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Site Selection and Characterization Processes for Deep Geologic Disposal of High Level Nuclear Waste

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Abstract

In this paper, the major elements of the site selection and characterization processes used in the U. S. high level waste program are discussed. While much of the evolution of the site selection and characterization processes have been driven by the unique nature of the U.S. program, these processes, which are well-defined and documented, could be used as an initial basis for developing site screening, selection, and characterization programs in other countries. Thus, this paper focuses more on the process elements than the specific details of the U. S. program.

Introduction and Background

The purpose of this paper is to present an overview of site selection and characterization methods developed and implemented as part of the U. S. Government's program to dispose permanently of high-level nuclear wastes generated primarily from the commercial power generation industry. While much of the evolution of the site selection and characterization processes have been driven by the unique nature of the U.S. program, these processes, which are well-defined and documented, could be used as an initial basis for developing site screening, selection, and characterization programs in other countries. Thus, this paper focuses more on the process elements than the specific details of the U. S. program.

Since the inception of commercial nuclear power in the 1950's the U. S. Government has explored options for the disposal of high-level nuclear wastes. Studies conducted by the National Academy of Sciences, the U. S. Department of Energy (DOE) and its predecessor agencies, and other federal agencies have examined such options as disposal in the ocean floor, deep-well injection, surface storage, and deep geologic disposal. Deep geologic disposal has emerged as a strongly preferable option because it requires only currently available technology, and it takes advantage of both natural and engineered barriers for protection of the environment and population. In addition, it can be implemented with long-term monitoring, maintaining the option to retrieve the waste, if necessary. Through the 1960's and 1970's numerous searches and studies were undertaken to identify potential sites for high-level waste disposal.

In 1982, the siting process was formalized with the passage of the Nuclear Waste Policy Act (NWPA). This law specified a sequence of steps to be followed for selecting repository sites.

DISCLAIMER

The first step was completed in 1984 by DOE through the establishment of guidelines for the evaluation of possible repository sites. The process established by the DOE is discussed in more detail in the next section. At the time this site selection policy was established, DOE was already well along in identifying sites for a first repository. Thus, the policy exempted the first repository from the early screening phase of the process. In late 1984, DOE implemented the second step of the NWPA process by identifying five sites as suitable for in-depth characterization. A subsequent study, employing formal decision methods, was conducted to subject the proposed sites to a more rigorous comparative evaluation. As a result of this study and other considerations, three sites were nominated for characterization.

Site characterization plans were prepared for each site to ensure that information necessary to complete an evaluation against the siting guidelines and to develop a repository design for the site would be collected. However, before site characterization was initiated, Congress amended the NWPA to specify that only Yucca Mountain would be characterized. If Yucca Mountain proved unsuitable, then other sites would possibly be considered.

Characterization of Yucca Mountain began formally in 1989, but because of permit disputes and the need to re-examine the proposed Exploratory Studies Facility, little site work was initiated until 1992. Characterization has proven to be a very dynamic and evolutionary process. Although, the basic tenants and strategy developed in the Site Characterization Plan (SCP) have been followed, the timing and scope of much of the work has been altered. This in due in large part to the results of early characterization efforts generating data that reduced the need for more extensive studies in certain areas. The changing nature of the characterization process was also affected by a change in programmatic strategy that resulted in a revised approach to licensing. In 1998, the suitability of the site will be evaluated based on data collected to date. If the site is found suitable, work will begin on preparing a license application to the Nuclear Regulatory Commission for construction of the repository.

Site Selection Process and Guidelines

The siting process actually started long before formal regulations or guidance was in place. A number of sites were investigated but no consensus was developed on how to proceed with selecting a site for the first repository. In 1982, Congress passed the Nuclear Waste Policy Act that established a national policy for geologic waste disposal. The DOE then issued a regulation under the code of federal regulations (CFR) that provided general guidelines for the recommendation of sites for nuclear waste repositories. This regulation, commonly referred to as 10 CFR 960, specified a four-step process for selecting a repository site:

- Identification of potential sites
- Identify a subset of sites suitable for characterization
- Recommend site(s) for characterization
- Recommend site (after characterization) for development of a repository

Because a substantial effort had already been completed on identification of potential sites, the selection process for the first repository site had already completed the first step by the time the regulations were in place. Each of the process steps will be discussed in more detail below.

