DOE/WIPP 00-3175

Permanent Markers Testing Program Plan

September 28, 2000

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

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List of Abbreviations and Acronyms

ASTM	American Society of Testing and Materials
AT	Awareness Triggers
ATP	Awareness Triggers Package
CAG	Compliance Application Guidance (EPA, 1996)
CAO	Carlsbad Area Office, U. S. Department of Energy
CFR	Code of Federal Regulations
CCA	Compliance Certification Application (DOE, 1996)
DOE	U.S. Department of Energy
EPA	U. S. Environmental Protection Agency
GPR	Ground Penetrating Radar
ISRM	International Society of Rock Mechanics
LWA	Land Withdrawal Act
MOC	Management and Operations Contractor
MTT	Message Translation and Testing
ORCA	Office of Regulatory Compliance and Assurance
PICs	Passive Institutional Controls
PMT	Permanent Markers Testing
QA	Quality Assurance
RM	Records Management
RRL	Radar Reflectivity Laboratory
RULSE	Revised Universal Soil Loss Equation
WIPP	Waste Isolation Pilot Plant

1.0 Introduction

The U.S. Department of Energy (DOE) is initiating a program of passive institutional controls (PICs) for the Waste Isolation Pilot Plant (WIPP). This program is required by U. S. Environmental Protection Agency (EPA) regulations 40 CFR 191.14(c) (EPA, 1993) and 40 CFR 194.43 (EPA, 1996). The primary purpose of the PICs program is to indicate the location of the repository and its dangers, thus reducing the likelihood of inadvertent human intrusion into the repository. The EPA regulations specify that radioactive waste disposal systems must be designated by multiple PICs including permanent markers, long-term records and "other PICs."

A PICs implementation plan has been prepared by the DOE Carlsbad Area Office (CAO) to facilitate the implementation of the overall PICs program for the WIPP. The PICs implementation plan is supported by three additional "lower tier"documents. Each of these three documents corresponds to one of three elements that comprise the overall PICs program. These individual implementation plans are:

- *Passive Institutional Controls Records Management Implementation Plan;*
- *Passive Institutional Controls Awareness Triggers Implementation Plan;* and
- *Passive Institutional Controls Permanent Markers Implementation Plan.*

This plan supports the third of these three plans. It presents CAO plans for the program to test reference designs and alternative permanent markers materials, physical configurations, and locations.

The current design for permanent markers at the WIPP includes five new markers systems. These are:

1. Large Surface Markers;
2. Small Subsurface Markers;
3. Berm;
4. Buried Storage Rooms; and
5. Information Center.

The testing program for these systems is described in this plan. The general purpose of the markers testing program is to develop information useful in materials selection and in the development of final designs. Testing will help to determine the effectiveness and durability of selected and alternative materials and design configurations.

The practicability of construction of alternative designs and the relative costs of alternatives will also be evaluated but are not within the scope of this document. "Constructability" and cost evaluations will be performed through the application of the *Permanent Markers Implementation Plan* (currently in draft).

Information provided in this plan includes the following.

1. The implementation of the testing program will require the performance of a series of general activities, such as literature reviews and a survey and assessment of existing markers which have been completed, the development of some testing methods, and the performance of both laboratory and field scale tests; the coordination and integration of these activities is described in Section 2.0. In addition, guiding documents needed to implement the testing program are described; these include test and analysis plans.

2. The rationale for the testing process is described. The testing rationale links individual marker systems, applicable design criteria, and testing objectives and issues. The testing objectives and issues are, in turn, addressed by the performance of specific tests and analyses. Testing and analyses occur in two phases, a screening phase and a long-term phase. The testing rationale and the phased implementation of the program are also described in Section 2.0.

3. Specific tests appropriate to address individual testing objectives and issues are identified for those cases where an appropriate method currently exists. Cases where no method currently exists are identified. This information is presented in Section 3.0.

4. Information that must be addressed in detailed test and analysis plans is described in Section 4.0. These plans must be developed before testing begins and will address topics such as test objectives, management of the testing activity, specific test methods, data quality objectives, data management, reporting, quality assurance provisions, and others.

5. The general manner in which testing and analyses results will be evaluated in the markers systems design process is described in Section 5.0.

