SELECTION OF DISPOSAL METHOD FOR NUCLEAR SPENT FUEL:

A PLAN FOR THE APPLICATION OF THE SYSTEMS ENGINEERING PROCESS

by

Bryan B. Min

Project and Report submitted to the Faculty of the

Virginia Polytechnic Institute and State University

in partial fulfillment of the requirements for the degree of

MASTERS OF SCIENCE

IN

SYSTEMS ENGINEERING

APPROVED:

Dean Benjamin Blanchard, Chair

Kenneth Harmon

Mario Cardullo

December 9, 1996

Blacksburg, Virginia

Key words: Nuclear Spent Fuel, Disposal Alternatives, NSF, Radioactive Waste Disposal

SELECTION OF DISPOSAL METHOD FOR NUCLEAR SPENT FUEL:

A PLAN FOR THE APPLICATION OF THE SYSTEMS ENGINEERING PROCESS

by

Bryan B. Min

Dean Benjamin Blanchard, Chairman
Systems Engineering

(Abstract)

Over the past decade, U.S. has been trying to identify a new means to provide the nuclear power industry with a method to permanently dispose of nuclear spent fuel. Most of the existing technologies such as storage pools and concrete vaults do not adequately meet the criteria for permanent storage. Many of these technologies, which will be introduced and reviewed for this project, have been used by the nuclear industry for many years. However, to date, no technology has been selected for permanent use.

This project will focus on reviewing six different disposal alternatives available for applying the systems engineering process. Each alternative will be analyzed qualitatively and quantitatively, with an in-depth review of a new technology known as the Multi Purpose Canister (MPC), which is still under development.

More specifically, this project will layout the basis for applying the systems engineering process in the future. The scope of this project is:

- Introduction to the build-up of nuclear spent fuel,
- Define the problem,
- Define the criteria established by DOE and NRC in selecting a disposal technology,

- Provide the basic guidelines for the application of systems engineering process using the MPC as the prototype,
- Lastly, demonstrate the power of systems thinking and how this process, when applied to the development of any system, can save valuable resources, both in immediate future as well as long-term.

Acknowledgment

To professors Ben Blanchard, Mario Cardullo, and Ken Harmon for your constant encouragement to complete this project and the degree.

To my wife and son, Julie and Brandon, for your unceasing patience, sacrifice, and support.

I am forever grateful to you all.

1.0. Background.. 1

2.0. Empathy for the Systems Engineering Process.. 3

3.0. Understanding the Problem.. 4
3.1. Characteristics of Nuclear Spent Fuel
3.2. Public Concern with Spent Fuel Radioactivity
3.3. Spent Fuel Inventory Projection

4.0. Definition of Need.. 7
4.1. Strategic Plan
4.2. Objective
4.3. Goals
4.3.1. Cost Goal
4.3.2. Time Goal
4.3.3. Safety Goal
4.3.4. Other Goals

5.0 Introduction to the Alternatives.. 12
5.1. Viable Alternatives
5.1.1. Wet Options
5.1.2. Dry Options
5.2. In-depth Review of Two Alternatives: Storage Pool and Reprocessing Tech.
5.2.1. Storage Pools
5.2.2. Reprocessing Technology
5.3. Quantitative Summary of Alternatives
5.4. Qualitative Analysis of Alternatives
5.4.1. Site Specific Conditions and Limitations
5.4.2. Fuel Type Limitations
5.4.3. Advantages and Disadvantages for Each Alternative
5.4.3.1 Wet Storage Options
5.4.3.2 Dry Options
5.5. Conclusion: Dry Method vs. Wet Method
5.6. Best Alternative

6.0. System Operational Requirement.. 23
6.1. Mission Definition
6.2. Use Requirement
6.3. Physical Parameters
6.4. Operational Deployment

6.5. Operational Life Cycle

7.0. Maintenance Requirements 27
7.1. Levels of Maintenance and Responsibility
7.1.1. Organizational
7.1.2. Depot
7.1.3. Supplier
7.2. System Level Logistic Support Requirement
7.2.1. Training
7.2.2. Maintenance Task
7.2.3. Task Frequency
7.2.4. Spares
7.2.5. Test Equipment

8.0. Functional Analysis 31
8.1. Operational Analysis
8.2. Maintenance Analysis

9.0. Resources Allocation 34
9.1. Reliability
9.2. Critical Components
9.3. Maintainability
9.4. Availability
9.5. Cost

10.0. Test and Evaluation 37
10.1. Type I Testing
10.2. Type II Testing
10.2.1. Performance Testing
10.2.2. Environmental Testing
10.2.3. Structural Testing
10.2.4. Reliability Qualification
10.2.5. Maintainability Testing
10.2.6. Technical Data Verification
10.2.7. Support Equipment Compatibility Test
10.3. Type III and IV Testing

11.0. Probability Risk Analysis 40
11.1. Effects from Temperature
11.2. Effects from Humidity
11.3. Effects from Wind Conditions
11.4. Summary

12.0. Engineering Management Plan 44

13.0. Conclusion 44

References 46

List of Figures

Figure 1: Nuclear Spent Fuel Inventory..5

Figure 2: Reactor Spent Fuel Storage Pool Locations within the U.S.............................6

Figure 3: Total System Cost Diagram..10

Figure 4: Fission Product Activity versus Time...14

Figure 5: Decay Heat versus Time..14

Figure 6: Storage Process Overview...23

Figure 7: Top Level Functional Diagram...31

Figure 8: First Level - Operational Functional Flow Diagram......................................32

Figure 9: Second Level - Operational Functional Flow Diagram..................................32

Figure10: First Level - Maintenance Functional Flow Diagram...................................33

Figure11: Canister Design..34

1. Background

"Thirty-Four stainless steel canisters rest in a drab concrete bunker symbolizing one of nuclear power industry's biggest and potentially deadliest problems. Stored inside the canister at Duke Power Company's Oconee Nuclear Plant is nuclear refuse that will remain deadly with radiation for more than 10,000 years." [1] As dramatic as this problem may seem, it did not develop over-night, but has been in the making since the U.S. decided to use nuclear power for generating electricity. One of the main advantages of using this fission process for generating power is that unlike co-generating plants, it does not directly pollute the environment, because there is no COx released to the atmosphere. However, the main disadvantage is that over the life of the power plant, the fuel used to generate power eventually reaches end of life, and becomes what is known as nuclear spent fuel (NSF) - a high level radioactive waste.

Over the past 40 years, this waste has been stored mainly in underwater storage pools. Virtually all existing nuclear power plants and research reactor installations have a NSF pool where the fuel is allowed to "cool". NSF pools use many gallons of water for heat removal and radiation shielding. But with limited pool space, not to mention the aging, there are concerns about what U.S. must do to safely store this high level radioactive waste.

Without identifying a new means of storage, the only viable alternatives are to either terminate the use of "nuclear power, which provides twenty percent of the electricity used in the U.S."[2] or learn to live with uncontained and uncontrolled high level radioactive waste in our backyard. Both of these alternatives are at extreme ends of the scale. Nuclear power is still an integral part of U.S.'s energy resource, hence to do without it would mean a greater burden on the Americans, since we must rely more heavily on petroleum imports from the volatile Middle East, as well as the coal industry. In contrast, the other extreme would be readily unacceptable to the public, who already has no tolerance to deal with safety issues associated with nuclear power. There is no doubt that such world renown accidents as Chernobyl have only further aggravated the negative perception towards nuclear power and waste.

---

[1] Lost in Nuclear Wasteland, Albuquerque Journal, July 2, 1995

[2] World Nuclear Outlook, Energy Information Administration Report, Section 2, December 1994.

A statement made by the Governor of Nevada at a High-Level Waste Convention, held in Las Vegas, summarizes this fear and concerns about using the proposed Yucca Mountains in Nevada or any other site in the U.S. for permanent disposal site. In his speech, the Governor stated that, "the Department of Energy is a maliciously incompetent entity (with "Keystone Kop scientists") that is not to be trusted, he asserted, and the state of Nevada will continue to resist—with firmer resolve than ever—any attempt to site an High Level Waste repository at Yucca Mountain."[3]

This project will focus on reviewing six different disposal technology alternatives available for permanent nuclear spent fuel disposal. Each alternative will be analyzed qualitatively and quantitatively, with an in-depth review of a new technology known as the Multi Purpose Canister (MPC), which is still under development. This study will lend itself to applying the systems engineering process to eventually select, design, implement and deploy the best storage alternative.

More specifically, this project will layout the basis for applying the systems engineering process in the future. The scope of this project is:

- Introduction to the build-up of nuclear spent fuel,
- Define the problem,
- Define the main criteria established by DOE and NRC in selecting a disposal technology,
- Provide the basic guidelines for the application of systems engineering process using the MPC as the prototype
- Lastly, demonstrate the power of systems thinking and how this process, when applied to the development of any system, can save valuable resources, both in immediate future as well as long-term.

---

[3] Nuclear News, American Nuclear Society, Section: Meetings; pg. 48, July 1995.

2. Empathy for the Systems Engineering Process

What is the path forward? What can be done about the waste produced from the existing and soon to be decommissioned nuclear plants, while also addressing public's concerns regarding nuclear waste? The answer to these questions are not simple. Rather, the right solution is very complex, because in attaining the answer, the scientists and managers in DOE and NRC must deal not only with the engineering and technological issues associated with developing a new technology for storage, but also other inter-linked factors such as economics, ecology, politics, and public perception must be included in finding the optimal solution. Each of these factors are very sensitive, therefore, the right balance between all the factors need to be achieved, in selecting the disposal method of choice. To that end, the researchers and project managers must analyze all criteria such as cost, risks, and hazards, both perceived and real, associated with the new system of nuclear waste disposal. This includes the long-term effect the system will have on the environment.

The complexity of this problem in developing a disposal method lends itself to using the systems engineering process. The difficulty in trying to enact a technology without fully comprehending the variables involved in the system will lead to a decision that is based on perceived quality or sufficiency, and one that is less than optimal. This problem will arise because "every development problem involves complex S-T-E-P systems, those possessing Social, Technological, Economic, and Political elements and implication."[4] The application of systems engineering will ensure that all variables and forces that influence the behavior of this problem.

---

[4] Donald R. Drew and Cheng-Horng Hsieh, A systems View of Development Methodology of Systems Engineering and Management, Cheng Yang Publishing Co., 1984.

3. Understanding the Problem

In the process of identifying the solution, one must first understand, in-depth, the problem at hand.

3.1. Characteristics of Nuclear Spent Fuel

Understanding the property of nuclear spent fuel will help understand the importance of the various design characteristics of radioactive waste storage methods.

