APPLICATIONS OF SYSTEMS ENGINEERING IN THE DEVELOPMENT OF THE FEDERAL WASTE MANAGEMENT SYSTEM

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ABSTRACT

The Department of Energy's (DOE) Office of Civilian Radioactive Waste Management (OCRWM) has as its mission the permanent disposal of spent nuclear fuel and high-level waste through a program and a system design which will protect the health and safety of the public and the quality of the environment, as provided in the Nuclear Waste Policy Act, as amended. OCRWM is applying systems engineering to this program mission. The results of the systems engineering approach identify and define the programmatic functions and the physical system functions. This systems engineering approach is the central feature of the Management Systems Improvement Strategy (MSIS). The systems engineering process is used by OCRWM to derive the requirements which must be satisfied in the design for a unique, first-of-its-kind, Nuclear Waste Management System (NWMS). This paper describes OCRWM's systems engineering process for transforming the program mission into physical system functions, and then into organized sets of specific requirements of the physical system configuration and design to insure the successful implementation of the NWMS.

INTRODUCTION

In November 1989, the Secretary of Energy announced several initiatives in fulfillment of the program mission of OCRWM. Among these initiatives are the development of options for ensuring the timely acceptance of spent fuel at an Monitored Recoverable Storage (MRS) facility; the initiation of comprehensive scientific investigations of the candidate site for a geologic repository; and the establishment of improved management structure and procedures.

The disposal of spent nuclear fuel and high-level nuclear waste is a key factor in the maintenance and improvement of the nuclear power industry. To meet these goals, OCRWM plans specify a capability to accept, transport, and store waste in an MRS by 1998, and to commence emplacement of waste in a geologic repository in 2010.

Management System Improvement Strategy

The MSIS serves to focus OCRWM attention on, and gives emphasis to, the following general guiding principles:

- Focus program activities on accomplishing the mission.
- Maintain standards of excellence as a fundamental policy.
- Establish and maintain accountability for the control of cost, schedule, and performance.
- Ensure that all quality assurance requirements are met.
- Establish and implement strict environmental, safety, and health compliance.
- Assign equal importance to institutional and technical activities.
- Coordinate technical, institutional, and management activities.

The MSIS recognizes that OCRWM needs to perform three functions: OCRWM must perform programmatic functions, management functions, and physical system functions. Consequently, OCRWM plans identify and integrate physical system functions, programmatic functions, and management functions by the systems engineering approach.

Systems Engineering Approach

OCRWM is employing the systems engineering approach as its program management methodology. Systems engineering converts the programmatic functions and the physical system functions into system requirements. Conceptual designs which satisfy these system requirements are created. These conceptual designs are then evaluated to narrow the set down to a few from which a selection decision can be made. Upon design selection, work will proceed into preliminary and final design stages.

The final design is then implemented, constructed, and placed into operation. The work activities of each phase are defined and specified within the System Engineering Management Plan (SEMP). The systems engineering approach uses a multi-phased process, called Functions/Requirements/Analysis, or F/R/A. The first phase, functional analysis, identifies the physical system functions and the programmatic functions. These functions are then integrated with the management functions as the second phase of this activity. The third phase, requirements analysis, identifies specific requirements which describe how the functions must be performed. These functions must be related to specific requirements from literally hundreds of programmatic, regulatory, and technical source documents.

Following the third phase, physical system and programmatic functions, together with their associated requirements, are used as the basis for preparing integrated work packages.

The systems engineering approach combines and applies the management functions --planning, organizing, acquiring necessary resources, directing, and controlling--to implement both programmatic and physical system elements. Further, the SEMP specifies the use of the system engineering process to translate the project objectives and constraints into the system architecture and finally into the system design solution.

Systems Engineering Process

OCRWM employs the systems engineering process as a series of defined steps for transforming the program mission into functions, and then into organized sets of specific requirements. The stages of the process include mission identification, functional analysis, functional allocation, design synthesis, system definition, evaluation/optimization using models, and system construction, testing, and demonstration.