6. The organization of the testing and analysis program in a sequential progression of activities and the general schedule of testing activities are described in Section 6.0.

7. Quality assurance provisions applicable to the implementation of the testing program are described in Section 7.0.

2.0 Markers Testing Program Organization

The general structure of the overall testing program is described in Figure 1. Testing activities are focused on the materials properties, physical configurations, and locations of the various marker systems. A variety of types of tests and analyses will be performed to support the testing program. These will include literature reviews, a survey and assessment of existing markers in the region, the development of some testing methods (where none currently exist), the performance of both laboratory and field scale tests, engineering analyses, and, in some cases, computer simulations.

It is planned that testing and analyses will occur in two phases, the first being a screening phase (Figure 2) followed by a long-term phase (Figure 3). The initial step in the process is test planning; the planning effort includes the development of this program plan and the preparation of more detailed specific test plans for individual tests or groups of similar tests. In some cases, engineering analyses, possibly involving computer simulations, will be appropriate instead of testing; analysis plans will be developed for these cases. Upon the completion of the necessary detailed test and analysis plans, testing and analyses will be performed in a screening phase and in a long-term phase.

Screening tests will be performed to evaluate reference designs and alternative materials, physical configurations, and locations in terms of how well they meet screening criteria.[1] Some screening tests will be completed in the near term while others will take more time to complete. The screening phase is, however, intended to be completed by the end of 2005.

Those materials, configurations, and locations that are shown to be suitable through screening will be subjected to long-term testing in those cases where a test objective or issue includes time-dependent factors. For example, the visibility of Large Surface Markers is not time-dependent and may be assessed during the screening phase. The durability of these markers, however, is time-dependent and will be evaluated over the long term.

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[1]For purposes of this document the terms "configuration" and "location" are used to mean the following:

Configuration - This is related to physical designs. Examples include the use of multiple pieces of rock for the large surface markers as opposed to only two monolithic members and the height and side-slope of the marker berm.

Location - This refers to the geographic location at which a particular marker or marker system will be placed. Examples include the depth and distribution of the buried small subsurface markers and the locations of the large surface markers.