Uranium-235 is the fuel that is used in a nuclear power plant. U-235 fuel releases energy in the form of heat during a fission process. It is this heat that is harnessed and used to generate steam which in turn works on the turbines to generate electricity. The fission fragments accumulate within the fuel and gradually reduce the efficiency of the chain reaction. The useless by-product is known as nuclear spent fuel.

Although this fuel is spent, it is far from benign. Rather, these by-products are still very hazardous, because radioactive decay is still occurring within these discharged fuel assemblies. It is these hazardous characteristics of nuclear spent fuel that needs to be understood to design a safe high level waste storage method that is as effective, if not more, than the underground pools. Another, hazard traits that need to be consider is criticality. Simply stated, given the proper amount of fissile material within a certain geometry of the storage device, criticality, a state in which chain reaction of the fission process is self-sustained, will occur, therefore releasing life threatening amounts of radioactivity to the surrounding. Minimizing the risk for exposure of people and environment to these hazards must be part of the design criteria. Also, another problem related to the decay of fission products is the decay heat that is generated from NSF. The problem is due to the thermal stress that decay heat will cause on the material being used for storage.

3.2. Public Concern with Spent Fuel Radioactivity

As demonstrated by the incessant public protests against nuclear power proliferation, which is to some degree based on fear of the unknown, the nuclear industry does not have any margin of error. For example, U.S. citizens are willing to accept the risk associated with flying in an airplane and driving an automobile, but they are not willing to accept the consequences associated with radioactive waste in their backyard. This is even if the science community uses such proven techniques as Probability Risk Analysis (PRA) to demonstrate that, with the use of proper waste containment, there is a smaller probability of the radioactive waste being found in one's backyard, assuming that the waste is buried in containment 2000 feet below surface, under proper seismic conditions, than the likelihood of a plane crash. Hence, this fear that the public has with radioactivity requires the U.S. government to go to extreme ends in identifying a safe storage method for NSF.

3.3. Spent Fuel Inventory Projection

According to industry average, the life span of a fuel rod is three to four years at which time it is removed from the reactor and placed into an underground pool as spent fuel. At the time of this report, it has been estimated that the amount of spent fuel in this country is approximately 30,000 metric tons.[5] Currently, there are 109 nuclear reactors[6] and over 50 navy nuclear vessels that are operating. Based on projection, it is estimated that by year 2010, the amount of spent fuel will reach 62,000 metric-tons. Figure 1 illustrates the spent fuel build up projection up to the year 2040.

Nuclear Spent Fuel Inventory

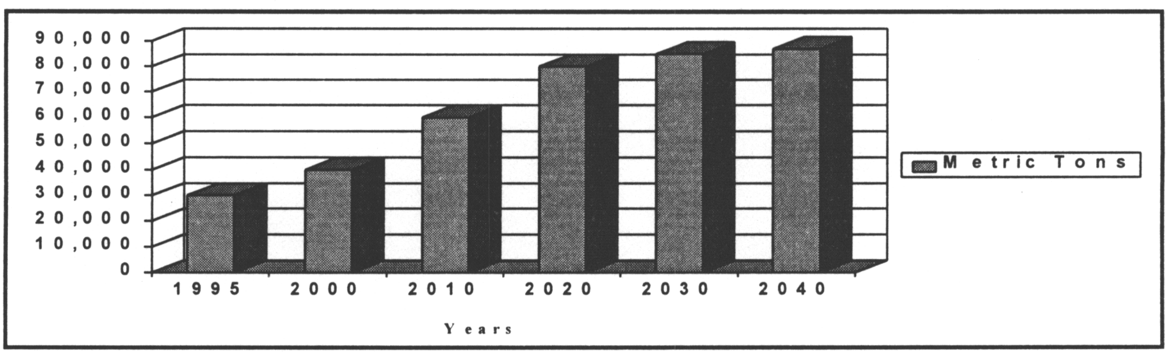

Figure 1 [7]

---

[5] "Lost in the Nuclear Wasteland", Albuquerque Journal, July 2, 1995.

[6] "World Nuclear Outlook", Energy Information Administration, December 1994.

[7] "Lost in the Nuclear Wasteland", Albuquerque Journal, July 2, 1995.

The following map, Figure 2, illustrates the reactor storage-pools throughout the U.S. that will exceed its capacity before 1998. Seven of these sites are shut down reactors with spent fuel on site.

Reactor Spent Fuel Storage Pools within U.S.

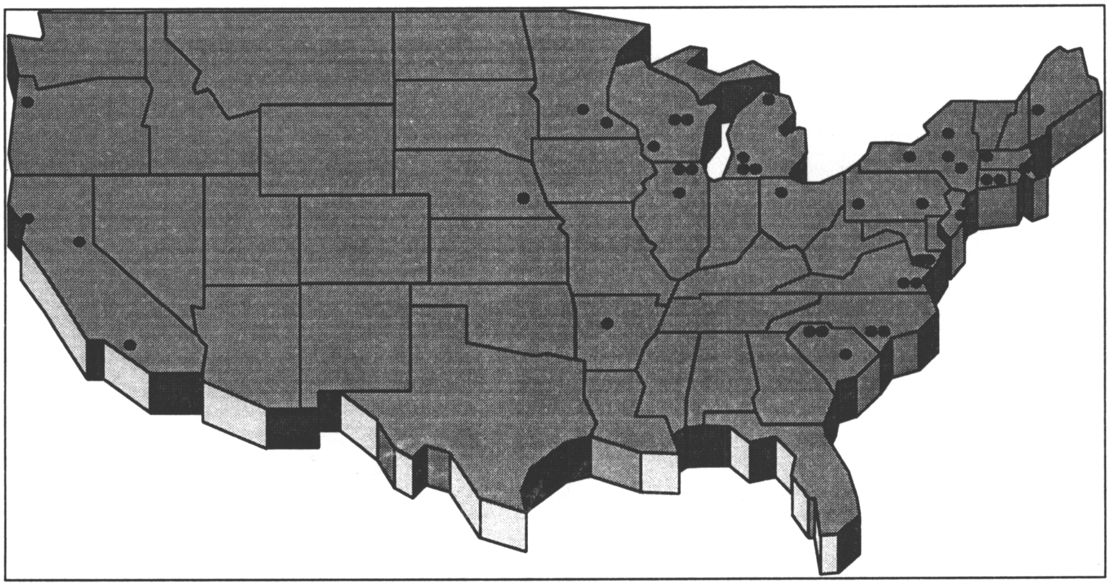

Figure 2 [8]

[8] "Office of Civilian Radioactive Waste Information Resources Map", OCRWM Bulletin, Spring 1993.

4. Definition of Need

Based on this projected rate of NSF build-up, as discussed in the previous section, and problems and constraints associated with designing and implementing a "reliable" storage method. The purpose of this section is to understand the needs of the customer such that the needs can be qualified and quantified into goals that are attainable and measurable.

4.1. Strategic Plan

To date, four main strategies have been enacted by the government to deal with the nuclear spent fuel problem. In defining the need, it is essential that these strategies are understood and linked to the requirements which will drive the development of the waste storage method. The four strategies are:[9]

1. Place NSF in 50 year safe interim storage as soon as possible;
2. Shut down inadequate existing storage facilities;
3. Minimize immediate characterization prior to disposal; and
4. Condition the NSF for disposal based on the repository waste acceptance criteria.

The scope of this project addresses strategies, one and two, since they are linked directly to the need for a new storage method. Strategies three and four deal with the permanent repository issues, which will not be reviewed in this project.

4.2. Objective

As stated in the strategic plan, the new waste storage system must provide means to dispose of the nuclear spent fuel inventory as soon as possible. However, the selected method can not compromise the critical safety issues which have been at the heart of DOE and NRC's initiatives to ensure that personnel exposure to radioactivity is as low as reasonably achievable (ALARA).

---

[9] "Office of Civilian Radioactive Waste Management Bulletin", Spring 1993.

Main explicit issue that the strategic plan addresses is the time issue. However, there are several implicit goals that are also very significant to consider in developing the best permanent disposal alternative. The two implicit factors that must always be addressed are cost and safety.

In regards to the safety issue, the system must ensure protection to the workers, public, and the environment. This can be achieved by either engineering a storage technology which uses shielding material which will provide the greatest attenuation of radiation or by developing a disposal operational procedure which will minimize the spent fuel handling method. Both DOE and NRC have established exposure limits and have promulgated procedures that limit workers' exposure to radioactive material. Based on this fact, one goal would be to design an all in one system which will allow the government to store, transport, and dispose of the spent fuel without having to handle the spent fuel for each phase of the operation. Therefore, a single system that can perform all functions will be ideal, however, not a necessity.

Another implicit objective deals with cost issue. Over the next five years, DOE's budget is projected to decrease. Therefore, one must take into account the ramification of building quality that far exceeds what is acceptable.

In total there will be seven goals that need to be met: Cost, Time, Safety, Operational Life, Storage Mode, Transportation Mode, and Deployment of the system.

4.3. Goals

4.3.1. Cost Goal

1. A system which will stay within the national budget for waste disposal. This includes operating and maintenance cost. This cost must be balanced with superfluous design features to mitigate radiological exposure to workers, the public, and the environment.
2. Magnitude of resources for investing in the new system. This data is based on the national budget allocated to this project.[10] Although this is the allocated amounts for the given years, these numbers will probably be adjusted as necessary. These

[10] Office of Civilian Radioactive Waste Management Bulletin, Winter 1995.

dollars need to be allocated as per the Total Life Cycle Cost table as illustrated in Figure 3 of the following page.

FY 94 - $32 Million

FY 95 - $57 Million

FY 96 - $61.6 Million

FY 97 - $69 Million

FY 98 - $86 Million

FY 99 - $89 Million

The basis for this budget allocation was not available, therefore, the actual life cycle cost analysis will not be a part of this project.

4.3.2. Time Goal

Date in which the proposed system needs to be completed and in place: As soon as possible. Translating ASAP to the demands of the States with Spent fuel who are expecting the government to provide the States with a means to dispose of the spent fuel by January 1998.