Siting Guidelines

All identification and recommendations of sites were to be based on specific siting guidelines. These guidelines are discussed in detail in 10 CFR 960. The guidelines are divided into sets dealing with the preclosure repository construction and operations period and the longer term postclosure period (Figure 1). Both preclosure and postclosure guidelines have technical and system guidelines. Technical guidelines are subdivided into qualifying and disqualifying conditions. Each technical guideline specifies at least one qualifying condition, but not all specify disqualifying conditions. Tables 1 and 2 provide a summary of all the site selection guidelines.

For a site to be considered suitable, it must satisfy all qualifying conditions with no disqualifying conditions present. An unsuitability finding relative to any of the system or technical guidelines means that (1) a disqualifying condition is present, or (2) a qualifying condition is not present. A suitability finding relative to any of the system or technical guidelines means that (1) a disqualifying condition is not present, and (2) a qualifying condition is present.

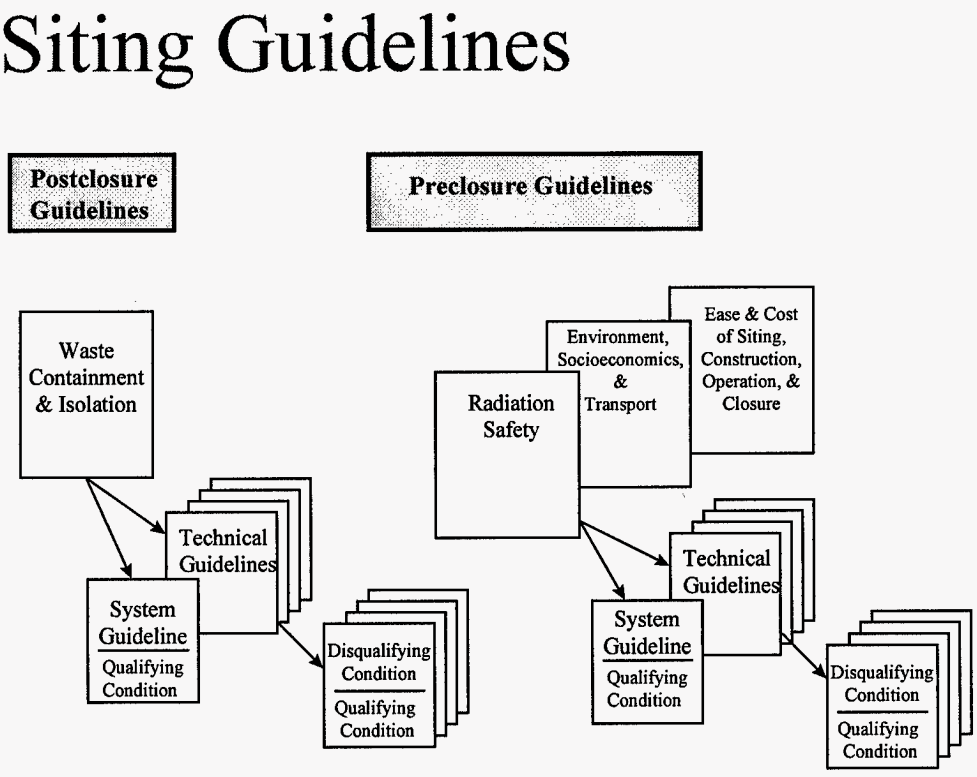

Figure 1. 10 CFR 960 Siting Guidelines Hierarchy (after SAIC, 1992)

Table 1. Preclosure Guideline Descriptions From the U. S. Department of Energy (DOE) Siting Guidelines in 10 CFR Part 960.

