APPLICATIONS OF SYSTEMS ENGINEERING TO CIVILIAN RADIOACTIVE WASTE MANAGEMENT PROGRAM

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ABSTRACT

The Office of Civilian Radioactive Waste Management (OCRWM) was established under the Nuclear Waste Policy Act of 1982 (NWPA) to carry out the development, deployment, and operation of the Federal Waste Management System (FWMS). The program will require a significant systems engineering effort. While the discipline of systems engineering is well documented, there are various approaches to the discipline appropriate in particular applications. This paper discusses the unique features of the waste management problem and the application of systems engineering to meet the requirements of these features. It must be recognized that the program is in a very early stage and that improvements to both the system and the systems engineering process will naturally emerge.

SPECIAL OCRWM SYSTEMS CONSIDERATIONS

The environment in which OCRWM operates has direct relevance for how systems functions are best conducted. This section briefly describes some of these features and their implications for the conduct of systems engineering.

Statutory Specification of Systems Description and Development Process

The NWPA is our national response to the problem of "radioactive waste [which] creates potential risks and requires safe and environmentally acceptable methods of disposal" (Sec. 111(a)(1)). This need for safe and environmentally acceptable disposal of spent fuel and high-level waste (HLW) is the central requirement for the FWMS. Consequently, the NWPA has considerable specificity concerning features of the system including the potential for a monitored retrievable storage (MRS) facility, the schedule for waste acceptance, and the process for site selection. The systems engineering program must reflect these statutory requirements.

Regulatory Performance Requirements on System Elements

Many regulatory requirements are imposed directly on system elements via the licensing process. Since it is the individual components (e.g., transportation, MRS, and repositories) which are responsible for satisfying these requirements during licensing, element-level designers must be given sufficient freedom to meet these requirements.

Long-Term Nature of Repository Program

The active phase of the FWMS including planning, design, licensing, construction, and operation, will be over 50 years. Design requirements based on licensing concerns extend over hundreds of years. This long time frame, coupled with the fact that the best technology for waste isolation will evolve, poses a unique challenge for system design and requirements specification. The need to guide system development using the best current technology capable of operation with high confidence at production rates must be traded against the desire to enable incorporation of superior future technologies.

SYSTEM ENGINEERING FUNCTIONS

Applications of system engineering within OCRWM include: system requirements and description, systems performance analysis, systems engineering studies, and technology assessment.

SYSTEM REQUIREMENTS AND DESCRIPTION

Since all subsequent design and development efforts hinge on the definition of requirements, clear attention to this function is important. Although top-level requirements may remain static, the system development function allocates requirements to elements in an increasingly specific fashion. Requirements definition evolves to progressively lower levels of detail as design progresses. The process of specifying system requirements is carried out with a formal hierarchy of documents. This document hierarchy, as well as some of the technical studies currently underway to clarify system requirements, are described below.

Requirements Documents

The Mission Plan for the Civilian Radioactive Waste Management Program and its amendments provide the program-level documentation of the objectives of the FWMS. Figure 1 identifies the Mission Plan (issued in 1985, with a Draft Mission Plan Amendment issued in January 1987) as the top-level document for a series of controlling documents which specify the requirements that the system and system elements must meet.

Consistent with the Mission Plan, but much more explicit concerning requirements, is the Systems Requirements and Descriptions (SRD) document, which is also subject to control as a baseline OCRWM document. During 1986, the first SRD for the FWMS was issued by the OCRWM. This defines the basic requirements and provides descriptions of the system and its elements. This document will be updated in the future, as required. In addition to the SRD, other requirements on the program appear in the lower-level requirements documents, such as in the Generic Requirements for a Mined Geologic Disposal System (MGDS) document, which support development of the repository and waste package designs.