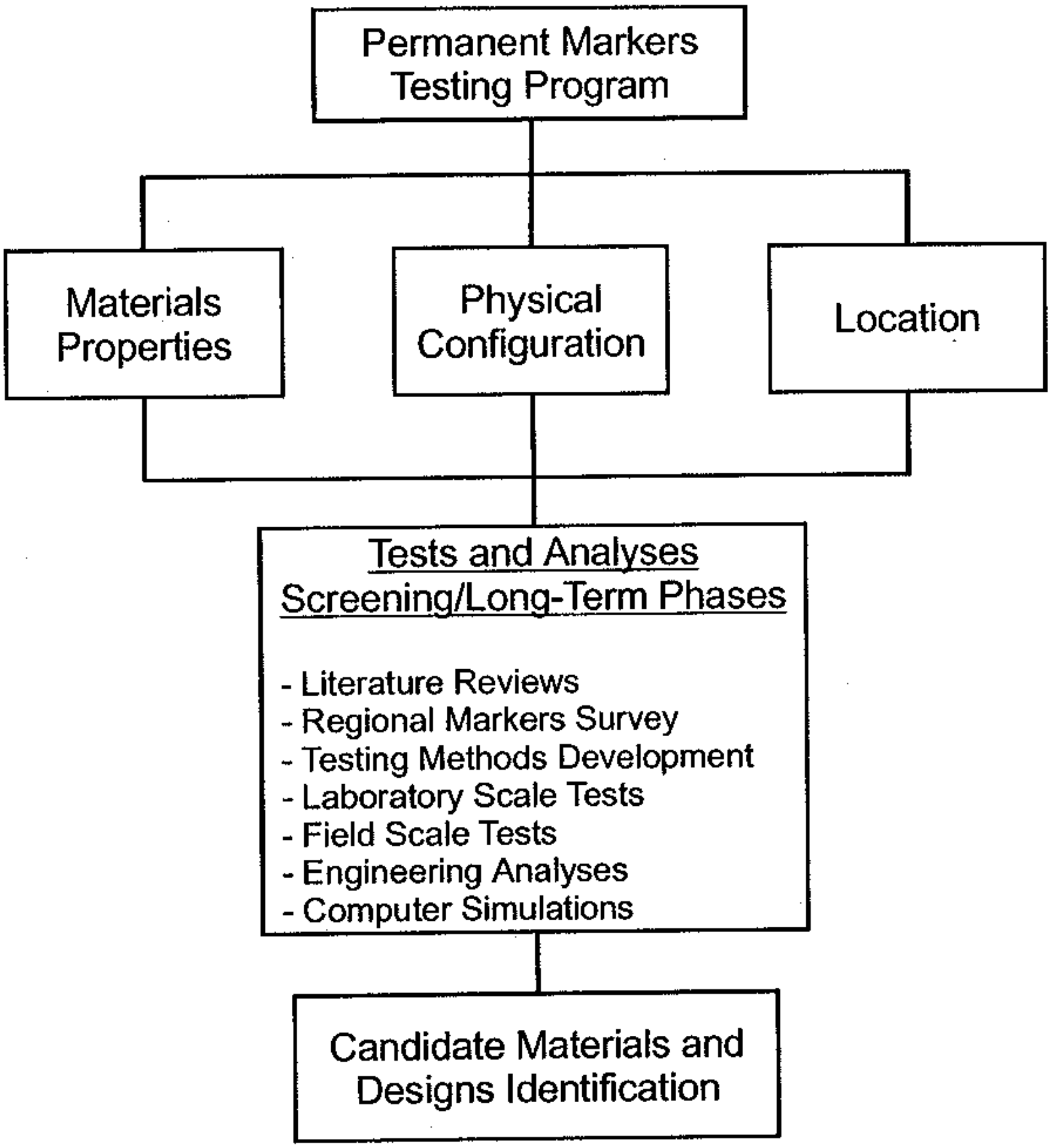

Figure 1. Testing Program Organization

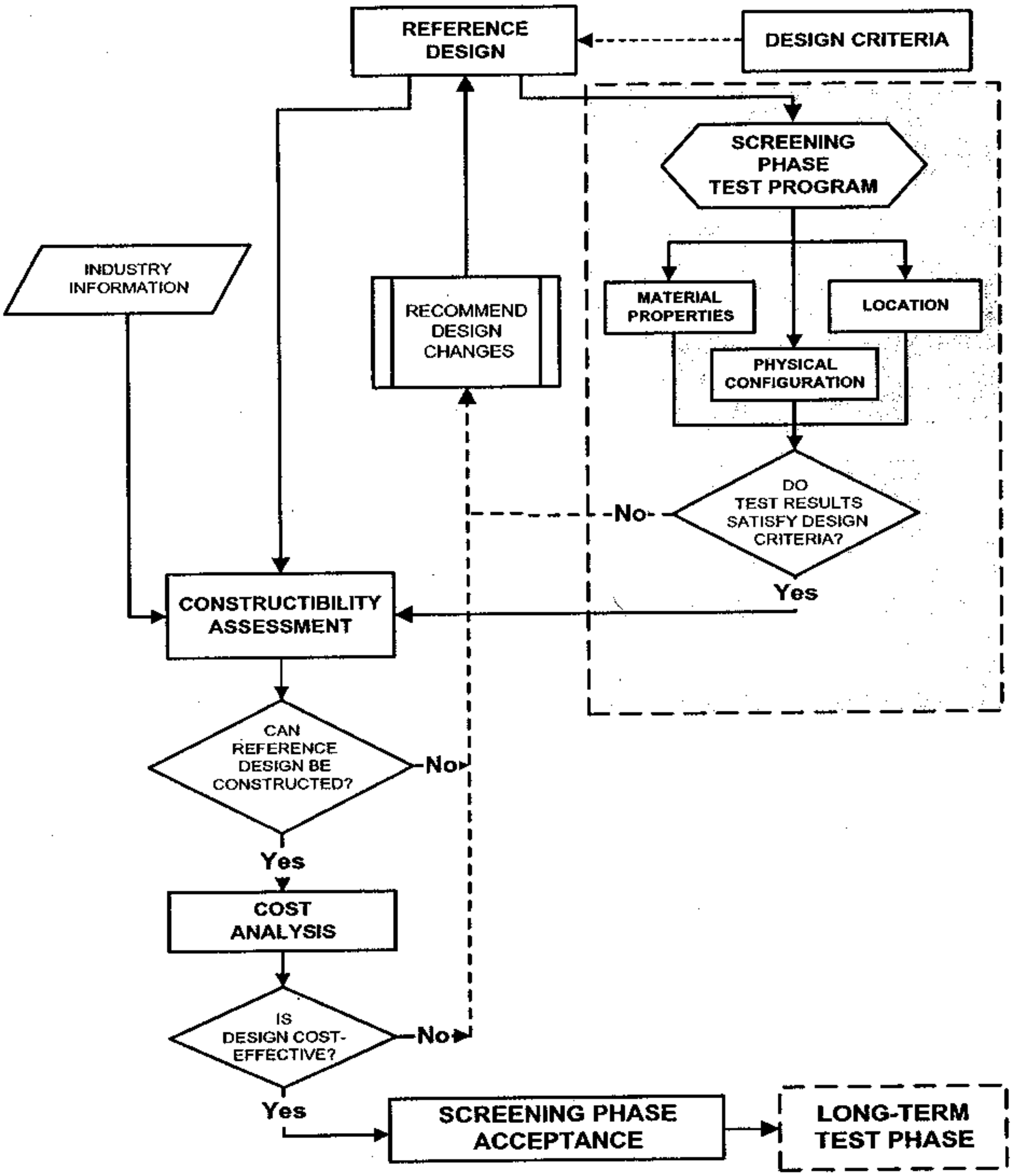

Figure 2. Screening Phase Testing Process

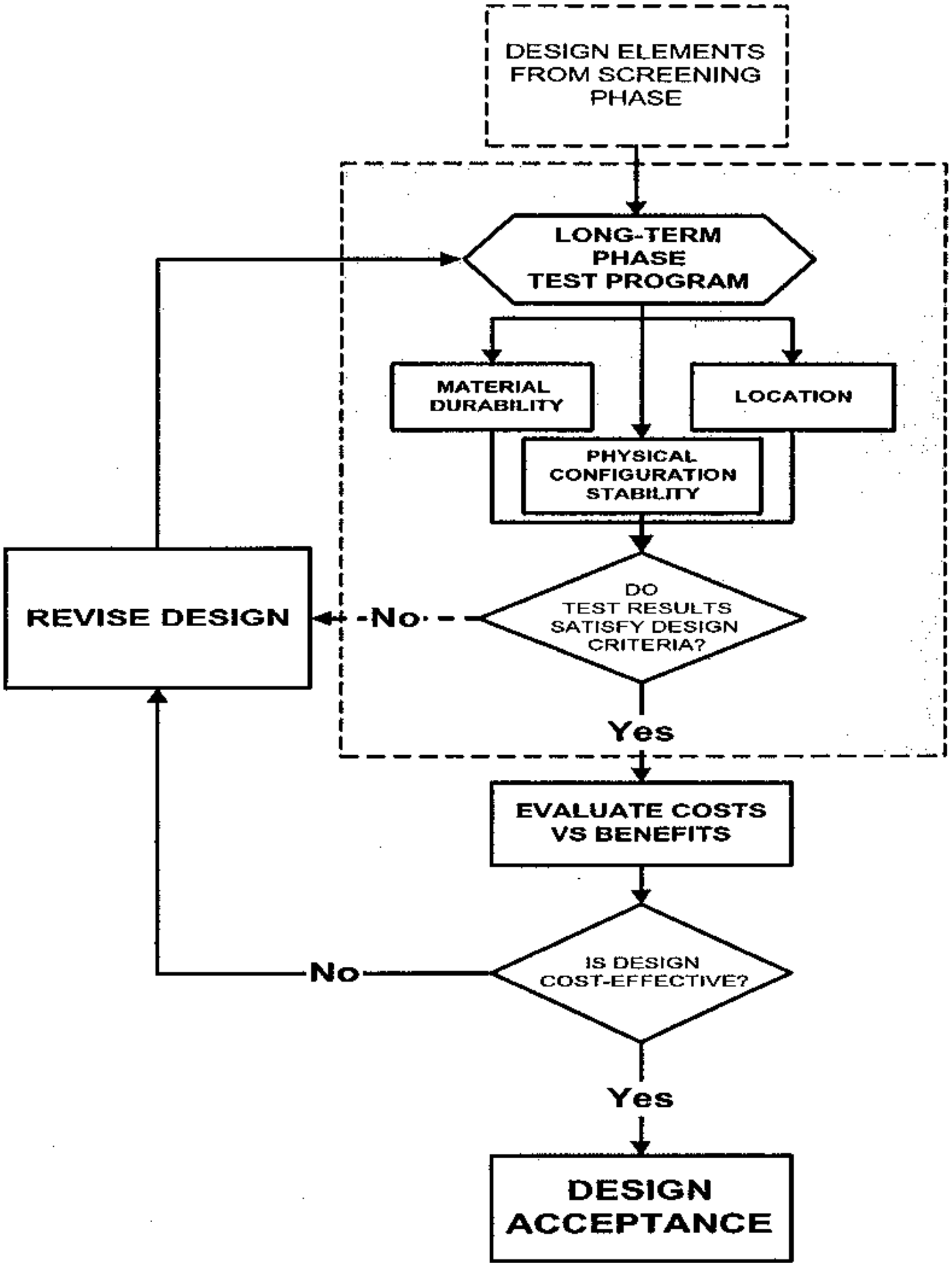

Figure 3. Long-Term Phase Testing Process

The testing process is expected to be iterative. As the results of testing are acquired and evaluated, it is likely that alternative materials, configurations, and locations will be proposed. These will be incorporated as modifications to the reference designs and, in turn, will be subject to testing and analysis.

3.0 Markers Systems Testing

The testing and evaluation logic for the tests to be performed during the screening phase and during the long-term phase is illustrated in Figure 4. Design criteria applicable to specific markers systems are identified in the *Permanent Markers Implementation Plan*. For each marker system or component, the applicable design criteria are associated with a screening phase test objective or issue. A specific test method or type of analysis, responsive to the test objective or issue, is then identified. Also, when available, one or more test references