THE SYSTEMS APPROACH TO SPENT FUEL AND HIGH LEVEL NUCLEAR WASTE MANAGEMENT

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ABSTRACT

This paper will describe the four principal components of the U.S. HLW Management System and their system management interdependence. These four components are the reactors or defense sources, transportation system, interim storage modes, and the final repository.

Residual products from the U.S. defense system and commercial reactors are now temporarily stored with various methods at many sites in the U.S. and in several forms. All U.S. defense HLW is to be processed, solidified, and bound in a solid borosilicate glass matrix. The present U.S. economics of power production and fuel cost dictate that commercial spent nuclear fuel will not be reprocessed at this time. Instead, it will be transported to a deep geologic repository site and disposed of in stable rock formations.

Commercial reactors in the U.S. are operated by 59 independent private and public utilities and fuel cycle management programs are designed to bring maximum benefit to its owners and customers. Reactor variables to be covered in the paper will include fuel contracts, reactor design, burnup, water chemistry management, crane capacity, rail access, pool storage modes, and fuel consolidation. These variables must be integrated with the transportation, interim storage, and repository components.

Transportation capabilities vary widely. Twelve (12) commercial reactor sites lack crane capacity for rail casks and 42 sites lack rail access. Thirty six (36) independent railroad companies service the remaining sites. Truck and rail casks presently licensed have capacities ranging from .5 to 5 tons of spent fuel and 10 to 18 ton capacity casks are being planned.

Interim storage of spent fuel at a Monitored Retrievable Storage (MRS) System is planned by DOE to permit more flexibility in the overall system and to increase transportation efficiency. Consolidation of spent fuel assemblies may also be performed at an MRS to reduce the spent fuel volume.

The repository must accept all of the variables coming from the reactors, MRS, and transportation system. Special tooling and handling for 10 to 20 cask designs, twenty five fuel assembly types, and numerous potential consolidated fuel rod configurations must be designed into the surface facility. Underground storage hole placement varies according to the heat load. Holes are prepared 12 to 24 months before waste receipt at the repository.

The resulting system integration problem generated by the multiple variables of the four components is massive. A system for successfully integrating the U.S. HLW Management Program will be described.

INTRODUCTION

Because of prior successful U.S. experience in the application of systems engineering techniques to large, complex, multi-participant programs the DOE has elected to apply the systems engineering process to the U.S. High Level Nuclear Waste Management Program (HLNWMP).

The U.S. HLNWMP must develop an integrated system which meets the complex national and international needs for safe long term disposal of the solidified residual High Level Wastes (HLW) from defense programs as well as spent fuel from over 100 commercial nuclear power reactors(1). The physical components include the: commercial reactors or defense sources, transportation systems, interim storage modes, and the final geologic repository(s).

In this paper, I will describe features of the systems engineering process as it applies to the U.S. HLNWMP and the importance of the component interdependencies from our corporate participant viewpoint.

THE SYSTEMS ENGINEERING MANAGEMENT PROCESS

Many detailed working documents describe specific applications for the Systems Engineering process, but the brief implementing circular, No. A-109[2], issued by the U.S. Office of Management and Budget in 1976 provides a useful introduction and describes several steps in the process.

Circular No. A-109
Systems Engineering Steps

- o Determine Mission Needs
- o Identify Alternative Designs
- o Perform Trade Off Studies (Capability, Schedule, Cost)
- o Evaluate and Test Alternatives
- o Select a System
- o Proceed with Full Scale Development

The circular also provides useful guidance for organization and management including: "Each agency should preclude management layering and placing reporting procedures and paperwork requirements on program managers and contractors," and "Development of subsystems that are intended to be included in a major system acquisition program will be restricted to less than fully designed hardware (full-scale development)
until the subsystem is identified as a part of a system candidate for full-scale development." Implementation of the process has led to the development of training programs for U.S. Government Program and procurement managers. The "Systems Engineering Management Guide"[3], has useful generic systems engineering information in the introduction which apply equally to the HLW Process: "Although programs differ in underlying requirements, there is a consistent, logical process for best accomplishing system design tasks. Figure 1-1 illustrates the activities of the basic systems engineering process"[3].