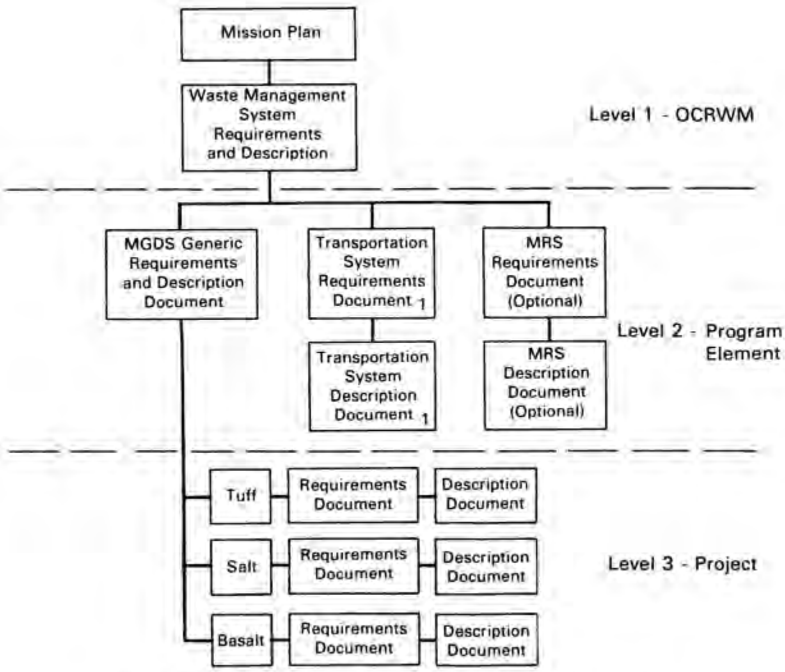

Fig. 1. OCRWM Requirements Document Hierarchy

Uniform Controlled Data Bases

System element designers require data for design and analysis. These data will be provided in the form of standard data bases so that all elements are using the same base data.

A data base on light water reactor (LWR) fuels is under development. This data base will include the mechanical design characteristics and materials of construction for LWR fuel rods and assemblies. In addition, the data base will predict heat generation rates, radioactivity, and photon and neutron emission rates as a function of time for up to 10,000 years after discharge. These characteristics are design driving factors for criticality, thermal, and shielding calculations.

An expanded data base is in preparation covering other wastes that may require mined geologic disposal, including defense and commercial HLWs; high temperature gas-cooled reactor (HTGR) spent fuels; research and test reactor fuels; and miscellaneous wastes such as nonfuel-bearing hardware, and activated metals from reactor decommissioning.

Computer codes commonly in use in areas such as shielding, criticality, and thermal analyses are being assessed against performance measures appropriate to OCRWM activities. Following assessment, selected codes will be verified and standardized for use by the FWMS elements.

Waste Characterization

Requirements for FWMS elements are governed by the characteristics of the waste to be accepted, processed, and emplaced. As illustrated in Figure 2, the input waste stream is diverse, with several types of spent fuel, many types of nonfuel-bearing hardware, plus defense and commercial HLW.

LWR spent fuel will comprise the majority of the waste stream on either a volume or curie basis. Current projections by the Energy Information Administration (EIA) estimate cumulative total discharges of from 80,000 MTU to 123,000 MTU through the year 2020. Although only six different fuel fabricators are shown, many different fuel types exist. Rod array design variations as well as special designs currently exist or are projected to exist. Commercial HTGR fuel is being generated at the Fort St. Vrain reactor.

The miscellaneous wastes category includes nonfuel components as well as other highly radioactive material that the Nuclear Regulatory Commission may determine to require permanent isolation. The Standard Contract for Disposal of Spent Nuclear Fuel and/or High-Level Radioactive Waste (10 CFR Part 961) states that nonfuel components include control spiders, burnable poison rod assemblies, control rod elements, thimble plugs, fission chambers, primary and secondary neutron sources, and boiling water reactor (BWR) channels.

There is a large uncertainty regarding the quantity of defense high-level waste (DHLW) which will be accepted by the FWMS. This includes canisters of vitrified wastes from Savannah River, Hanford, and the Idaho National Engineering Laboratory. Through the year 2020 an estimated 16,000 canisters (or nearly 10,000 m^3) of DHLW are currently believed to require geologic disposal. Additional quantities may be designated for disposal in the future; some estimates are as high as 54,000 canisters.

Approximately 300 canisters of vitrified commercial high-level waste (CHLW) will be produced at the West Valley Demonstration Plant (WVDP) in West Valley, New York. This waste is currently stored as alkaline and acidic wastes in underground tanks. The waste was generated from the reprocessing of commercial and Hanford N-Reactor fuels prior to 1972.