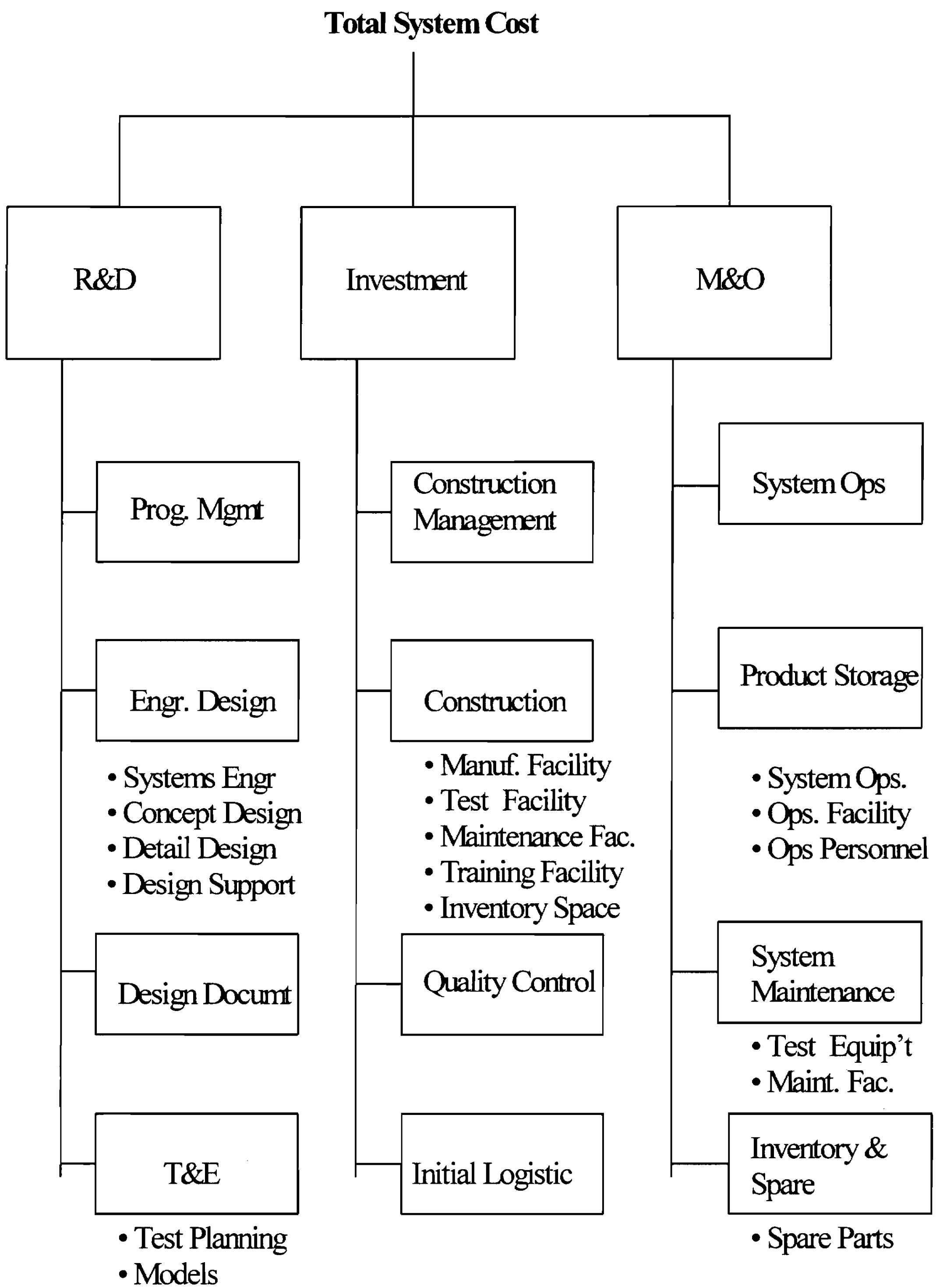
Total System Cost
R&D
Investment
M&O
Prog. Mgmt
Engr. Design
• Systems Engr
• Concept Design
• Detail Design
• Design Support
Design Documt
T&E
• Test Planning
• Models
Construction Management
Construction
• Manuf. Facility
• Test Facility
• Maintenance Fac.
• Training Facility
• Inventory Space
Quality Control
Initial Logistic
System Ops
Product Storage
• System Ops.
• Ops. Facility
• Ops Personnel
System Maintenance
• Test Equip't
• Maint. Fac.
Inventory & Spare
• Spare Parts

Figure 3

4.3.3. Safety Goal

1. The containment and structure of the storage method must comply with the applicable code of federal regulations.

2. Minimize radiation exposure by ensuring that there is enough shielding to minimize worker exposure to radiation. Also, reduce the number of loading and unloading (transfer) activity to minimize workers' handling operations of the waste.

3. The containment and structure of the storage method must be designed to ensure that the possibility for criticality accident is infinitely small.

4. Reduce the possibility of stress fracture of the material and therefore the probability of leak to the environment.

4.3.4. Other Goals

1. Operational Life: The operational life of the system will be indefinite. To quantitatively define the meaning of indefinite, 40 plus years will be used.

2. Deployment of the System: The system will be deployed to those reactor sites in the US as was shown previously in figure 2.

3. Transportation Mode: The system will be transported either on truck and/or rail. They must meet the regulations established by the Department of Transportation.

4. Storage Mode: The initial storage will be at the site of the nuclear reactor. The system will then be transported to a temporary area, also known as monitored retrievable storage (MRS) or its permanent area.

5. Introduction to the Alternatives

In general, there are two different options in which to group the alternatives: Wet Option and Dry Option. Within each of these options are several viable alternatives, which will be reviewed in this section. The outcome of this section is to show the technologies that are available as well as to quantitatively and qualitatively compare the alternatives. The result of this review can be used in a future feasibility study to select the best alternative.

5.1. Viable Alternatives

5.1.1. Wet Options

Alternative 0: Do nothing - This alternative is to do nothing. Allow the operating nuclear power plant to reach its end of life and build fence around it and let it stay shut down. Allow the spent fuel to decay.

Alternative 1: Spent Fuel Reracking - This requires reconfiguring the pool to create more room for incoming discharged fuel. The fuel racks need to be re-manufactured to make this feasible.

Alternative 2: New Pool Construction - New pools can be constructed for long-term storage.

5.1.2. Dry Options

Alternative 3: Modular Vaults (MV) - MVs consist of sealed metal tubes inside an above surface concrete structure. Inside the sealed metal tubes, the spent fuel is kept under an inert cover gas or air. A single fuel assembly is stored in each tube, and each module could store up to 100 spent fuel assemblies from a pressurized water reactor or 200 assemblies from a boiling water reactor.

Alternative 4: Concrete Container (CC) - With this design, the spent fuel would be stored in containers made of steel or a similar metal and reinforced concrete. The containers would be stored on the concrete floor of a storage yard. Each container would be an independent storage unit.

Alternative 5: Concrete Modules (CM) - With this design, spent fuel would be stored inside a sealed metal canister shielded by a concrete module. The canister would be made of stainless steel and those in use range in capacity from 7 to 24 fuel assemblies. Internal racks would hold the fuel assemblies in place. At a facility with this design, the canister could be loaded at the MRS or at the reactor.

Alternative 6: Transportable Metal Containers (TMC) - This storage container will allow for storage, transportation, and/or disposal in one containment. The TMC would potentially allow spent fuel to be stored, transported and disposed of in the same container it was originally placed into. The spent fuel in this case, would be sealed inside a canister that is not intended to be reopened. The canister then would be place into a different cask or canister at each stage, but the canister itself would not need to be reopened.

5.2. In-depth Review of two Alternatives: Storage Pool and Reprocessing Technology

5.2.1. Storage Pools

Pools remain a proven method for cooling thermally hot LWR fuels. Typically, this cooling period lasts from 5 to 10 years. Thereafter, the fuel can be removed from the pool to make room for new inventories of hot fuel. Figures 3 and 4 below show the thermal and radioactive decay of a typical Advanced Test Reactor (ATR) fuel element. These figures are representative of typical end of life behavior for fully enriched fuels which show a majority of the thermal and radioactive decay occurring within the first five years of storage.[11]

[11] "Comparison of Dry and Wet Methods to Store Spent Nuclear Fuel", Idaho National Engineering Laboratory Report, April 1994.