Guideline	Condition	Description
		PRECLOSURE RADIOLOGICAL SAFETY
System Guideline	Qualifying	Preclosure exposures meet applicable safety standards
Technical Guidelines		
Population Density and Distribution	Qualifying	1. Doses to highly populated areas are not likely to exceed small fraction of limits 2. Dose to any member of the public in unrestricted area is not likely to exceed limits
	Disqualifying	1. Site located in a highly populated area 2. Site located adjacent to a one-square-mile area with population greater than 1,000 3. DOE cannot develop emergency preparedness program
Site Ownership and Control	Qualifying	DOE can obtain ownership, surface and subsurface rights, and control of access
Meteorology	Qualifying	Meteorological conditions are not likely to lead to releases above limits
Offsite Installations and Operations	Qualifying	Effects from offsite facilities can be accommodated and will not lead to releases above limits
	Disqualifying	Irreconcilable conflicts with atomic energy defense activities are expected

Table 1. Continued

Guideline	Condition	Description
ENRIVONMENTAL QUALITY - SOCIOECONOMIC IMPACTS - TRANSPORTATION		
System Guideline	Qualifying	Public and environment are adequately protected
Technical Guidelines		
Environmental	Qualifying	Environmental quality is adequately protected
	Disqualifying	1. Environment cannot be adequately protected or impacts acceptably mitigated 2. Site is located within protected area 3. Irreconcilable conflicts are expected with a protected area
Socioeconomic Impacts	Qualifying	Impacts can be offset by reasonable mitigation or compensation
	Disqualifying	Significant reduction in water quality/quantity at offsite sources is expected
Transportation	Qualifying	1. Access routes will not cause irreconcilable conflicts with a protected area 2. Routes can be designed with reasonably available technology 3. No extreme performance standards are required 4. No unacceptable risks or environmental impacts are expected

Table 1. Continued

Guideline	Condition	Description
		EASE AND COST OF SITING, CONSTRUCTION, OPERATION AND CLOSURE
System Guideline	Qualifying	Repository siting, construction, operation, and closure will be feasible using reasonably available technology
Technical Guidelines		
Surface Characteristics	Qualifying	Can be accommodated using reasonably available technology
Rock Characteristics	Qualifying	1. Thickness and lateral extent are adequate
		2. No undue hazards to personnel are expected
		3. Reasonably available technology will be adequate
	Disqualifying	Presence of significant risk to health and safety of personnel taking into account possible mitigation using reasonably available technology
Hydrology	Qualifying	1. Setting is compatible with repository development
		2. Liners and seals will function as designed
		3. Reasonably available technology will be adequate
	Disqualifying	Expected ground-water conditions require engineering measures beyond reasonably available technology
Tectonics	Qualifying	Expected tectonic activity can be accommodated with reasonably available technology
	Disqualifying	Expected fault movement will require engineering measures beyond reasonably available technology

Table 2. Postclosure Guideline Descriptions From the U. S. Department of Energy (DOE) Siting Guidelines in 10 CFR Part 960.

Guideline	Condition	Description
System Guideline	Qualifying	Postclosure performance meets regulatory standards
Technical Guidelines		
Geohydrology	Qualifying	Geohydrologic setting is compatible with waste containment and isolation
	Disqualifying	Ground-water travel time is less than 1,000 years along paths of likely and significant radionuclide travel
Geochemistry	Qualifying	Geochemical characteristics are compatible with waste containment and isolation
Rock Characteristics	Qualifying	Rock characteristics will accommodate thermal, chemical, mechanical, and radiation stresses
Climatic Changes	Qualifying	Future climate is not likely to lead to releases greater than regulatory limits
Erosion	Qualifying	Erosion is not likely to lead to releases greater than regulatory limits
	Disqualifying	Site conditions preclude 200 m overburden above the repository
Dissolution	Qualifying	Dissolution is not likely to lead to releases greater than regulatory limits
	Disqualifying	Active dissolution could result in loss of waste isolation
Tectonics	Qualifying	Future tectonic processes and events are not likely to violate release limits
	Disqualifying	Fault movements are expected to cause loss of waste isolation

Table 2. Continued

Guideline	Condition	Description
Human Interference		
Natural Resources	Qualifying	Natural resources are not likely to cause interference activities that could lead to releases greater than regulatory limits
	Disqualifying	1. Previous exploration has created significant pathways
		2. Activities outside the controlled area are expected to lead to loss of waste isolation
Site Ownership and Control	Qualifying	DOE can obtain ownership, surface and subsurface rights, and control of access

Siting Process

The first step in the siting process is to identify potential sites. As noted above, this process was completed for the purposes of the first repository before the guidelines and process were established. However, if siting for a second repository is undertaken, it will follow the general screening process. Site screening is a process that considers large land masses that contain rock formations of suitable depth, thickness, and lateral extent and have structural, hydrologic, and tectonic features favorable for waste containment and isolation. This search should also consider diversity of geohydrologic settings, diversity of rock types (if possible), and proximity of sites to locations where waste is generated. Within the land masses, subsequent screening focuses on successively smaller and increasingly more suitable land units. Land units are then screened against the disqualifying conditions to eliminate land units that might have major flaws. Further screening can be done by comparing favorable and unfavorable features of each potential site. In the U.S. effort, twelve sites were initially identified as potential candidates for characterization.