SYSTEM PERFORMANCE ANALYSIS

An important function of any systems engineering program is analysis and assessment of overall system

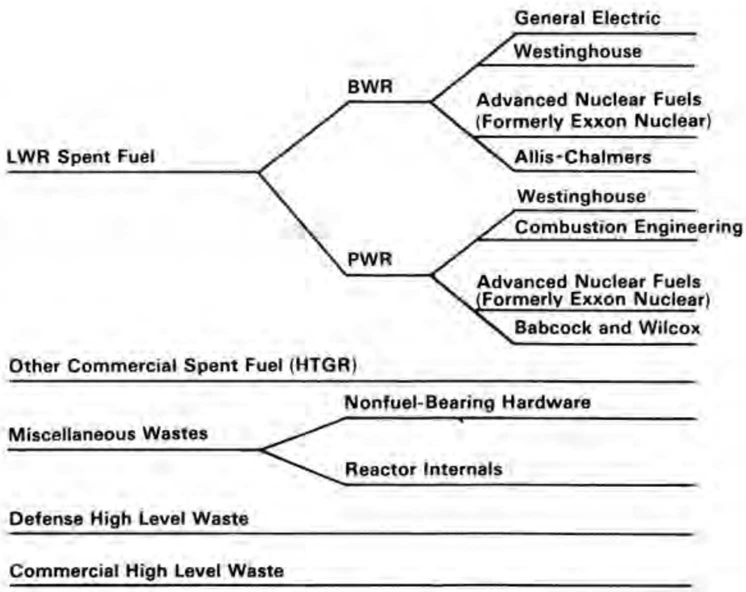

Fig. 2. Waste Stream Composition

performance. The OCRWM Systems Integration Program has the responsibility for analysis and assessment of those aspects of system performance which depend on more than a single system element or which are affected by interactions between system elements. Current and evolving measures of system performance include the following: safety, cost-effectiveness, operations and logistics, reliability, and schedule impacts.

Safety

Although safety requirements apply specifically to particular system elements, there are elements of safety which are influenced by systems considerations. Since the protection of public health and safety are of paramount importance to the program, the degree to which system safety requirements are met will be a clear measure of system performance. The system design should minimize overall risk to the public. A high proportion of the worker dose in the system is expected to occur at interfaces between system elements and can then be most effectively managed in a system framework.

One study has resulted in the development of new analytical tools to predict worker doses as functions of design and operating parameters. These models will be used in conjunction with cost estimates for various potential design and operating changes to evaluate methods to achieve the "As Low As Reasonably Achievable" (ALARA) goal.

Cost-Effectiveness

The cost at which a fixed set of other system requirements are achieved is a commonly used measure in systems engineering, and cost-based assessments play a major role in conducting the systems engineering program. Major cost centers include development and evaluation costs, facilities capital costs, operating costs, and decommissioning costs. Parametric cost models for the various system elements including these costs have been developed. The models can predict total system costs in response to a system configuration change.

As in any multiple-component system development program, it is important that these studies are conducted early so that the requirements for system elements are soundly based and maximize the value of element design activities. For this reason, application of cost assessments to fundamental systems configuration issues have been important.

Future applications of cost analysis for systems engineering will include a new set of analyses required to support evaluation of configuration change proposals under the OCRWM change control process. It is expected that this set of applications will require a cost analysis capability more closely linked with the details of element designs, and integrated to capture various types of cost effects within a single framework.

Operations and Logistics

Another class of system performance measures centers around system operability. System operability is concerned with how the various system elements function on a materials flow and inventory management basis. This measure of performance is necessary to structuring a workable system, and is also the basis of system operating scenarios used to model other performance measures. The analytical tools account for and characterize material flow through the various facilities and processes of the waste management system as a function of process operating rates, acceptance criteria, facility limitations, and waste inventory characteristics. Model outputs include such "figures of merit" as system throughput, total cask-miles, waiting time and inventory distributions at various processing points, and impacts on at-reactor spent fuel inventories.

Major applications of operations and logistics analyses currently in progress include defining waste stream characteristics, studying lag storage requirements, and providing operating scenario bases for studies of occupational dose management and reliability.

Reliability

The need for operating reliability is strongly implicit in the system operating schedules, which call for continued acceptance, transport, and emplacement of several thousand spent fuel assemblies per year for between 20 and 30 years. Establishing a sound technical basis for a specific, quantitative system reliability requirement is one goal of system performance analysis. A reliability goal can be achieved through redundancy, conservative design, and in designing for modular replacement.