or test standards are defined for each test. When a needed test method does not currently exist it will be necessary to develop the test method early in the test program. This decision-making logic is applied to the evaluations of the markers systems material properties, physical configurations, and locations.

Upon the completion of the screening phase testing or analysis, the extent to which the screening criteria are met will be evaluated. If design changes are warranted, the modified or new design will be subject to screening evaluations. If design changes are not warranted, long-term tests or analyses will be performed, as appropriate.

The test program is organized according to the matrix shown in Table1. In this matrix structure each marker system component has tests or analyses in each of three categories: material properties; configuration; and location, as described earlier in this plan. The tests are also grouped into two phases, screening and long-term, in which the issues in the three test categories are addressed in their logical sequence and appropriate time frame.

The screening phase is further divided into two stages, the initial (or laboratory) stage and the field stage. The structure of the two stages will vary according to the marker component and its individual testing and evaluation needs. For example, in the initial stage of testing the components of the Berm, a variety of appropriate standard test methods already exist and testing can begin immediately. (Established test methods identified in Table 1 are listed and briefly described in Appendix A.) For other marker systems like the radar reflectors, however, test methods must be developed because no appropriate standard methods currently exist.

In addition, for some tests, it is not yet possible to define the most appropriate established standard method because the materials or configurations of some markers systems are not currently well defined. Therefore, Table1 is a working document that will evolve as specific tests are developed and performed and as the reference designs are modified in response to test results. The following sections describe the test objectives or issues and the tests and analyses selected at the initial stage of test program development to meet those test objectives.