Figur^ 1-1[3]
The Systems Engineering Process

"The systems engineering process is iteratively applied. The product element descriptions become more detailed with each application and support the subsequent systems engineering design cycle."[3]

Managers are taught that the systems engineering process is intended to:

- o Direct the program in a logical flow.
- o Assure communications up-down-and across to all system components.
- o Assure that a paper trail for all decisions is available and readily accessible.

Figure 1-1 shows the logic flow steps. The iterative nature of the process is also illustrated. The process of systems engineering is sometimes implemented without due consideration of this iterative feature. When an evaluation of alternatives is made there should be multiple alternatives. some of these potential alternatives will be discovered in the analysis, synthesis, and evaluation processes. When another way to meet the needs is discovered, it should be brought ba k in the process to the start of the requirements, function analysis, or synthesis phase for consideration. This iteration is especially productive early in the design or site evaluation phase because changes can be made early without major cost. As the numbers of management layers in a system build it becomes increasingly difficult to communicate and iterate changes back through the system. A formal change control process is an important aspect of system management, but this change system should be kept relatively open to change during early phases of the program.

There is a strong tendency of engineers to reject ideas "not invented here." Thus a higher tier contractor may find it difficult to accept new ideas from sub-contractors, and thereby pass over the safest or most cost effective solution.

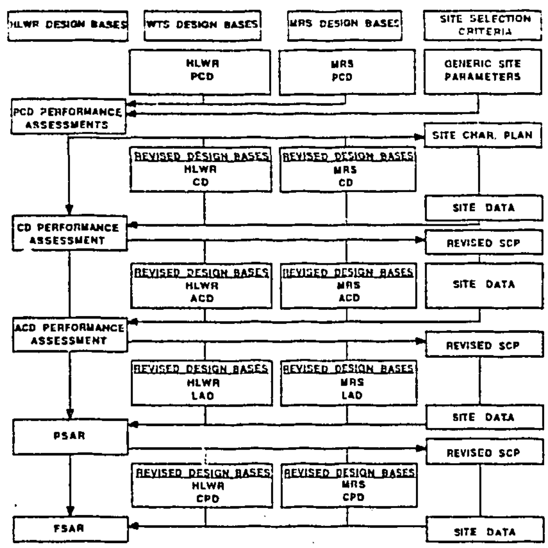
APPLICATION OF SYSTEMS ENGINEERING TO FACILITY DESIGN

We are applying the systems engineering process to our design activity at Bechtel for a number of clients. In the unique application which I will present here, system performance is used as the measure of the success of a design alternative. Figure 2 notes High Level Waste Repository design bases across the top and increasingly more detailed phases of design down the left side. Repository and MRS design bases for the repository are derived from DOE interpretation of numerous regulatory documents including 10CFR60, 10CFR72, 40CFR191, Department of

Transportation acceptable routes and transportation impacts, and State, tribal and local laws. DOE design requirements prepared from these sources along with known or generic site parameters are used to prepare the design bases. At the conceptual design phase, site data may be available, but are not detailed. From the bases a performance driven system design process can be implemented:

- o Prepare Design Bases
- o Prepare Design Alternative
- o Perform Performance Assessment
- o Reevaluate alternatives and design bases and revise design to eliminate unacceptable consequences.

Figure 2
The U.S. High Level Waste Management Program-
Performance Driven
High Level Waste Management Criteria



NOMENCLATURE

HLWR	High Level Waste Repository
WTS	Waste Transportation System
AFR	Away from Reactor Storage
PCD	Pre-Conceptual Design
CD	Conceptual Design
ACD	Advanced Conceptual Design
LAD	License Application Design
CPD	Construction Package Design
SCP	Site Characterization Plan
PSAR	Preliminary Safety Analysis Report
FSAR	Final Safety Analysis Report

This process is described in more detail in recent Bechtel papers(4)(5)(6). The Performance Assessment must be carried through to the nuclear dose consequence level to correctly evaluate the need for another design alternative, i.e.:

PERFORMANCE ASSESSMENT PROCESSES

- o Systems Modeling and Analyses
- o Radioactive Release Analyses
- o Dose Consequences Analyses
- o Regulatory Compliance Assessment

It is vital to the process to use the most realistic value for each site or design parameter, not an assumed conservative value. Use of conservative values for performance analyses will compound conservatism on conservatism and result in an erroneous answer. The use of sensitivity analyses after the initial calculation of performance will be meaningless if the performance result has been made erroneous by conservative assumptions.