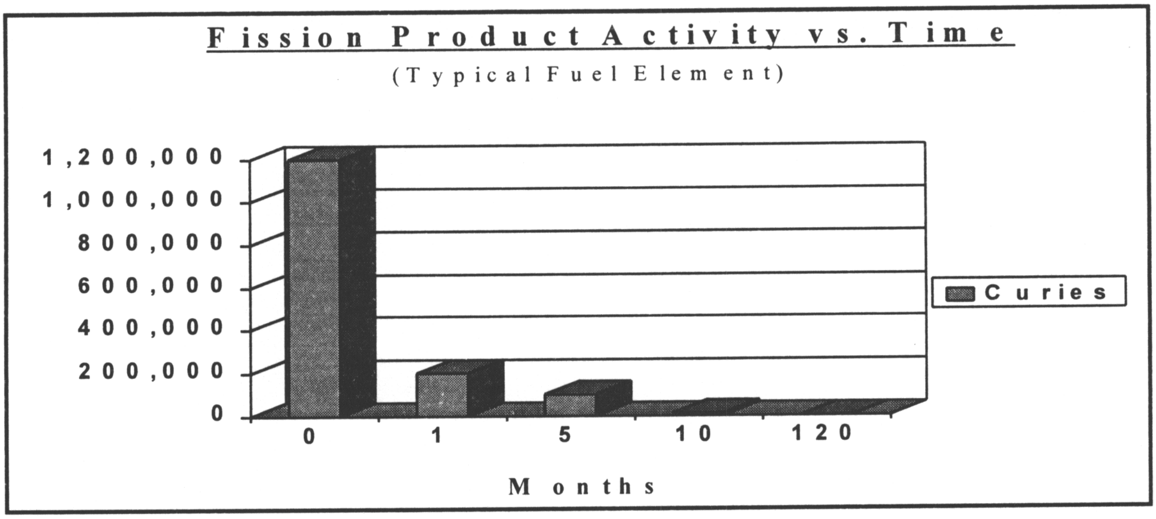

Figure 4

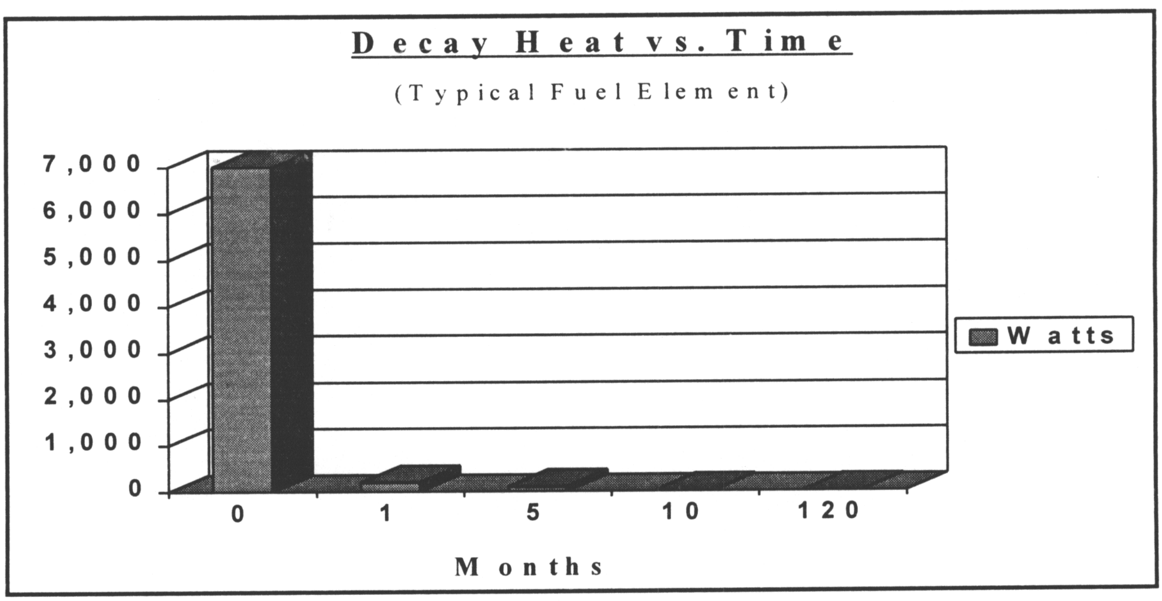

Figure 5

The challenge then is to identify a viable means of storing cooled spent fuel since the existing pools was not designed for long term storage of NSF. Some of these pools were built during the 1940's and 1950's and need to be replaced with contemporary means of fuel storage. Fuel which is, or is planned to be, removed from service also contributes to the need for greater storage capacity. So while pool storage remains an acceptable method of storing hot LWR fuel, dry storage offers a sound option for storing cooled fuels, fuels not suited for water storage and relocated fuels from aged facilities. The alternatives are presented below.

5.2.2. Reprocessing Technology

Reprocessing of the fuel is not an option in the U.S. In 1976, reprocessing was forbidden by Presidential Order in order to reduce the potential for nuclear power proliferation.[12] Therefore the methods that remain are either the dry or the wet method of storage, from which seven alternatives are being proposed.

5.3. Quantitative Summary of Alternatives

With each of these options, there are advantages and disadvantages. The alternative selected will be the system that best meets all the design criteria while offering the most effective solution. The following Table 1[13] provides a summary of the characteristics of each alternative as compared to each of the goals.

---

[12] The Nuclear Waste Primer, The League of Women voters Education Fund, 1993, Pg. 39.

[13] "Comparison of Dry and Wet Methods to Store Spent Nuclear Fuel", Idaho National Engineering Laboratory Report, April 1994.

Quantitative Summary of Alternatives **Table 1**

Alternative	A(1) Rerack	A(2) New Pool	A(3) Metal Vault	A(4) Concrete Containr	A(5) Concrete Module	A(6) Transp't Metal Containr
Operat'al Life	10 Years No	10 Years No	40 Years Yes	40 Years Yes	40 Years Yes	40 Years Yes
Transport Mode	N/A	N/A	Yes	Yes	Yes	Yes
Storage Mode	No	No	Yes	Yes	Yes	Yes
Cost per 500 MTU Capacity	10 - 15 Million	40 - 80 Million	20 - 30 Million	29 Million	29 Million	TBD
Operating $/Yr.	1.5 M	1.5 M	250K	250K	250K	TBD
Storage Capacity	50% increase of pool	Depends	Flexible	Flexible	Flexible	Flexible
Construct Time (Includes Design and Licensing)	70 to 84 months	84 months	62 months	60 months	60 months	68 months

5.4. Qualitative Analysis of Alternatives

5.4.1. Site Specific Conditions and Limitations

A re-racking operation is limited by the size of the existing pool and by technical considerations such as allowable structural loads for the facility and the physical condition of the pool. A new pool is entirely integral and its capacity is limited to an initial estimate. Dry storage facilities are flexible. Some types of dry storage facilities can be erected separately to provide storage at various locations as needed and can accommodate additional capacity easily.

The most prevalent site specific limitation affecting dry storage facilities is handling capability. Depending on the dry storage unit type, different handling equipment may be necessary. In addition, new procedures may need to be established for loading and handling the casks.

5.4.2. Fuel Type Limitations

Fuel type is of vital importance in the selection of a system. While pool storage remains a favorable choice for recently discharged LWR fuels, it is not suited for non LWR fuels like graphite fuels. Pool storage is not a favorable long term means of storage for some fuels like aluminum clad fuels due to corrosion.

The condition of the fuel will affect the selection of the storage method. Storing severely degraded fuel is a difficult challenge for wet or dry methods. Typically, severely degraded fuels require over-canning to contain the fuel materials from excessively contaminating pool water. Dry storage methods would most likely also require over-canning for severely degraded fuels to allow proper handling. Since a dry storage environment is typically inert and passive, a dry environment could significantly mitigate any material interactions that would degrade the fuel further.

As far as dry storage methods are concerned, the available literature suggests that material stability in a dry environment largely depends on the cover gas used in storage cavity. The amount of water retained by the fuel at the time when placed in dry storage is also of consideration. Reported observations indicate that presence of moist air in a dry system could lead to attack of sensitized cladding materials.

5.4.3. Advantages and Disadvantages for Each Alternative

The following are the apparent advantages and disadvantages of each alternative.

5.4.3.1. Wet Storage Options

Reracking Advantage

1. Less expensive than constructing a new pool
2. It can be a phased operation to provide increased capacity as needed

3. Extensive commercial experience and uses known technologies.

Reracking Disadvantage

1. Complicated water clean up and service inspection
2. May not meet seismic criteria
3. Additional weight could exceed pool facility structural limits
4. Poses a greater potential for abnormal operating conditions due to a criticality, increased heat loads, and increased radiation fields
5. It is limited by the physical dimensions of the pool
6. Requires a good pool

New Pool Advantages

1. Considered to be a mature fuel storage concept
2. Ready access to a single fuel piece with minimal effort and enhanced visibility
3. Thermal inertia and high thermal capacity
4. Substantial Radiation shielding
5. Protection of fuel from falling objects
6. Water is inexpensive and readily available
7. Water is an excellent radiation shield

New Pool Disadvantages

1. Considered to be the more expensive option
2. Requires an initial estimate for the capacity to be needed in the future and would be limited by its physical dimensions

3. Relatively high operating costs
4. Thermal variances may degrade fuel cladding
5. Water is not necessarily compatible for long periods with aluminum clad fuels
6. If fuel cladding contains pitting or cracks, the water could affect the fuel meat stability
7. Active storage system requires water cycle cooling and waste treatment
8. Requires active maintenance
9. Requires a structure to house the pool, fuel handling, recovery and transportation activities.

5.4.3.2. Dry Options

Concrete Vault, Concrete Module, and Metal Vault

Advantages

1. Would not require large initial capital outlays
2. Storage capacity can be obtained in steps
3. Adequate shielding
4. Custom design would allow variable storage capacity per individual unit
5. Material of construction are available and economical
6. Fuel clad oxidation would be reduced due to inert environment
7. NRC has reviewed the designs and has ranted operating licenses attesting the validity of the methods
8. Design life of 20 years or more
9. Systems are entirely passive and do not require periodic maintenance beyond monitoring as dictated by safety analysis

10. Facility would not require continuous staffing other than for monitoring as require by safety analysis
11. Appreciable protection against physical damage of the fuel
12. Can be loaded through wet or dry procedure

Disadvantages

1. Acquisition of new handling equipment may be necessary
2. Canisters are large heavy and difficult to handle
3. Canisters may not be necessarily compatible with a Federal spent fuel management facility or geologic repository transportation cask
4. An inert atmosphere may need to be maintained to prevent oxidation/corrosion of the fuel cladding
5. Not particularly suited for recently discharged fuel due to their high heat generation and high radiation levels.
6. A recovery facility is necessary to load and unload fuel

Transportable Metal Cask (Multi Purpose Cask)

Advantages

Aforementioned dry storage advantages apply with the added advantage that the cask can be used for transporting the fuel to a Federal spent fuel management facility when used as part of a licensed transportation package.

Disadvantages

Aforementioned dry storage disadvantages apply with the added disadvantage that the technology remains in development and has not been demonstrated. The transportation licensing aspects and repository acceptance criteria aspects are expected to make its development and implementation very costly.

5.5. Comparison: Dry Method vs. Wet Method

Based on this analysis, the conclusion is that dry storage method provides a much more flexibility and does not constrain the designers to hard size requirement as with a pool. Another notable advantage of the dry method is because each cask or module is a stand alone, there is reduced maintenance associated with the system when compared to what is typically needed to maintain a pool. Therefore, it becomes obvious that the new means by which the U.S. should be resolving the NSF issue is to use a dry storage option over wet. The wet option is only good for short-term storage and will not meet the need for permanent storage. However, this does not mean that the pools should be discarded completely. Rather, it may still be reasonable to use the pool as an interim storage for the first five years that the fuel assembly is pulled from the reactor. By doing this, the thermal stress on the storage container will be reduced. This will reduce the material cost.

5.6. Best Alternative

Based on reviewing the dry storage methods, the alternative which seems to best meets the safety goal is the transportable metal container. There seems to be no better system which will ensure minimum radiation exposure to workers as well as allowing for an "all in one" method for storage, transportation, and disposal. This canister provides a means to take the waste from cradle to grave with reduced handling of the waste by workers, therefore reducing the likelihood of exposure. The canister will allow direct acceptance of NSF without repackaging.

However, the uncertainty in this system lies with the fact that it is still new and has not gone through the rigor of licensing therefore the cost and time requirement factors are still questionable. Before going forward with production of this alternative, further analysis needs to be done to define the optimal operational and maintenance concepts.

The following sections provide a further review of the Transportable Metal Cask Concept. This study should be further evaluated using the Systems Engineering Process in the future.

6. System Operational Requirement

The design of this new system will be based on the operational and maintenance requirements.

6.1. Mission Definition

The mission of this system will be to store, transport, and dispose of high level waste - nuclear spent fuel. The following diagram illustrates general overview of the storage process.