In the second step, candidate sites are evaluated further to obtain a short list (five sites) of the most promising sites. This evaluation is performed by collecting available information about each site and performing a preliminary evaluation against the qualifying and disqualifying criteria listed in Tables 1 and 2. In the U.S. program, this step resulted in five sites being identified for more intensive study. These sites were:

- Davis Canyon, Utah
- Deaf Smith, Texas
- Hanford, Washington

- Richton Dome, Mississippi
- Yucca Mountain, Nevada

In the third step, the five candidates were subjected to a direct comparative evaluation using the siting guidelines as a basis for the comparison. The outcome of this process is to select the three best sites for characterization. A formal decision analysis approach, using multiattribute utility analysis, was taken to ensure that the analysis was both rigorous and unbiased (Merkhofer and Keeney, 1987). The analysis resulted in a ranking of the sites that was presented to DOE. However, DOE did not choose the top three sites, instead choosing the first, third, and fifth ranked sites. These were:

- Yucca Mountain, Nevada (site in volcanic tuff, ranked first)
- Deaf Smith, Texas (site in bedded salt, ranked third)
- Hanford, Washington (site in basalt, ranked fifth)

At this point in the process, all three sites were to be fully characterized, and after characterization was completed, one site would be recommended for the repository. However, at this point Congress amended the Nuclear Waste Policy Act and designated Yucca Mountain as the only site to be characterized.

The fourth and final step in the siting process is to recommend a site for repository development after all characterization is completed. In the U.S., this step has not been taken as yet, although characterization of Yucca Mountain is nearing completion.

Site Characterization

Site characterization has three principal purposes:

- To provide data to be used to determine the suitability of a site
- To provide data needed for regulatory approvals, such as construction and operation of a repository at the site, if the site proves to be suitable
- To provide the data for design of the repository and waste package

In planning a program to achieve these purposes, several factors must be considered. First, the legal and regulatory requirements that must be satisfied in siting and licensing the repository must be considered. Second, characterization must identify the performance and design information needed to address all the requirements. Finally, specific investigations must be identified that will obtain the needed information at an acceptable level of confidence. This last factor is particularly important because it must address the question of "how much data is enough?"

Strategy and Planning

One approach to planning, which was adopted by the DOE for the Yucca Mountain site, is a top-down systems method based on an issue resolution strategy (DOE, 1988). This approach, as illustrated in Figure 2, looked at the potential repository site as a system composed of the following components:

- Unsaturated rock units
- Saturated rock units that lie below the unsaturated units
- Engineered barrier system