Systems engineering activities include establishing the criteria, concepts, scope, and division of responsibilities, and preparing systems engineering management plans, and a work breakdown structure.

Functional analysis activities include developing the needed functions, determining the performance levels, and preparing system architectural solutions and time lines. Functional allocation includes developing subsystems requirements, identifying and describing interfaces and support systems, as well as optimizing the system architecture.

The functional analysis approach is employs teams of experts, together with the task team comprising the programmatic functional analysis, physical system functional analysis, and regulatory research and analysis, produce the functions and the requirements. These requirements are processed by the data management team for building and updating the system functions and requirements database. The functional analysis approach provides the basis for traceability in the selection of alternatives, as well as accuracy, in the definition of the optimum or best set of alternative design solutions. Traceability and accuracy are important verification steps in the system engineering process. Traceability from the top-most functions downward to the lowest practicable level, and accuracy of requirements allocations, are particularly important is assuring that the systems engineers involved in the functional analysis approach have access to, and the opportunity for complete reviews of, requirements documents impacting both the program and the physical system and their respective constraints.

The physical system functional analysis employs the same steps in the process used for the program functional analysis. The Physical System Functional Analysis Approach is depicted in Fig. 1. The functional analysis of the physical system is accomplished by decomposition of the functions (by the technical experts), specifying and allocating requirements (by the regulatory experts), selecting the system architecture (by the OCRWM management), and preparing the functional analysis reports.

Nuclear Waste Management System

This section of this paper describes the application of system engineering to the mission statement of the Nuclear Waste Management System (NWMS), the functional analysis of the mission, the identification of the physical system functions, and the functional analysis of the physical system, and the establishment of the physical system architecture and design.

A comprehensive analysis is underway to identify all the functions that must be performed by the physical system and each of its elements to accomplish their respective parts of the mission.

The physical system consists of four elements that will perform the functions necessary for achieving the overall mission -- Manage Waste Disposal. These are: accept waste, transport waste, store waste, and dispose waste.

The lower level decomposition of these functions describes the detailed functions involved with accepting, transporting, storing, and disposing of waste. These detailed functions are discussed below.

Accept waste. The waste management system will include an element for waste acceptance from its owners and generators. The waste to be accepted will include both spent fuel from commercial reactors and high-level waste; these wastes differ significantly in their physical form, dimensions, and heat and radiation characteristics. When the waste is accepted, it will be necessary to perform certain actions to prepare the waste for transport, storage, or disposal.

Transport waste. The transportation element must transport spent nuclear fuel and high-level radioactive waste to a waste management facility and, as necessary, between waste management facilities. Transporting wastes