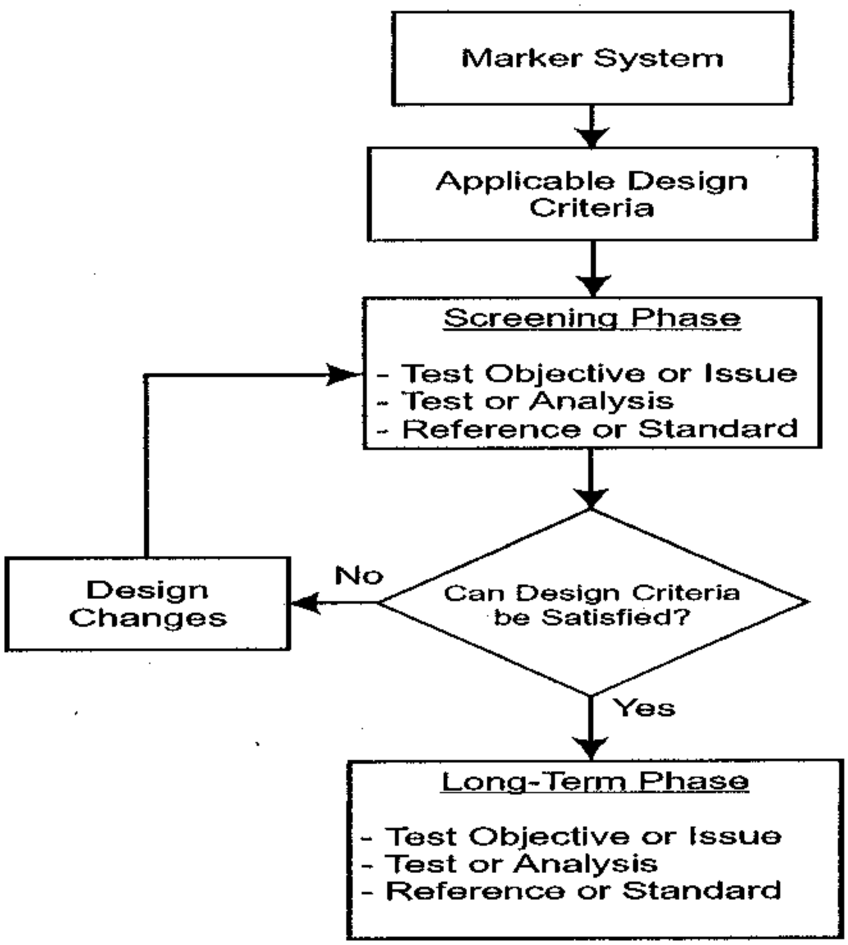

Figure 4. Tests Selection Rationale

Table 1. Tests by Marker System and Alternative Materials and Phase

MARKER SYSTEM	DESIGN CRITERIA (1) Addressed by Test	SCREENING PHASE			LONG-TERM PHASE		
		TEST OBJECTIVE OR ISSUE	TEST OR ANALYSIS	REFERENCE OR STANDARD	TEST OBJECTIVE OR ISSUE	TEST OR ANALYSIS	REFERENCE OR STANDARD
Large Surface Markers		Configuration			Configuration		
	1a, 1b, 1c 2a, 2b	*Evaluate **visibility** of single marker and of inscriptions on marker*	Full-scale mock-up with inscriptions	TO BE DEVELOPED	none		
		height and shape	Mutliple full-scale mock-ups	TO BE DEVELOPED			
		Location			Location		
	1a, 1b, 1c, 4g	*Evaluate **number and positions** of markers*	Multiple mock-up locations	TO BE DEVELOPED	none		
		*Evaluate effects of **sand deposition***	Wind transport/ sedimentation model	TO BE DEVELOPED			
		Material Properties *Evaluate rock properties that affect **durability**, including:*			Material Properties		
	4a	stable mineralogy	petrographic study	ASTM D294, C295; ISRM 1977c	*Evaluate **rate of weathering***	Record weathering of rock minerals and fabric	prototype field demonstration
	4a	density, weight	specific gravity	ASTM C97; ISRM 1972a			
	4a	resistance to weathering	sodium sulfate soundness	ASTM D5121, D5240			
	4a, 4b, 4d	resistance to impact damage	Schmidt Hammer hardness	ASTM C805; ISRM 1977a			
			Charpy impact	ASTM E23			
	4a	resistance to water penetration	absorption	ASTM C97; ISRM 1972a			
	4a	resistance to water erosion	liquid impingement erosion	ASTM G73			
	4a, 4b	resistance to erosion	L.A. Abrasion	ASTM D5121, C535; ISRM 1977a	*Evaluate **resistance to erosion***	Measure losses in rock surface on all sides	prototype field demonstration
			solid particle impingement	ASTM G76			
	4b, 4c	*Evaluate **strength***	unconfined compressive strength	ASTM C170; ISRM 1972b	*Observe **fractures***	Measure and record fractures	prototype field demonstration
			splitting tensile strength	ASTM D3967; ISRM 1977b			
			point load strength	ASTM D5731; ISRM 1985			
		*Evaluate rock properties that affect **inscription**, including:*			*Evaluate **durability of inscription***	Measure losses in inscription depth and sharpness	TO BE DEVELOPED
	3a	stable mineralogy	petrographic study	ASTM D294, C295; ISRM 1977c			
	3a	mineral hardness	L.A. Abrasion	ASTM D5121, C535			
	3a	matrix hardness	Schmidt Hammer hardness	ASTM C805; ISRM 1977a			
	3a	inscribability	inscription trial	TO BE DEVELOPED			
	3a, 4a	durability	sodium sulfate soundness	ASTM D5121, D5240			
	4b, 4c	*Evaluate **bearing capacity** of selected foundation strata*	test drilling and sampling of soils	ASTM D1452, D1586, D1587 D3441, D5434, D5778, D6151	*Assess **foundation performance***	Measure changes in X-Y-Z coordinates of survey points	Current land surveying best practices