Schedule Impacts

An aspect of system performance slightly different from those discussed above is the degree to which a particular system can meet the goal of timely waste acceptance. Recent analyses of program schedules in support of the Mission Plan Amendment suggest that different system configurations offer significantly different performance and that there may be schedule and cost tradeoffs within a particular system configuration.

SYSTEMS ENGINEERING STUDIES

Systems configuration and operations questions which have impacts across more than one element become the focus of systems engineering studies. Several basic system configuration issues which require resolution early in the program have been analyzed. These include a study of spent fuel rod consolidation and the selection of an aggregate system receipt rate.

Rod Consolidation Study

Spent fuel rod consolidation is the process by which fuel rods (originally held within the structure of a fuel assembly) are pulled from the fuel assembly and are inserted, closely packed, into a canister. The volume of the spent fuel is reduced to about one-half the original volume by this process. This reduces the number of waste packages or allows the use of smaller waste packages, reducing the costs for producing, handling, and emplacing the waste packages. Additional transportation savings are realized in a system in which consolidation is performed at an MRS. The study has made a recommendation that the OCRWM should continue to develop consolidation equipment and to proceed with parallel design studies for emplacing consolidated fuel.

Aggregate Receipt Rate

The aggregate receipt rate selected for the FWMS is a tradeoff between smaller capital facilities with longer operational periods or larger capital facilities with shorter lifetimes. The average fuel age (and thus thermal and radiological output) changes significantly as a function of receipt rate.

Almost all aspects of system configuration are affected by the choice of system throughput, including size of plant and plant layout at receiving, handling, and processing facilities; size and design of the transport fleet; underground operations at the repositories; the sizing and/or spacing of waste packages in the repositories; and the scale of repository support systems.

A system study accounting for these efforts is underway and is scheduled for completion prior to initiation of the next phase of design for MRS or repository receiving facilities.

TECHNOLOGY ASSESSMENT

Certain technologies are expected to be used by more than one FWMS element. Systems engineering is providing assessments of these technologies to all element designers. Technologies under review include remote handling and robotics, waste characterization instrumentation, foreign technologies, and nonfuel-bearing hardware (NFBH) treatment alternatives.

Remote Handling and Robotics Technology

Remote handling and robotics technology will be considered because of a number of possible benefits (e.g., improved safety, reduced personnel exposure, and improved facility reliability). A remote systems technology program plan is being developed to: ensure that system element designers have access to appropriate technology in the proper time frame; identify potential common applications for the technology; set priorities for technology acquisition, verification, and testing; and ensure that technology is transferred, acquired, and tested.

Waste Characterization Instrumentation

There may be benefits to some "in-stream" characterization of individual fuel assemblies as part of routine acceptance processing. Since these characterization technologies might conceivably be applied at reactor sites, an MRS, or at repository receiving areas, the systems engineering evaluation of these technologies offers potential economies. Current study areas include assessment of reactivity and burnup measurement instrumentation.

Assessment of Foreign Technology

The operational experience of foreign industrial facilities can provide valuable input into the design of similar equipment and facilities that are being considered for the FWMS. Major industrial facilities are in existence and are being constructed for spent fuel and HLW management in Sweden, France, West Germany, and the United Kingdom. An assessment of facilities in these countries is being planned, with focus on cask handling, transportable storage, cask fabrication, fuel handling, truck/rail transfer, and HLW canister storage.

Studies on Nonfuel-Bearing Hardware Treatment Alternatives

The consolidation of commercial spent fuel creates a separate waste stream, nonfuel-bearing hardware. This material was subjected to high neutron fluxes; consequently, activation products may be present in sufficient quantities to require disposal as high-level radioactive waste.

The alternatives under examination are: shredding, low pressure compaction, supercompaction, and melting. System studies have identified melting and supercompaction as showing significant waste form advantages and cost savings over shredding. These cost savings are experienced largely through volume reduction of the waste (i.e., fewer disposal containers and lower transportation costs).

SUMMARY

This paper has reviewed the unique features of the Federal Waste Management System and discussed the application of the systems engineering discipline to these problems. The current emphasis is on clear definition of systems requirements, a review of various technical options possible within the system and in program planning. Details of specific studies can be found elsewhere in these proceedings.