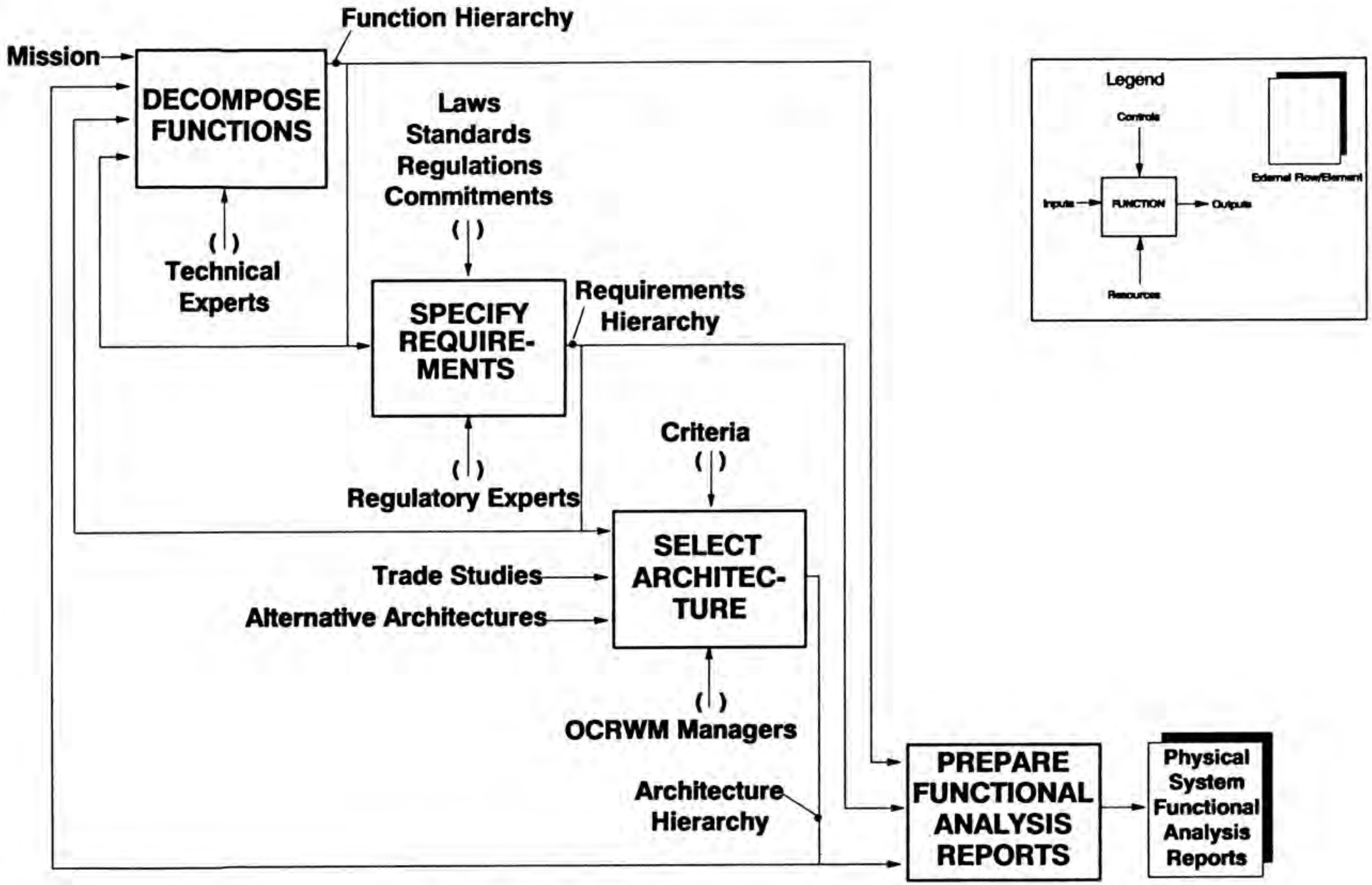

Fig. 1. Physical System Functional Analysis Approach.

includes the requisite packaging, inspection, loading, and receiving activities.

Store waste. The storage element must be capable of temporarily storing spent nuclear fuel before permanent disposal in a geologic repository. This function will be performed by the MRS facility, although lag-storage capabilities will be required at the repository to accommodate variations in waste shipping, preparation, or emplacement rates.

Dispose waste. The disposal element must dispose of all spent nuclear fuel and high-level radioactive waste in a deep geologic repository, maintaining the option for a specified time to retrieve all emplaced waste.

These functions can be depicted on a Function Tree Description, as shown in Fig. 2.

As more detailed functions are identified for these elements, they will be broken down in most cases to five levels. As part of these activities, the system requirements, including regulatory and performance requirements, are being identified. When completed for the total system and system-element levels, appropriate reviews will be conducted of the current, program management documents, such as the Program Management System (PMS) Document and the System Engineering Management Plan (SEMP). The functional baselined requirements for the NWMS are being published in several volumes, referred to as Waste Management System Requirements Documents, or WMSRs.

The physical system architecture description of the NWMS is depicted in Fig. 3, entitled Physical System Architecture Description. The NWMS system is composed of several major components. In turn, each of the major components under the OCRWM Waste Management System are subdivided into components associated with the major component. This architecture depicts the Waste Acceptance System as comprising the Waste Transportation System, the MRS Facility, and the Repository.

