areas of responsibility; however, it is maintained that having the system properly pre-defined, the data collection properly identified and planned, and a systematic evaluation process in place will lead to an efficient conduct of their activities.

System Evaluation and System Optimization

These two steps are iterative and utilize systems studies and recognized engineering practices to improve the system characteristics over the initial design.

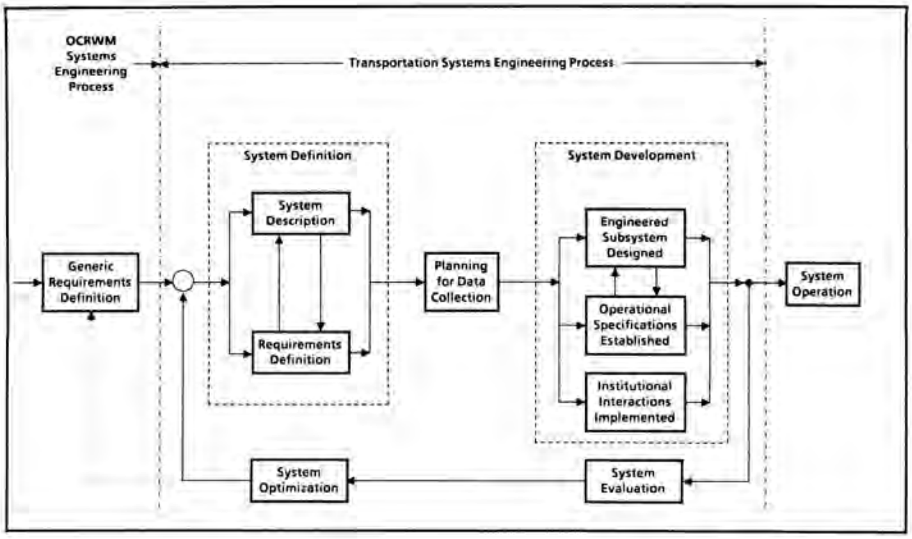

Fig. 3. Transportation Systems Engineering Process.

System Operation

The emphasis on proper output from the systems engineering approach to appropriate decision makers is expected to yield dividends by providing input to the development of decisions that lead to the operation of an efficient and effective system.

CONCLUSION

The paper has presented an overview of the initial systems engineering approach being considered for implementation by the U.S. Department of Energy program directed toward the safe transportation of commercial spent nuclear fuel and high-level waste. The approach emphasizes the systematic and early identification of the necessary technical activities to fulfill the program objectives. As part of the process, approaches to technical prioritization and decision making will guide and support the conduct of the technical work. The activities are being defined in a fashion that should lead to the development of an integrated system supported by documentation that is acceptable to regulatory agencies and the public.

REFERENCES

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