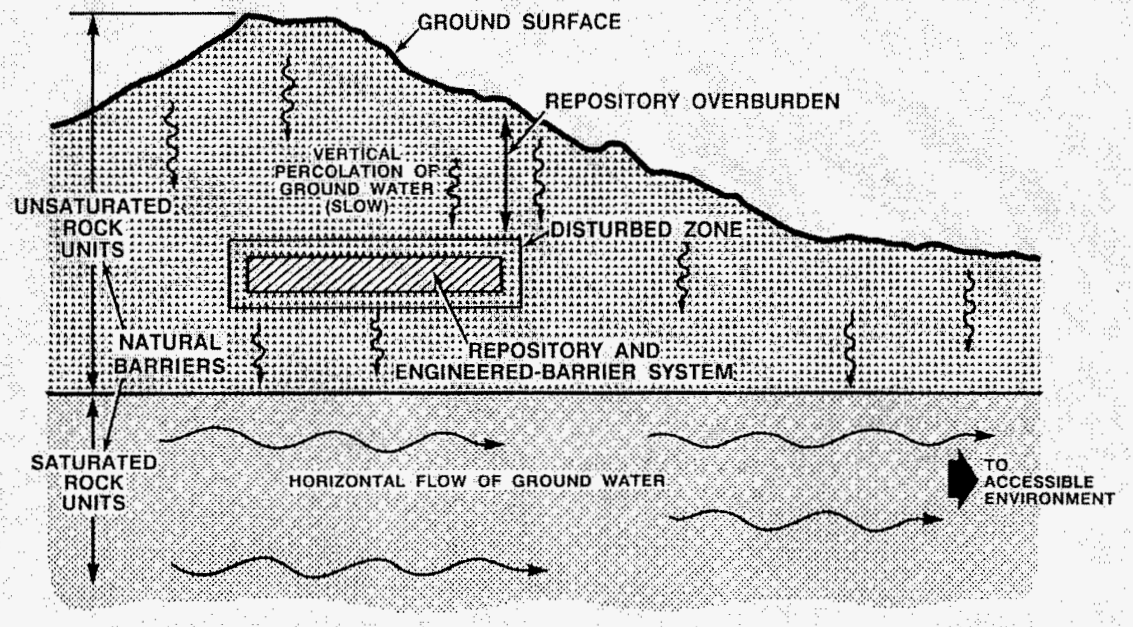

Figure 2. Yucca Mountain Site Repository System Components (after DOE, 1998).

Once the major system elements are identified, the planning process uses an issue resolution strategy to incorporate regulatory and other requirements into the planning process (Figure 3). The important element of this strategy is the development of an issues hierarchy. The issues hierarchy consists of key issues, issues, and information needs. The key issues and issues are based on the regulatory requirements that govern a repository. The information needs define the data and analytical techniques that are needed to resolve each issue. Thus, by developing a set of characterization activities that will satisfy the identified information needs, the issues are resolved, which in turn will lead to resolution of the key issues.