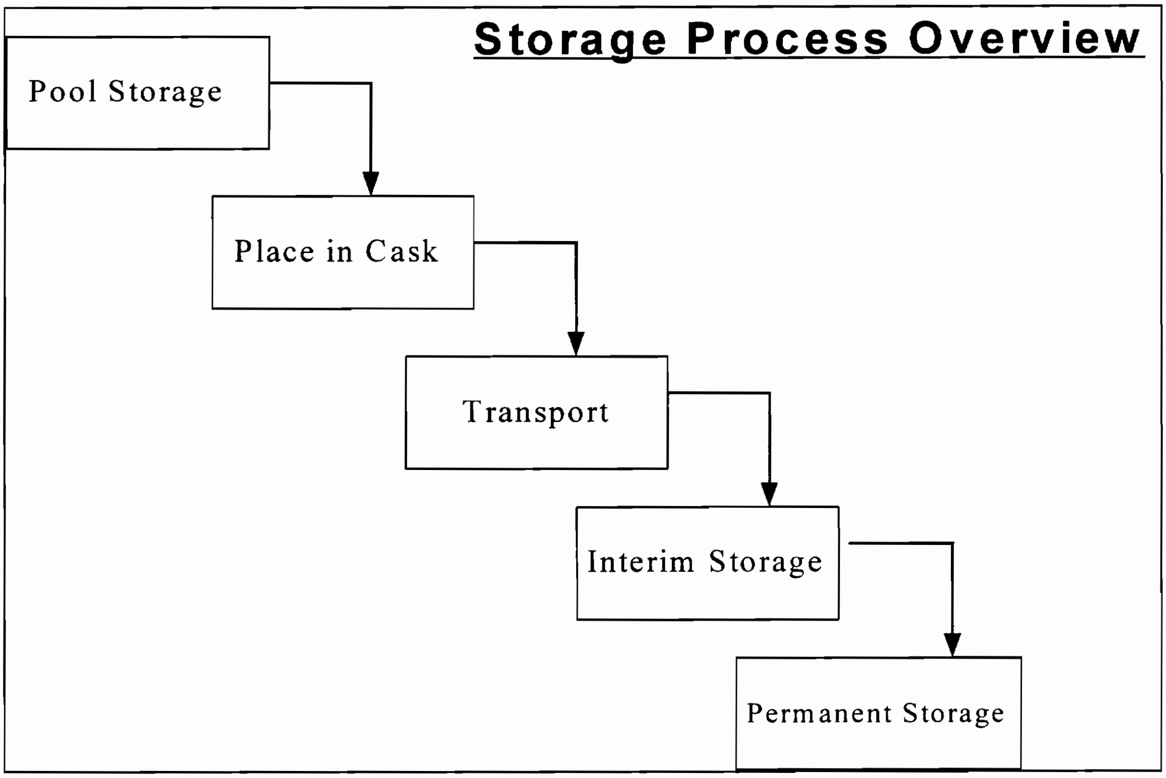

Figure 6

In implementing a storage method which will allow meeting this process, the following operational requirement must be met.

6.2. Use Requirement

- Year 1 through 5 - Commence 1998. Store in a pool on-site

- Year 5 - 10 - Store it in a Canister and then into a storage unit. Place it in a transportation cask which is designed to meet the transportation requirements. Since it is expected that the earliest time for the permanent disposal site to receive waste is in year 2010, the canister will be shipped and staged in an interim storage facility. The prime site for temporary storage is Carlsbad, New Mexico at the Waste Isolation Pilot Project (WIPP). WIPP was designed to receive transauranic waste, however, assuming that the canister is designed to minimize any potential for release of radioactive waste, it should be acceptable to store it at WIPP during the transition period.
- Year 10 - Canister is packaged into a disposal container. This will be shipped to a designated permanent site, most likely the Yucca Mountains, for final storage.

6.3. Physical Parameters

Containment

A storage system which will meet the requirements for containment of 10 CFR Part 72, 71, and 60 respectively. These Code of Federal Regulations establish the requirements for storing, transporting, and disposing of radioactive waste.

Shielding

The storage medium must provide adequate shielding to maintain occupational exposure to workers as low as reasonably achievable during every phase of storage, transport, and disposal.

Criticality

The storage medium must maintain the spent fuel from causing criticality. Calculations have shown that highly enriched uranium present in some of spent fuel could achieve a criticality with as little as .7kg in one package during disposal.

Thermal Limit

Commercial fuels which consist of heavy metal oxides and zircalloy cladding have been thoroughly evaluated and determined to be able to withstand a cladding temperature of 340 degrees Celsius. The storage medium must be designed to withstand similar thermal stress.

Structural

The storage medium must be able to withstand all hypothetical accident conditions with only a minimal chance of radioactive release. This requirement is driven by the Nuclear Regulatory Commission and includes designs to withstand:

- a 30 foot drop on an unyielding surface;
- a puncture test involving a 40 inch drop onto a pin with a diameter of 6 inches;
- a 30 minute, all-engulfing fire at 802 degrees Celsius; and
- an eight -hour immersion under .9 meter of water.

Capacity

Canister capacity will be two sizes 75 Tons and 125 Tons. The capacity is driven by transportation requirements.

6.4. Operational Deployment

- Number of facilities: There will be 109 facilities that will be serviced. Each facility has different handling capabilities. This will dictate what type of load will be shipped and which capacity container will be used.
- Number of waste handlers: Six at each facility. Waste handling will be done only during daylight hours reduce potential for accident.
- Number of Transport Specialist: Fifty trained crew men will be maintained. Couriers who have been trained in Albuquerque, NM will be employed to transport

the waste. Because of potential for terrorist, a minimum of six members and one leader is needed for any shipment.

- Number of Load operator at WIPP: To support this effort, staff of 40 will be employed. This includes technicians and support personnel.
- Control Center: The control center will be in Albuquerque, NM.
- System Fully deployed: November 1998

6.5. Operational Life Cycle

Projected Timeframe for system use between overhaul

a. Trucks: 2.5 years

b. Waste Handlers: 5 years

Inventory Profile during life cycle

a. Canister: TBD

b. Trucks: 6 trucks with 2 spares. Expect to change out the trucks after 10 years for transportation safety reasons.

c. Waste Handlers: One at each facility. Use for duration of the project

d. Transport Cask: TBD

e. Disposal Cask: TBD

The disposal cask will not be needed until year 2010. Therefore this should not be calculated into the initial cost of procurement.

7. Maintenance Requirements

7.1. Levels of Maintenance and Responsibility

There will be three levels of maintenance: organizational, depot, and supplier, on the key subsystems of this Waste Storage System.

7.1.1. Organizational

The organizational level is defined as the local reactor site where the spent fuel will originate from. Each of these locations will be provided the necessary canisters and transfer system. Also each site will be required to maintain the pools in which the spent fuel will be stored for the first five years prior to storing it in the transportable canister.

- Daily, weekly, monthly, and yearly on-site corrective and preventive maintenance checks of the waste-transfer system and the transportation vehicle will be performed.
- Chemistry of the pool will be maintained to ensure corrosion is minimized. This means that the pool water will be sampled once a day. Each pool will have an agitator to maintain even mixture of chemicals.

7.1.2. Depot

There will be one main hub which will be the central location from which all transport and storage operations will be controlled. This hub will also be the temporary waste storage facility and will house all the transport vehicles when not in use. The depot site will be divided into three areas: (1) an area for spent fuel handling and transfers, (2) a storage area, and (3) an area for support services.

The spent fuel will be delivered to this site by the transport vehicle. It will occupy a site of approximately 450 acres; continuous monitoring of facility operations will be provided to ensure that activities are carried out in a manner that protects both public health and the environment.

The spent fuel handling and transfer area will be used for receiving and inspecting incoming shipments of spent fuel, moving the spent fuel from the shipping containers to storage containers, decontaminating and repairing the shipping containers, and related activities.

The main structure will be the building for spent fuel handing and transfer. This two-story steel and reinforced concrete structure would be about 200 feet long and 150 feet wide. Areas in which radioactive material is handled would be enclosed in additional steel and reinforced concrete to protect workers and the public from radiation.

This building will contain one concrete transfer cell for transferring spent fuel from shipping containers into storage containers. The cell will have two openings, called ports for unloading incoming spent fuel from the transport containers and other ports for loading the spent fuel into storage containers. The building will include remotely operated equipment for moving the spent fuel; an operating gallery from which the operations in the transfer cell are controlled; equipment areas and equipment for the inspection, cleaning, and repair of shipping containers; personnel support facilities; general maintenance facilities; and the special facilities needed for the maintenance of the transport container crane and fuel handling equipment.

An incoming shipping container will be secured to one of the unloading ports of the transfer cell. The spent fuel will then be unloaded with equipment remotely controlled from the operating gallery and moved to the unloading port where it will be transferred into a storage container. After being loaded, the container will be sealed and moved by a special transporter to a designated area in the storage yard.

The support services provided at the site will include administration offices, security, a fire station, warehoused, maintenance facilities, and a visitor center. The entire site will be protected by a fence with a buffer area between the facility and the surrounding property line. The fuel transfer and storage area will be surrounded by a monitored security fence.

7.1.3. Supplier

The supplier level will be the designers for each of the procured mechanisms.

The supplier maintenance will consist of work that is above and beyond the skill level and the maintenance tools provided to the organizational level.

Supplier maintenance personnel known as tiger team will be available to participate in any maintenance upon request.

Supplier will be an integral part of the extensive overhaul and the phaseout of any subsystem. The overhaul may include replacing some of the critical components with a more technologically advanced equipment which will require high skill level.

Each component will carry a different warranty which will be tracked under a database provided by the vendor. With the exception of normal wear and tear, the supplier will provide replacement with parts that are identical to the failed component.

When transporting parts for maintenance, the cost incurred will be assessed to the government. The supplier will provide insurance for anything that may happen to the equipment while it is being transported.

7.2. System Level Logistic Support Requirement

7.2.1. Training

Training is critical for safe operation of the facility. Prior to the initial start up of the plant, each operator and maintenance personnel must complete the qualification program developed by the supplier training division. To ensure that the waste facility will be operating by 1998, the training program will be implemented by 1997. This will provide adequate time to qualify the initial crew.

The organizational and depot maintenance personnel will be required to go through an extensive maintenance training on the various systems which they will be responsible for. Depending on the system, the training will require approximately six to twelve months. All maintenance personnel must also go through the basic system and radiological fundamentals training.

The supplier being the subject matter experts will be the trainers of the basic systems. Training will be on integrated plant knowledge as well as a more in-depth safety design training for the supervisors and senior technicians. There will be qualification curriculum established to qualify personnel from level one, to take care of housekeeping, to level five, which is supervisory level.

A re-qualification program will be established to ensure that all qualified technicians and maintenance personnel maintain the necessary knowledge level to safely operate the waste operations. This is particularly critical during periods of extensive delay between waste handling operations. An external assessment team will formed with cooperation of the DOE and NRC to oversee the readiness prior to start-up after long delay.