As changes and updates are needed in the program level management documents, and in the system-level requirements documents, these will be processed, reviewed, and accepted for release as revisions in accordance with the program change control procedure that is part of the overall OCRWM Configuration Management System.

Programmatic Functions

The programmatic functional analysis is the systematic approach to the identification of all of the essential functions that must be performed, and the requirements that must be met in performance of those functions in the process of establishing physical elements of the waste management system. Primary programmatic functions include the following:

- Provide quality assurance -- perform all those planned and systematic actions necessary to provide adequate confidence that a structure, system, or component will perform satisfactorily in service.
- Site -- perform all the actions necessary to identify, locate, and qualify sites for waste-management facilities, including the determination of site suitability for a geologic repository.
- Perform systems engineering -- translate a defined mission into a set of balanced requirements for a system that will fulfill that mission.
- Provide regulatory compliance -- ensure that all applicable regulations are satisfied as required to demonstrate regulatory compliance during NRC licensing.
- Design -- perform all the engineering activities necessary to develop designs for each of the physical-system elements. Design immediately follows the establishment of requirements and includes the activities necessary to translate the requirements into drawings, specifications, etc., as required for the procurement and construction of the required waste-management facilities, equipment, and services.
- Test and evaluate -- perform all the activities needed to verify that all applicable system requirements are fully satisfied.
- Construct the physical facilities and equipment needed to provide the physical-system functions, including the MRS facility and the geologic repository.
- Operate.
- Decommission.
- Develop and maintain external relations.
- Provide long-range strategic and contingency planning.
- Integrate international programs.
- Provide contract business management.
- Provide administrative services.
- Provide program cost and schedule controls.

This analysis provides a through understanding of the programmatic functions and requirements, including identification of the interrelationships between functions that must be integrated and controlled through the development of management processes and procedures. The results of the analysis will provide a full set of functions, requirements, and management policies, processes, and procedures that will be described in the hierarchy of management docu-