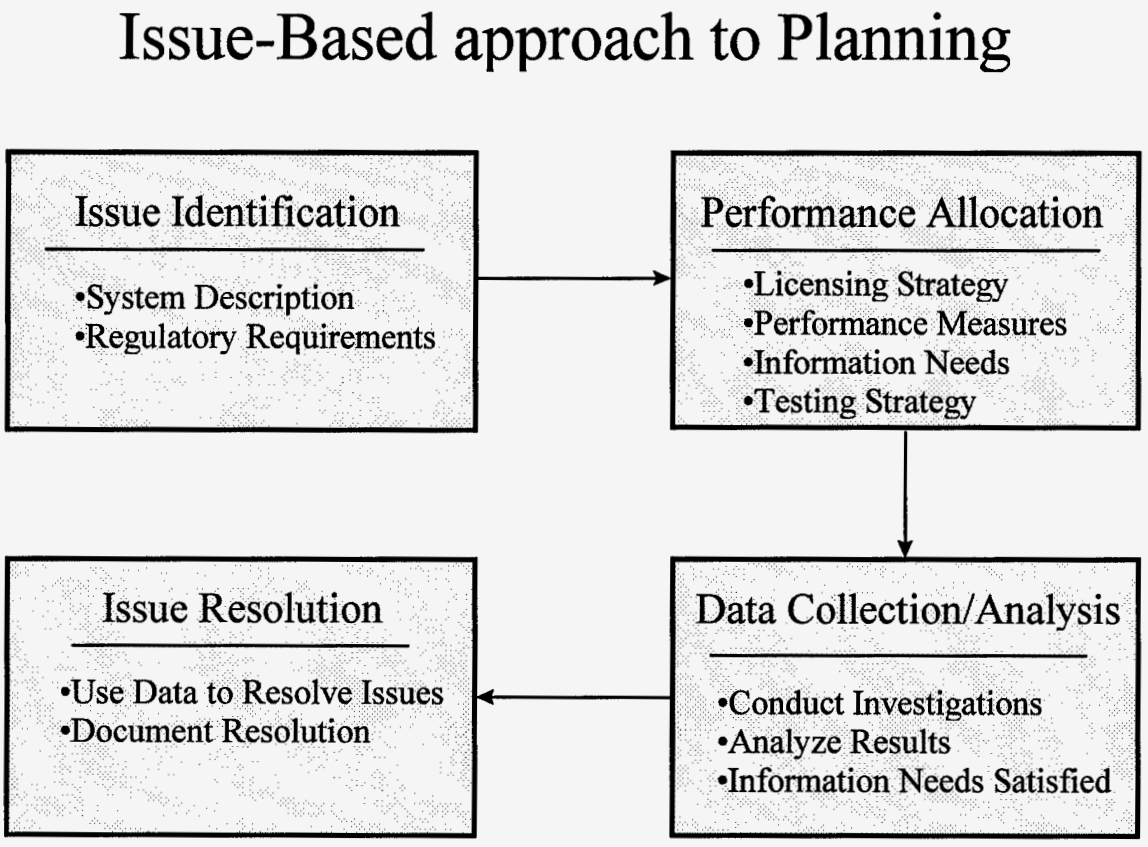

Figure 3. Basic Approach to Site Characterization

Another important part of the issue resolution strategy and the development of information needs for the issues is the "performance allocation" process (Figure 3). Performance allocation consists of (DOE, 1998):

- Deciding which repository-system elements will be relied on in resolving each issue
- Identifying the processes that will affect the performance of each element and quantifying the expected performance
- Developing a testing program to obtain the needed information about the performance

Illustration of Site Characterization Plan Development

The site characterization strategy and planning process can best be illustrated by going through an example from the Yucca Mountain Site Characterization Plan (DOE, 1988). For Yucca Mountain four key issues were identified:

Key Issue 1	Will the repository system isolate the radioactive waste from the accessible environment after closure in accordance with regulations?
Key Issue 2	Will the projected releases of radioactive materials and resulting exposures to workers and the public during operation and closure meet applicable regulations?
Key Issue 3	Can the repository be constructed and operated and can the associated transportation of waste be conducted without unacceptable risks to the public?
Key Issue 4	Will construction, operation, and closure of the repository be feasible using reasonably available technology at a reasonable cost?

Focusing on Key Issue 1, which deals with the long-term performance of the repository, a set of issues was identified that are to be resolved by information from various elements of the characterization program. This relationship is illustrated in Figure 4. Key Issue 1 was divided into twelve issues that must be resolved to address the system concern expressed in the Key Issue. Each of the twelve issues will be resolved by collecting data under various parts of the site characterization plan. Looking in particular at issue 1.11, which deals with the design of the underground facility, it can be seen that the basis of the issue is a set of requirements in section 60.133 of the Nuclear Regulatory Commission regulation 10 CFR 60. This regulation requires that the underground facility be designed to:

- Contribute to containment and isolation
- Assist the geologic setting in meeting performance objectives
- Take into account the thermal and thermomechanical response of the rock

Therefore, the information needed to resolve this issue are such things as a detailed description of the geologic setting, a determination if there is enough area at the proper depth to accommodate all the waste, and the thermal and mechanical properties of the rock.