7.2.2. Maintenance Task

Maintenance will be distinguished as either corrective or preventive. All preventive maintenance will be accomplished by the organizational and depot maintenance personnel. Some corrective maintenance will require supplier level support.

7.2.3. Task Frequency

Maintenance frequency will be per maintenance schedule. It will generally be conducted either monthly, semi-annually, or annually.

7.2.4. Spares

Each site will maintain certain number (spares) of critical parts to ensure the systems are back in service as soon as possible. This does not become a time critical operations, unless the breakage occurs during the middle of handling waste or if there is an accident while the cask is being transported.

By keeping the part available, both logistics delay time (LDT) and administrative delay time (ADT) will be kept at a minimum. Therefore, Mean Downtime (MDT), which influences A(0), will be kept at a minimum.

7.2.5. Test Equipment

All parts support will be provided by the supplier at cost. This includes test equipment necessary for calibration.

8. Functional Analysis

Functional analysis will translate the operational and maintenance requirements into specific Waste Storage System design requirements. This process is iterative and is accomplished through the development of functional flow diagrams. Figure 7 displays the top level functional flow diagram for the waste storage system.

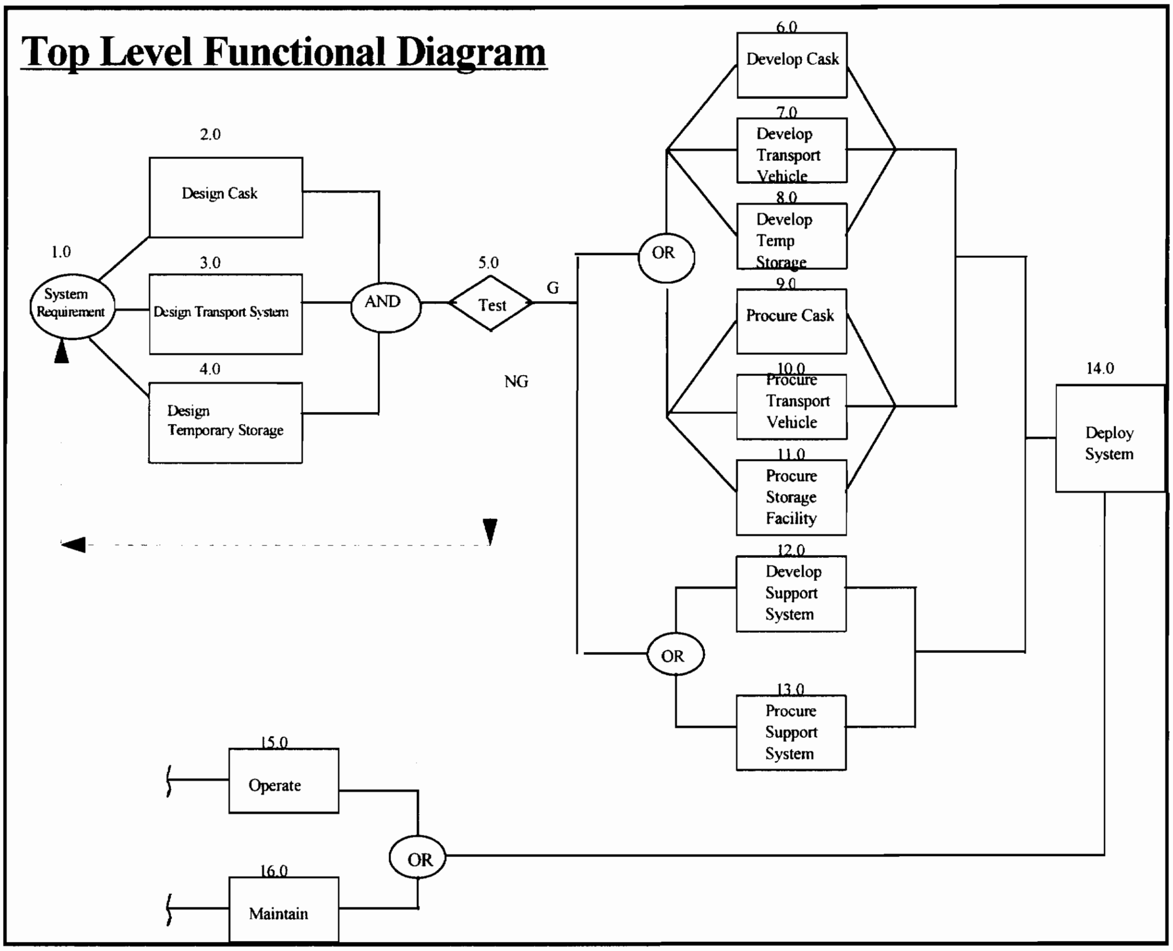

Figure 7

8.1. Operational Analysis

Operational analysis will demonstrate in detail the functions and subfunctions which are associated with fulfilling the mission requirements.

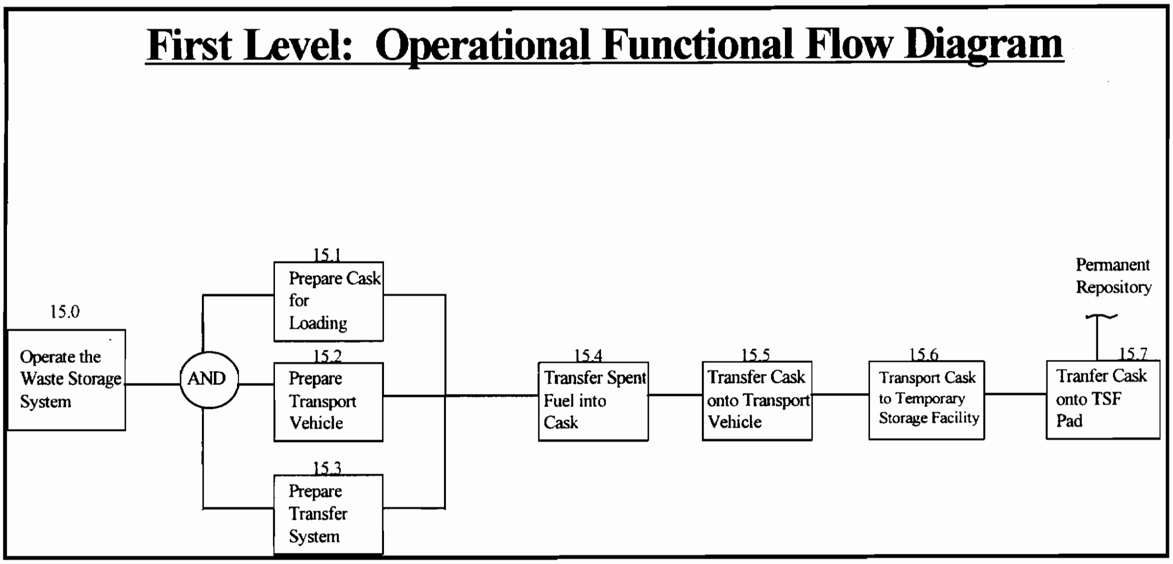

Figure 8

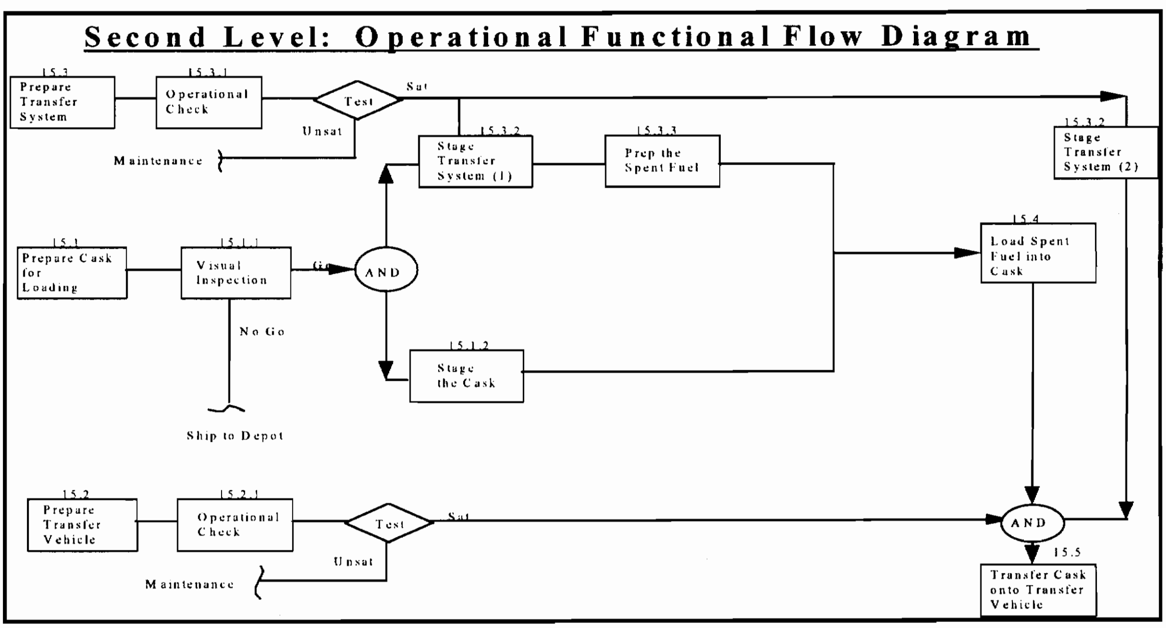

Figure 9

8.2. Maintenance Analysis

The maintenance functional analysis is divided into two distinct maintenance types, preventative and corrective maintenance. Preventative maintenance will be scheduled based on the specified maintenance interval required for each component. Corrective Maintenance on the other hand will be based on the unexpected problems of the component. Each maintenance action will directly affect or influence the system effectiveness for this project. Figure 9 displays the flow chart of maintenance functional analysis.