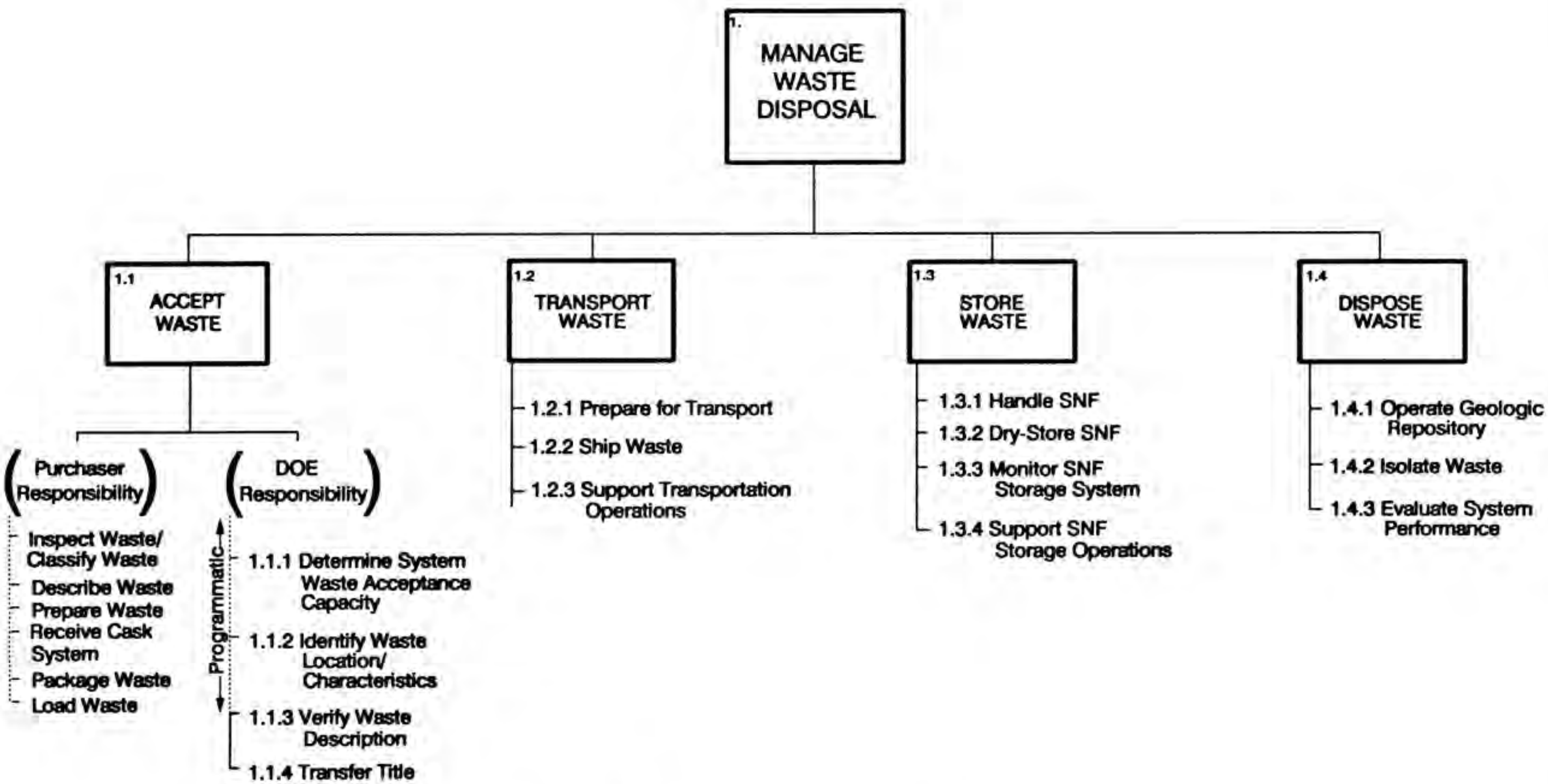

Fig. 2. Physical System Architecture Description.