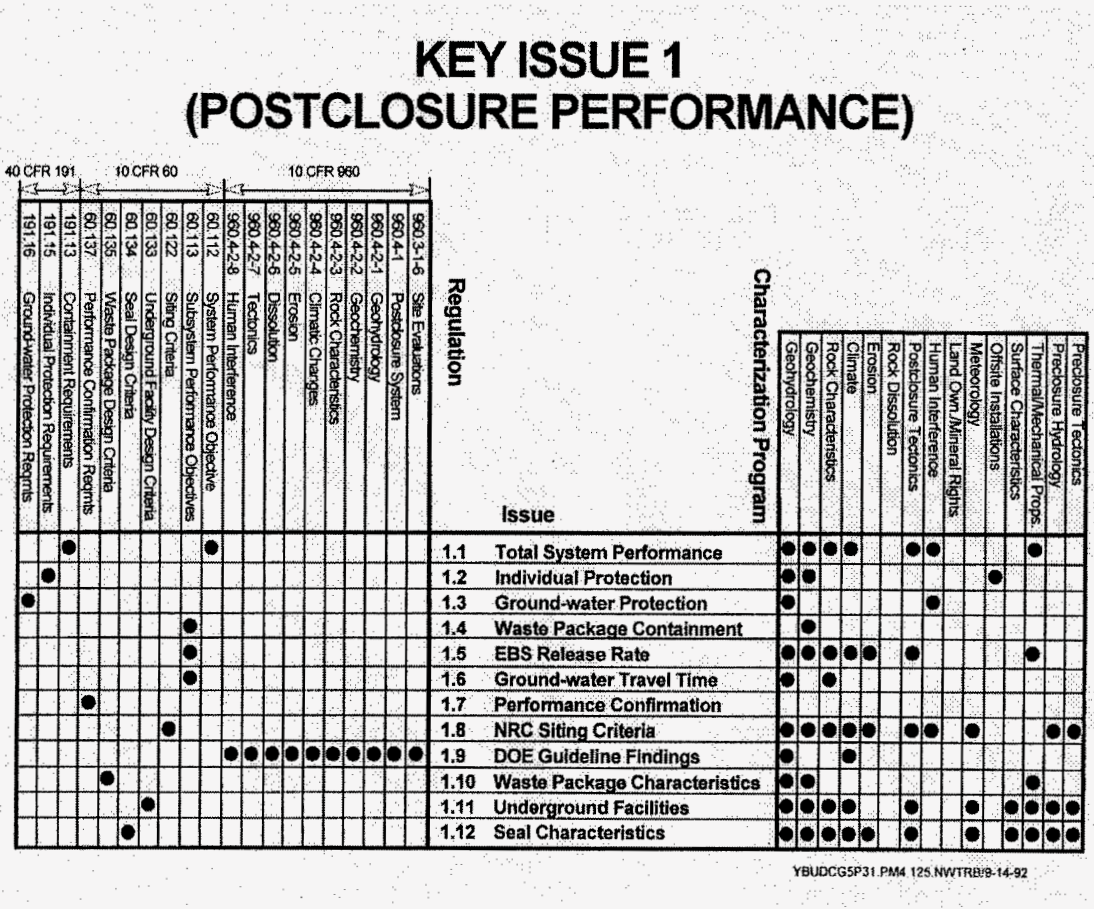

Figure 4. Relationship of issues to requirements and characterization program for Key Issue 1 (after DOE, 1998).

To determine exactly what data needs to be gathered and what confidence level is needed for the data, we go through the performance allocation process. A sample of the results of performance allocation are shown in Table 3.

From performance allocation, a set of information needs arises. These information needs are those that will be needed to determine if the performance goals can be met, or if not, can other reasonable goals be met that will assure resolution of the issue. In the case of Issue 1.11, to perform the analyses that will be required to address issues such as rock movement, allowable thermal loading, canister spacing, and rock failure, specific data from the site will be required. This flow-down of data needs is shown in Figure 5.

In the example shown in Figure 5, the need for thermal properties data is identified and specific parameters to be measured are determined. For each characterization activity, such as laboratory thermal properties, a study plan would be written that provides the specific details as to where samples would be collected from, how many, what kind of measurement techniques would be used, and how many tests would be required to reach the confidence levels determined by the performance allocation process.

Table 3. Sample performance allocation results.

Process	Performance Measure	Tentative Goal	Needed Confidence
Vary depth, orientation, and extent of facility to provide favorable containment characteristics	Usable area adequate for 70,000 MTU	• Area available > needed • >200m overburden • Stay in TSw2 • Disturbed zone > 70m above water table	High High Medium High
Limit deleterious rock movement or preferred pathways	Potential for significant displacement	• Relative motion < 1m at top of TSw1 • No Intact rock failure • No continuous joint slip	Medium Medium Medium
Vary canister and drift spacing to control thermal loading and container temperature	Thermal loading	• Design basis thermal loading less than allowable thermal loading.	High