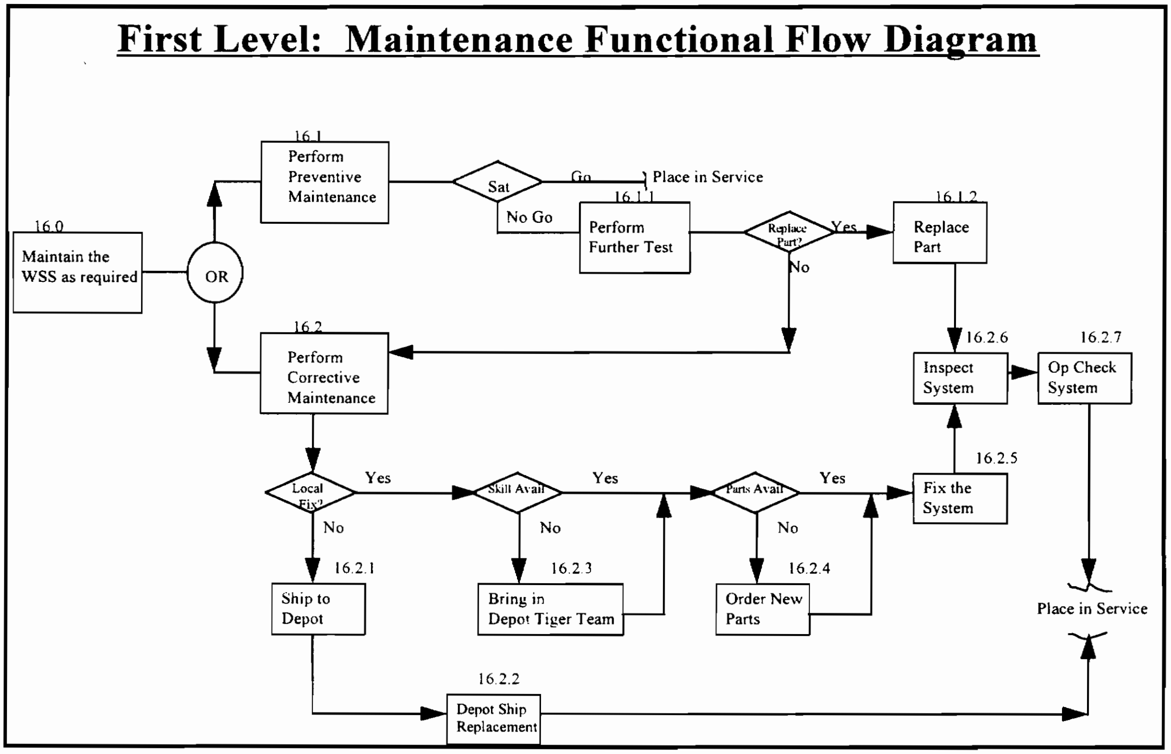

Figure 10

9. Resources Allocation

As previously mentioned, there are four major subsystems within the waste storage system: Pool, Canister, Transfer System, and Transport Vehicle. Since the storage canister is the main driver for the design of other subsystems, only the design for the canister will be reviewed in detail. The diagram illustrates the main components of the design.

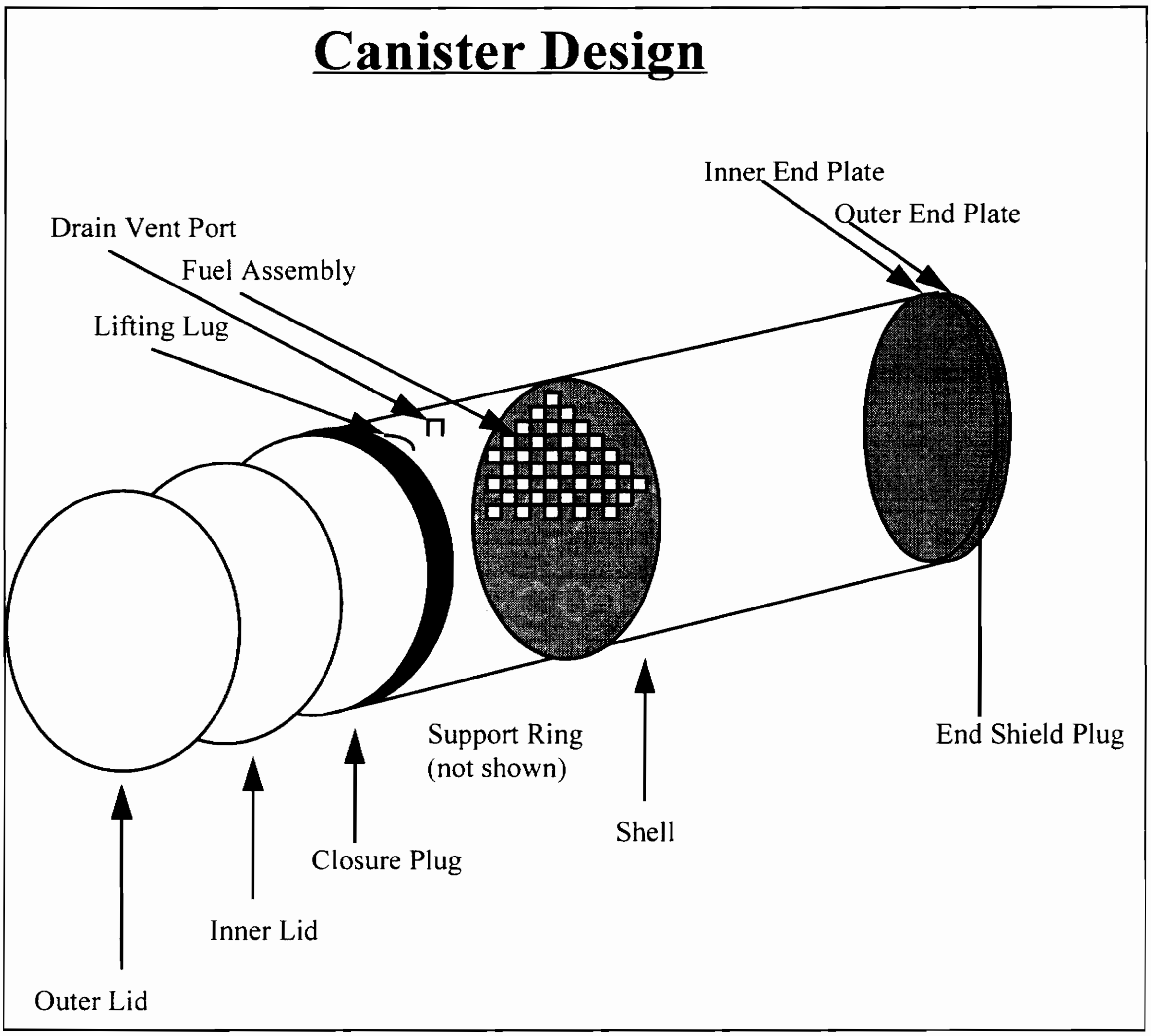

Figure 11[14]

14 Office of Civilian Radioactive Waste Management Bulletin, Summer 1995.

9.1. Reliability

Reliability is based on mean time between failure (MTBF) of each component. The value of MTBF is based on several variables: inherent reliability failure rate, manufacturing defects, dependent failure rate, operator-induced failure rate, maintenance-induced failure rate, equipment damage rate and wearout rate. The aggregate of these factors will give the overall MTBF. MTBF for each canister must be designed such that it complements the availability requirement of the canister such that the storage mission of spent fuel can be met. A radioactive material (spent fuel) leak caused by material failure of the canister constitutes failure of the canister. Based on design even a small leakage is unacceptable, therefore, the probability of the canister material failing and causing contamination of the environment is improbable. However, it is more likely that the canister will fail while it is being transported or transferred due to accidents such as fires or due to operator error.

This reliability will later be tested and confirmed during integration test.

9.2. Critical Components

One area of interest will be to identify the critical useful life components which will be the limiting components of the system. These critical components have been identified and analyzed through Failure Mode Effect Critical Analysis. To increase the reliability of these critical components, either redundancy or preventive maintenance will be used on these components to ensure A_O is at least a certain percentage defined by the customer. This can be defined by identifying mean down time (MDT) and mean time between maintenance (MTBM). Only in cases where the component MDT, whether the downtime is scheduled or unscheduled, is greater than the value needed to make the system A_O at least a certain percentage defined by the customer, will we make component redundancy an option.

9.3. Maintainability

Maintainability is a design feature which directly deals with the ease, accuracy, safety and economy in performing maintenance. However, due to financial limitations, it is cost prohibitive to design the system with limitless features. Hence, the most cost-effective maintainability can be achieved if return per dollar is optimized. This means finding the balance between design cost and support cost, which are directly influenced by the amount of features added into the facility.

9.4. Availability

Availability is directly influenced by reliability and maintainability. The availability measure of the system components will dictate whether the system will be able to meet the operational objective. The availability of interest is the operational availability - A_O. Availability of the equipment is established such that the lowest availability of a component meets the system requirement.

A_O = MTBM / (MTBM + MDT)

9.5. Cost

The allocated cost for this system will be based on four main areas. This is research and development, construction, maintenance and operation, and phaseout and disposal. Further analysis of the life cycle cost needs to be done as part of the decision process. The cost elements that are described in Figure 3, total system cost, should be considered. For this project, the actual cost data was not available. However, any further systems engineering analysis needs to account of the life cycle

10. Test and Evaluation

Test and Evaluation phase will be significant to demonstrate that the approach we have chosen is technologically sound and more importantly meets the customer requirement. In performing these tests up front prior to actual construction, we can minimize the modification and sunk cost which will grow exponentially the longer we wait to identify and correct any problems.

10.1. Type I Testing

Type I Test will be performed early in the design phase. This test will ensure that the alternative and approach we have chosen is operationally and logistically feasible and realistic. A major portion of the design modeling and test will be done using Computer Aided Design (CAD). Using CAD, we will be able to simulate the operations with constraints and environment that is as similar to reality as possible.

10.2. Type II Testing

Type II testing will occur at the latter part of detailed design. This is a formal test and demonstration of the model developed to simulate the waste storage system and process. Because of the complexity of this system, the CAD modeling will be used to develop a complex prototype design of the canister, transfer system, transport vehicle, and the temporary storage facility. The specific tests that will be conducted during this phase are as follows.

10.2.1. Performance Testing

This test will certify the effectiveness of individual system components. The test will be used to compare the operational reliability of the system components so that the design of the system can be finalized.

10.2.2. Environmental Testing

This test will subject the system to the real life conditions. The two environmental factors that will have the most influence on the life of the system will be temperature and component irradiation from radioactive sources. Both effects can reduce the life of the component, thus affecting the life cycle cost which we have previously estimated. Hence it is critical that this test be done to verify the reliability of the components as well as reconfirming that the cost estimations are as accurate as possible.

10.2.3. Structural Testing

This test will verify the effects of corrosion, stress and strain which will influence the integrity of the canister. The success of this test will be an important aspect in identifying how safe the facility structure is in controlling the potential radiation and chemical hazards from the environment.

10.2.4. Reliability Qualification

This test will determine whether the system MTBF meets the customer's MTBF requirement. Since many of the components to be used in this canister will be used for the first time, we can to some extent reduce the uncertainty of the components by performing this test. We can design the CAD model to account for some of the sub-component specifications as well as the material strength of the equipment.