The sensitivity analysis process can be briefly described:

- o After performance consequences have been calculated, select a new (higher or lower) value for a single parameter, such as seismic ground motion value.

- o Redo the performance calculation to determine the sensitivity to the variable parameter.

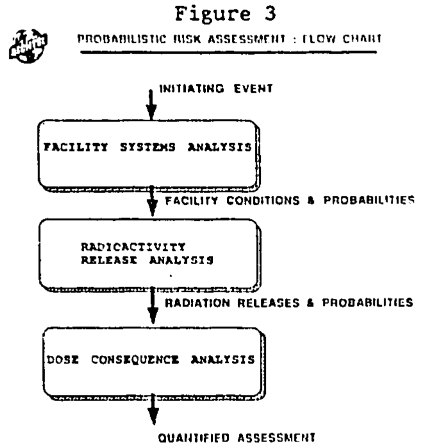
- o Repeat for multiple values of parameters of interest.

- o If the change does not affect the performance unacceptably then the level of accuracy for the parameter need not be determined with great accuracy.

- o Unacceptable consequences resulting from a changed parameter will show the need for either more accurate definition of the parameter or design change to mitigate the fault leading to the consequence.

A Probabilistic Risk Assessment (PRA) Methodology from the U.S. NRC(7) was used for the recent Bechtel analyses (Figure 3). Existing facility designers do not usually incorporate the discipline skills required to perform such analyses as a part of the design team. By integrating the performance assessment discipline into the design team we have significantly facilitated the feedback process both in terms of time and dollars. This closely integrated process also reduces the rejection rate of new ideas because the ideas for corrective action are created within the design team. The result, within the systems engineering process, should be a better or less costly facility.

Figure 3



THE PERFORMANCE BASED SYSTEM APPROACH TO THE HIGH LEVEL NUCLEAR WASTE MANAGEMENT

I will now expand the application of this performance based feedback concept to include other aspects of the overall High Level Waste Management System.

The site characterization portion of the U.S. program is very extensive. Hundreds of scientists and engineers are required for the collection and analysis of data. But, which data are required? The process just described will function equally well to optimize the site characterization process by performing the following steps:

- o Prepare a Site Characterization Plan.
- o Implement the conceptual phase and collect data.
- o Use the site data along with the conceptual design in a PRA performance analysis to determine nuclear dose consequence of the selected design alternate on the selected site.
- o Perform multiple sensitivity analyses for key site data values to determine how significantly performance is affected by uncertainties in specific site data parameters.
- o Revise the Site Characterization Plan to focus on the collection of the sensitive site parameters during the succeeding phase of Site Characterization and eliminate data collection for parameters where the existing level of detail are adequate to demonstrate the system performance.

The overall High Level Waste Management System is complicated in the U.S. by a changing environment outside the system. There is a technical, a political, and a social environment. The later two are affected by U.S. and World political decisions, policies, and incumbents and by the energy supply and economics. We will not try to improve on or predict the political or social environments in this paper. We will however consider the technical environment in which the overall system must perform.

With over 100 commercial nuclear power stations on line and a 40 year inventory of defense HLW byproducts to manage and dispose, the U.S. has, by far, the world's largest total quantity of defense high level waste and spent fuel. These residual wastes are now temporarily stored with various methods, in several forms, at many sites in the U.S. All defense HLW is to be processed, solidified, bound in a solid borosilicate glass matrix and transported directly to the repository when it is available. The variables in the commercial spent fuel program present a particularly complex system management problem which must be resolved. These variables include a staggering list of interdependent items only some of which are shown in Table I[6].