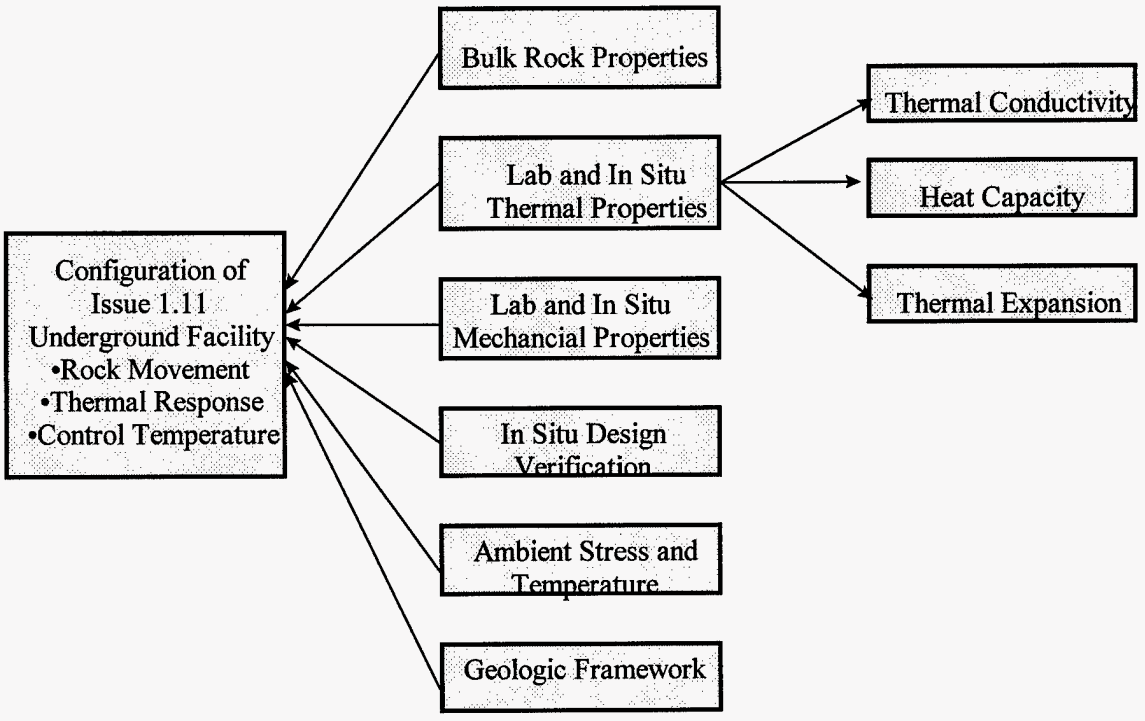

Figure 5. Illustration of Characterization Activities and Data Needed to Resolve Issue 1.11.

Summary and Conclusions

In this paper, the major elements of the site selection and characterization processes used in the U. S. high level waste program are discussed. The major lessons learned from the site selection process that led to the identification of Yucca Mountain for extensive characterization are that (1) public participation in and acceptance of the process is critical, and (2) formal decision methods and tools should be applied to the process of comparison of potential sites. The public must have confidence that site selection will made on the basis of meeting stringent technical and performance criteria.

The site characterization planning must be driven by regulatory requirements and performance needs and must be fully integrated with repository design. The key to achieving complete characterization and controlling costs is to remain flexible as characterization proceeds and continuously evaluate the need for further information. In the case of Yucca Mountain, several studies that were planned in the beginning will not be carried out because analysis of early site information indicated that data to be gathered by those studies would not be needed to resolve issues to the point that site suitability could be determined.

The principal means of digesting new information and redirecting the site characterization should be: (1) an iterative system performance assessment, and (2) a periodic evaluation of the repository design. Assessments of the anticipated performance of the repository system, including the natural system, the waste package, and the other engineered barriers should be conducted periodically during characterization. This is the only way to evaluate whether the information being collected is of value in reducing uncertainties about the potential performance of the site. By performing sensitivity studies on models and input data to determine what the greatest uncertainties are and what their potential impact might be, the data and parameters that will have the greatest impact on determining site suitability can be identified. The characterization program can then be directed to collect the data that will be of most value.

No repository system can be assessed properly unless a repository design is developed in parallel with the planning for characterization. Much of the characterization of a site will be directed toward information that is needed for repository design. If there is no design in progress, at least at a conceptual level, then critical information may be missed during characterization. This does not mean that the repository design cannot change drastically, but most of the change should be accomplished during characterization so that maximum advantage can be taken to produce a design that integrates well with the site and other system components. For example, at Yucca Mountain, the initial repository design, on which the characterization plan was developed, was a repository that was to be developed by drill and blast construction, had short emplacement drifts arranged in panels, and waste in small canisters that would be emplaced in boreholes in the drifts. The current design, driven in part by information developed during characterization, is a repository that will be developed by tunnel boring machines, will have long emplacement drifts that span the entire site, and large waste packages that will be emplaced in the drifts themselves.

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