10.2.5. Maintainability Testing

This test will review whether the concept of using transfer system for maintenance is feasible and controllable. This test can be used to identify the labor skill level that will be required to perform some of the maintenance and whether the labor will be able to readily see the problems of the components when they are working from the other side of the viewing window. It can answer such questions as, how many viewing monitors do we need to install in the maintenance room? The test can be used to determine M(ct) and M(pt) maintenance times.

10.2.6. Technical Data Verification

This test will check to see if the technician performs his duties with the level of training received. It will also help to establish the level of technical data and documentation that will be required to ensure that the technicians are performing their job as required.

10.2.7. Support Equipment Compatibility Test

This test will verify the handling capability of the support test equipment.

10.3. Type III and IV Testing

Upon developing the prototype of the canister, test will be conducted under actual environmental conditions. Although the material to be loaded in the canister is not the actual fuel assembly, an imitation material that will have green coloring will show if in fact there is leakage from the canister. During this test, the canister will also be loaded onto the transport vehicle and real accident such as a crash and fire will be simulated. At this time, we will evaluate if there is any failure in the material during the fire. Using this data, we will do a probability risk analysis to see the effects that a rupture of the canister will have on the environment.

11. Probability Risk Analysis

As part of the testing, a probability risk analysis should be conducted on the canister to see what kind of effect a failure in the canister will have on the public and the environment.

The assumption for this analysis is that the accident occurs in Albuquerque, NM, the central courier hub. Although not all accident will happen in Albuquerque, this analysis will outline some of the parameter t that needs to be reviewed during future analysis.

11.1. Scenario

With the failure of the transport cask after the vehicle crash, U-235 and its fission products will be released into the atmosphere. Assuming that 100% of the material is released, plume of colloidal particulate will be either dispersed into the atmosphere or precipitated to cause ground contamination. In this section, we will review the factors that affect the state of released particulate. The amount of particulate that remains in the atmosphere or on the exposed surface is controlled by weather conditions and corrective actions taken by the emergency action team. However, once the particulate is airborne, it is safe to surmise that emergency action teams will have little or no influence in controlling public exposure to airborne radioactivity. It is only when particulate precipitate that the action team will be able to isolate the contaminated area and limit the exposure to the public. Therefore, in the case where the particulate precipitate, the deleterious effect on a person is reduced when compared to a situation where the person immediately ingests the particulate. Based on this observation, it is important to analyze the effects of meteorological condition on the released particulate since weather conditions mainly dictate the concentration of the radionuclides at a certain point in the atmosphere..

The meteorological conditions that influence the dispersion or precipitation of air pollutants are atmospheric temperature, wind speed, precipitation (rain), and humidity.[15] For this study humidity and precipitation will be combined for simplicity since 100% humidity means that it is raining. Each of these variables will affect the plume - the released particulate - differently. In the following sections we will review each of these meteorological factors and its effect on the plume.

[15] Perspective on Reactor Safety - NUREG/CR-6042 SAND93-0971, Haskin and Camp

11.2. Effects from Temperature

There are five different plume patterns: fanning, fumigation, looping, coning, and lofting, based on slope of the temperature profile, which is the temperature difference at two or more heights of the lower atmosphere. This slope can be compared by dividing the difference of temperature by the difference in height of the measurement. Depending on the terrain and the location of the population density relative to the direction of the plume, the exposure to the pubic will vary.[16] For example, Of the five patterns, looping (plume is emitted into an uncapped unstable atmosphere which causes breakup of the plume) provide the most unstable condition for the plume. Looping leads to a more turbulent air flow therefore the particulate are more readily exposed, since the particulate are distributed horizontally as well as vertically, than during other conditions where the particulate appear to stay within a tighter boundary of flow. Therefore, if the population density is greater at the vicinity of the release point than at farther distance, looping will be the most unfavorable condition.

11.3. Effects from Humidity

Another factor, humidity, will affect the plume by causing more particulate to precipitate as the humidity level increases. For example, if we assumed that it was raining on the day of the accident, then exposure through skin contamination will be the main concern. However, in this situation, the contamination can be more readily controlled before it causes harm to the population, since we are assuming that the emergency action team takes appropriate action to isolate the contaminated areas. In this project, we are assuming that Albuquerque is the site of the accident where relative humidity is approximately 10% or less for most of the year, therefore, the humidity effects will be negligible.

11.4. Effects from Wind Conditions

The last factor to consider is the wind. In evaluating the effects of the wind on plume dispersion, the Gaussian plume model[17] will be applied. This model shows that the time-

---

[16] Perspective on Reactor Safety - NUREG/CR-6042 SAND93-0971, Haskin and Camp

[17] Perspective on Reactor Safety - NUREG/CR-6042 SAND93-0971, Haskin and Camp

integrated concentration at the point in question is proportional to the quantity of radionuclide released times gaussian shape function, which depends on the location, the stability class, and the release height divided by the wind speed. This model is captured as follows:

= Q*(P divided by U) where

X(t) = time integrated radionuclide concentration at point in question (Ci sec/meter cubed)

Q = quantity of radionuclide released (Ci)

U = wind speed (meter per second)

P = Gaussian shape function, which depends on the location, the stability class, and the release height (inverse meter squared)

Pasquill-Gifford Stability Classes shows that here are seven stability classes from Class A, extremely unstable, to Class G, very stable. This categorization takes into account both the intensities of the sunlight, which in effect influences the temperature and the humidity of the atmosphere. When we correlate the stability classes to the plume patterns affected by temperature, we can conclude that looping, from effects of temperature section, is similar to Class A while fanning is similar to Class G.[18]

The Gaussian Plume Equation in essence, takes into account all three factors of interest. By evaluation of the equation, we can deduce what the concentration of radionuclide will be at the point in question. Let us look at how the change in the three factors will affect X(t).

As the wind speed increases, X(t) will be reduced. As the temperature increases, the stability class is affected. As the atmosphere heats up, the particulate molecules will have a tendency to become less stable. However, since stability class is only one of the contributing factors of P, the Gaussian Function, temperature has less affect on X(t) than wind speed. Therefore, wind speed will dominate the status of radionuclide concentration.

As the humidity increases, the air molecules and there particulate will become more stable. However, as with temperature, humidity is an indirect attribute of stability class.

---

[18] The Health Physics and Radiological Health Handbook, Section 3

Therefore, just as with temperature, wind speed will dominate the status of radionuclide concentration.

11.5. Summary

These assumptions will be applied to develop a risk model that will demonstrate the effects of an accident to the workers, the public, and the environment. This is just one example of a probability risk analysis that should be conducted to demonstrate to the public the probability and effects of ingestion of the particulate if the canister is to fail during an accident or many years after disposal in a repository.

12. Engineering Management Plan

The systems engineering management plan (SEMP) is developed early in the conceptual phase. It is used to ensure that all organizational responsibilities and engineering disciplines are identified up-front so that all resources are properly and adequately utilized during the design, development and production phases. The thoroughness of this plan and subsequent follow through will ensure that systems engineering process is successfully implemented on schedule. A project milestone which includes the design, development and production schedule can be developed and presented to the decision board for adequacy and implementation.

13. Conclusion

For this project, several viable alternatives for nuclear spent fuel disposal were introduced as well as a plan for applying the systems engineering process in selecting the best alternative in the future.

There is a definite need in this country to identify a new means to permanently store spent fuel disposal system. For without it, the nuclear power industry will not be viable since there will be no room to dispose of the spent fuel which are currently stored in many of the over used storage pools.

DOE and NRC have continued to search for new methods to for spent fuel storage, transportation, and disposal. However, with the social, economic, political, and technical (STEP) issues at hand, there has been much delay in developing and implementing a new spent fuel disposal technology.

With these STEP constraints, there is no better method to take this project from cradle to grave than the application of Systems Engineering Process. Because during this study, it became apparent the magnitude of resources that this project will require. Without using a holistic approach to develop that system with the mission and objective in mind, one could easily stray from the original intent in developing the system, which would translate to using up valuable resources. Additionally, it is in using such process as the systems engineering methodology, that one can take complex issues and criteria and attempt to methodically simplify it. Only in using processes such as this, will scientists and managers be able to demonstrate to the public that all factors are being reviewed adequately and systematically. With this said, the power of systems thinking, when used appropriately, can be the best sales tool available to scientists and managers, who wants to demonstrate to the public that it is safer to bury nuclear waste in Yucca Mountains than for them to drive a car or fly in an airplane.

This study did not take into account the life cycle cost nor was resources fully allocated to each component of the nuclear waste storage system, mainly due to the lack of data available during research. However, this study did provide the baseline for applying the systems engineering approach in selecting and developing a nuclear waste storage method.

Future study should take into account the following:

1. Life Cycle Cost
2. Further definition of Maintenance Concept
3. Further definition and Analysis of Resource Allocation
4. Probabilistic Risk Assessment Model development and analysis using the outline provided in this project.
5. Development of the Systems Engineering Management Plan

References

1. A systems View of Development Methodology of Systems Engineering and Management, Donald R. Drew and Cheng-Horng Hsieh, Cheng Yang Publishing Co., 1984.

2. Code of Federal Regulations, 10 CFR Parts 60, Federal Regulations on Disposal of Radioactive Waste

3. Code of Federal Regulations, 10 CFR Part 70, Federal Regulations on Transporting Radioactive Waste

4. Code of Federal Regulations, 10 CFR Part 71, Federal Regulations on Storing Radioactive Waste

5. "Comparison of Dry and Wet Methods to Store Spent Nuclear Fuel", Idaho National Engineering Laboratory Report, April 1994.

6. "Lost in the Nuclear Wasteland", Albuquerque Journal, July 2, 1995.

7. "Nuclear News", American Nuclear Society, Section: Meetings; pg. 48, July 1995

8. "Office of Civilian Radioactive Waste Management Bulletin", Spring 1993, Summer 1995, Winter 1995.

9. "Office of Civilian Radioactive Waste Information Resources Map", OCRWM Bulletin, Spring 1993.

10. "Perspective on Reactor Safety", NUREG/CR-6042 SAND93-0971, Haskin and Camp.

11. Systems Engineering and Analysis, Blanchard, Benjamin S. and Fabrycky, Wolter J., Englewood Cliffs, New Jersey, Prentice-Hall, Inc., 1981.

12. The Health Physics and Radiological Health Handbook, Section 3, December 1989.

13. The Nuclear Waste Primer, The League of Women voters Education Fund, 1993, Pg. 39.

14. "World Nuclear Outlook", Energy Information Administration Report, Section 2, December 1994.