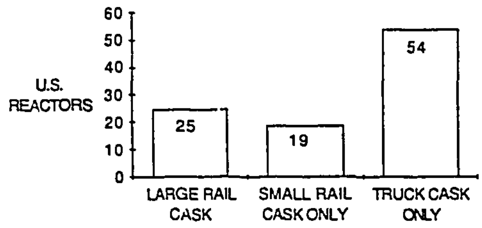
Table I[6]
Spent Fuel Status, Transport, and Storage Interdependent Variables

- o Spent Fuel Assembly Design Configuration
- o Consolidated Fuel Configuration
- o Fuel Burnup History
- o Reactor Water Chemistry History
- o Spent Fuel Time Out of Reactor
- o Known Damage to Fuel
- o Reactor Pool Storage Capacity
- o At Reactor Dry Storage Configuration and Capacity
- o Rail and Utility Owned Road Access and Capacity at Each Reactor
- o Interfacing Public Use Railroad (if any) Load Capacity, Routing, and Hazardous Waste Transport Policy from Reactors to MRS or Repository
- o Interfacing Public Road Capacity, Routing, and Local and State Hazardous Transport Policy from Reactor to MRS or Repository
- o MRS Handling Capability as Designed, Built, and Licensed Under 10CFR72
- o Railroad Capacity, Routing, and Hazardous Waste Transport Policy from MRS to Repository
- o Repository Handling Capability as Designed, Built, and Licensed under 10CFR60.

Commercial reactors in the U.S. are operated by 59 independent private and public utilities. Each utility plans and implements a fuel management program developed to bring maximum benefit to its owners and customers. Since new fuel cost and contract details as well as reactor designs differ widely, a single optimum system for fuel management does not exist. Some utility owners are working toward much greater total burnup levels than the 30,000 MWd/MTU for BWR's and 43,000 MWd/MTU for PWR's considered as maximum over the past decades. Higher burnup fuels will require higher enrichment and have greater heat and radiation output levels after removal from the reactors. The amount of CRUD (Chalk River Unidentified Deposits) and the fraction of fuel with pinholes or other damage can be expected to decrease as the utility's water chemistry quality improves and increase as the burnup level increases. Reactor crane capacities for loading new fuel into pools or removing spent fuel in casks from the pools also range widely, from as low as 24 tons capacity to as great as 185 tons capacity[8]. New information program contracts presently underway in the U.S. will identify and document in more detail actual reactor system and fuel inventory differences so the waste source component can be integrated closely with the other three physical components; transportation, interim storage, and the repository.

Transportation is the link which ties all four physical components together. Twelve commercial reactor sites do not have the crane capacity to handle present rail casks and are therefore presently constrained to offsite transfer in truck casks. Truck casks have currently been licensed for a maximum capacity of 1 1/2 tons of spent fuel (TN-8L). Forty-two sites do not currently have rail access. In those cases the system management trade offs may consider placement of truck trailers and/or casks on offsite rail cars or even the dry transfer of spent fuel from low capacity truck casks to rail casks off site. Present rail casks licensed in the U.S. are limited to 5 tons capacity of spent fuel (NLI 10/24), but licensing applications are pending for a 10 ton capacity cask (Castor V) and commercial consideration in being given to 150 ton casks for shipment from an MRS. Nineteen of the reactors with rail access have crane capacity for only the smaller 3 1/2 ton capacity rail cask (IF-300). Some U.S. rail right-of-ways would require up grading to handle 150 ton overweight rail casks now being considered. Waste received at the repository may arrive by truck or rail in a range from 100% truck to 100% rail. Spent fuel time out of the reactor may range from 5 years to 40 years. Western reactor spent fuel is planned to be campaigned directly to the repository without prior processing at an MRS. As many as 25 spent fuel assembly designs from HTGR, PWR, and BWR reactors may eventually be in the inventory, and reactor burnup may range over several hundred percent. Cask designs licensed for truck or rail shipment may total 10 or more. The numerous system interfaces between reactors owned by the 59 independent utilities and the interfacing 36 independent railroads will require sophisticated systems engineering performance assessment to achieve an optimized system.

Figure 4
U.S. REACTOR CASK HANDLING CAPABILITY [8]



Subsystem variables are also generated by utility interim storage methods. Pool storage capacity has been enhanced by reracking to denser configurations, by in pool wet consolidation, by redesign of the pool storage racks to reduce their weight and allow a greater proportion of the maximum pool floor load for spent fuel, by the consideration of reduced water weight on the pool floor by insertion of light weight water displacement fillers near the pool bottom, and by reduced water depth and weight by the denser horizontal storage of spent fuel on the pool floor and consequent reduction of pool water depth and weight. Another utility technique to permit greater on-site spent fuel storage capacity has been the purchase of casks licensed for on-site dry storage.