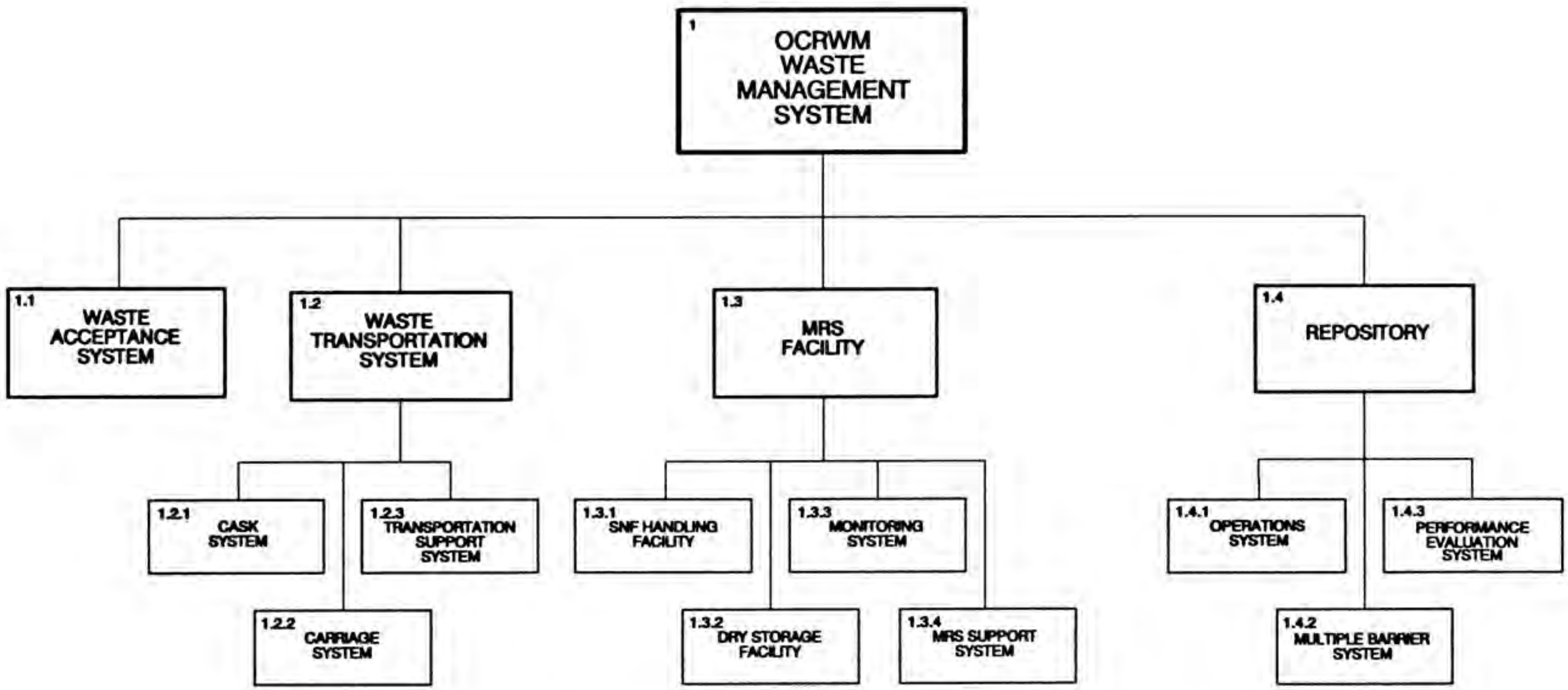

Fig. 3. Physical System Architecture Description.

ments used by the OCRWM Program to guide the development of the physical system.

Management Functions

Another dimension must be added to the framework to incorporate the classical management functions. The classical management functions are applicable to all program activities and can be briefly described as follows:

- Planning. Mission-driven planning is done by managers at all levels to carry out specific activities. Corresponding schedules are developed for each activity, ensuring integration with related activities.
- Organizing. Organization is the process of deciding, for each activity, who is best suited for the work, designating who is responsible for performing each activity, and delegating appropriate authority.
- Resource acquisition. Resource acquisition is the process of identifying and providing the resources necessary to perform planned activities, including staff, funds, contract support, facilities, space, equipment, services, and supplies.
- Directing. Directing is the process of approving work activities and work plans and authorizing expenditures and resources in accordance with those plans.
- Controlling. Controlling is the process of measuring progress in the activities being performed, conducting evaluations to ensure adherence to the approved plan, and modifying the direction given as necessary to respond to changing conditions.

Requirements Research

Technical and program specialists are currently reviewing source documents --laws, regulations, DOE orders, etc., -- to identify requirements and associate them with specific physical system and programmatic functions. Additionally, each requirement from the source document is loaded into a computer database along with identifiers that link the requirement to a specific physical system and/or programmatic function. All of the requirements are then sorted into appropriate work packages.

Systems Database

In support of systems engineering activities, an automated data base is being developed to organize and compile the large quantity of information in a form convenient for program participants to produce and use program documents. The data base will provide an interactive system to accumulate and update program requirements and relate them to system functions as well as providing a cost savings by minimizing the record keeping and clerical retrieval activities.

The data base will provide for enhanced configuration management of data, providing a single source for the latest information, providing timely feedback to users through query capability, and will facilitate evaluation of impacts or risks of proposed changes to requirements. A two-phase approach is being used for the data base. The first phase has provided a usable system, utilizing the existing program computer network and software. The second phase will provide improved database management capabilities, networking of users, and improved matrix traceability.

SUMMARY AND CONCLUSIONS

The MSIS is founded on the efficient and effective use of systems engineering. This approach involves three elements: the identification of essential functions, and processes; the defensible and traceable identification and implementation of requirements, and the integration of physical-system, programmatic, and management functions into a structured and comprehensive system for accomplishing work.

The systems engineering approach is producing valid, defensible results. Systems engineering processes are aiding OCRWM in both effective system engineering management as well as furnishing a framework for integration and communication. The systems engineering approach, as the central feature of the MSIS, will ensure the successful accomplishment of the many activities necessary for OCRWM to complete the NWMS as required by the NWPA, as amended.