Equipment and tools in the repository and MRS waste handling buildings for cask handling, opening, unloading, fuel consolidation, placement in final storage containers, and final placement underground must be suitable for all of these shipments; cask, and fuel form modes. Since remotely operated tools and equipment in hot cells will be changed to match the receipt characteristics, it is desirable, for efficient operations, to "campaign" a maximum quantity of similar spent fuel through the repository facility before changing to a new configuration. The maximum on site storage capacity of three months provides for limited flexibility in processing campaigns unless utility cooperation can be agreed to in providing maximum advance notification of the waste configurations to be received. Underground development in the repository to achieve optimum utilization of space for the thermal limits imposed will require that emplacement panel, room, and bore hole spacings be planned and implemented several years before waste receipt. These repository system constraints require direct coordination and cooperation between the utility or interim storage system shippers and the repository developers and operators.

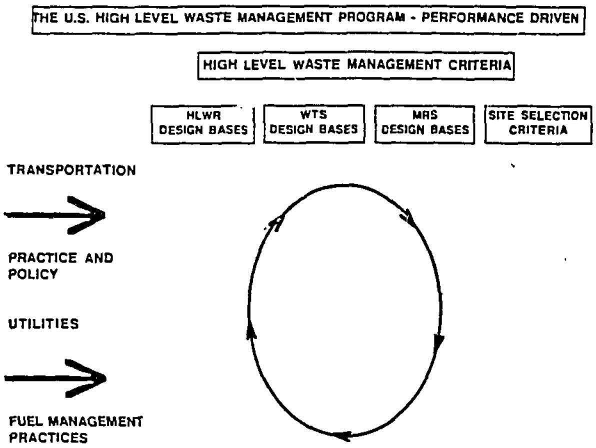
The overall U.S. Waste Management System will be approved for construction by the U.S. Nuclear Regulatory Commission based on its performance measured against EPA and NRC requirements. To expedite the parallel development of the subsystems, requirements have been allocated early in the system design process. However, these allocations of performance to the subsystems should be periodically reevaluated using the iterative system engineering technique applied above to the repository design. The lack of a positive control over some of these variables should not be a reason to omit them from the system analyses. If a significant cost or safety benefit can be attained from one of the variables, several courses may be open for action:

- o Trade off the cost of changing or controlling the utility or transportation variable against the potential benefit.
- o Revise the allocated requirement and reassess the performance consequence.
- o Revise the MRS or Repository Design to meet performance requirements.

CONCLUSION

Present U.S. waste management technical program efforts are directed toward defining these complex system interfaces, disseminating the details of the needed system integration among the four system components' operators and designers, and implementing the cooperative agreements including public interaction that can make this complex system function efficiently. This system integration process is an iterative one. The optimization of all the subsystems in any system will not equate to the optimization of the total system. If the overall system management controls are permited to accept alternative solution evaluations, the technical result will approach closer to an optimum. This iterative process is simply illustrated in Figure 5. Repository site selection criteria and deign bases are controlled by the EPA criteria, 40CFR191; the NWPA of 1982; and the NRC Regulation procedure of 10CFR60 for the repository, and 10CFR72 for the MRS; plus others. There are, however, significant latitudes permitted in the design bases developed from these laws. Utility and transportation components operate under other codes including 10CFR50, 10CFR71, 10CFR20, 49CFR173, and 49CFR178. These too, permit some implementing latitude. As site selection and characterization proceeds and MRS and repository designs become better defined, it is necessary that the site data and design configuration be assessed at each design level for public safety and environmental protection.

Figure 5



Such early and repeated performance assessments will not only permit improvements of the designs, but will also provide recommendation for changes or standardization of utility fuel management practices, cask design, transportation practices, and higher level system requirements which will improve the overall high level waste management performance. When it can be shown that overall final disposal safety can be improved by utility or transportation actions, storage or transportation cost allowances may be allocated to utilities or transportation companies to make the changes. This close examination of the overall system performance and corrective feedback between system components will be necessary to provide an optimum and an operable system.

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