			load test	ASTM D1194			
			full-scale prototype marker	monitoring plan, to be developed			
Small Subsurface Markers		Configuration			Configuration		
	1a,1b,1c	*Evaluate **detectability** of single marker*	ground-penetrating radar blind excavation test	TO BE DEVELOPED TO BE DEVELOPED	none		
		Location			Location		
	1a, 1b, 1c, 4g	*Evaluate **number and positions** of markers*	ground-penetrating radar blind excavation test	TO BE DEVELOPED TO BE DEVELOPED	none		
		Material Properties *Evaluate rock properties that affect **durability**, including:*			Material Properties		
	4a	stable mineralogy	petrographic study	ASTM D294, C295; ISRM 1977c			
	4a	density, weight	specific gravity	ASTM C97; ISRM 1972a			
	4a	resistance to weathering	sodium sulfate soundness	ASTM D5121, D5240	*Evaluate **rate of weathering***	record weathering of rock minerals and fabric	TO BE DEVELOPED
	4a	resistance to water penetration	absorption	ASTM C97; ISRM 1972a			
		*Evaluate rock properties that affect **inscription**, including:*			*Evaluate **durability of inscription***	measure losses in inscription depth and sharpness	TO BE DEVELOPED
	3a	stable mineralogy	petrographic study	ASTM D294, C295			
	3a	mineral hardness	L.A. Abrasion	ASTM D5121, C535			
	3a	matrix hardness	Schmidt Hammer hardness	ASTM C805; ISRM 1977a			
	3a	inscribability	inscription trial	TO BE DEVELOPED			

MARKER SYSTEM	DESIGN CRITERIA Addressed by Test	SCREENING PHASE			LONG-TERM PHASE		
		TEST OBJECTIVE OR ISSUE	TEST OR ANALYSIS	REFERENCE OR STANDARD	TEST OBJECTIVE OR ISSUE	TEST OR ANALYSIS	REFERENCE OR STANDARD
Buried Storage Rooms		Configuration			Configuration		
	4b, 4c	*Evaluate structural design for stability under extreme load conditions, including*					
		strength in compression	compressive strength	ASTM C170; ISRM 1972b	*Evaluate long-term stability*	Monitor prototype room structural performance by periodic deformation measurements	Instrumentation and data recording system to be developed
		response to bending	modulus of rupture	ASTM C99			
		strength in flexure	flexural strength	ASTM C880			
		tensile strength	splitting tensile strength	ASTM D3967; ISRM 1977b			
		response to loads	structural analysis	TO BE DEVELOPED			
			point load strength	ASTM D5731; ISRM 1985			
		Location			Location		
	1a, 1b, 1c	*Evaluate detectability of buried room*	Construct full-scale prototype, then:		none		
			ground-penetrating radar	TO BE DEVELOPED with RRL			
			seismic refraction survey	ASTM D5777			
			seismic reflection survey	TO BE DEVELOPED			
		Material Properties			Material Properties		
		Evaluate properties that affect durability, including:	granite dimension stone standards	ASTM C615			
	4a	stable mineralogy	petrographic study	ASTM D294, C295			
	4a	density, weight	specific gravity	ASTM C97; ISRM 1972a			
	4a	resistance to water penetration	absorption	ASTM C97; ISRM 1972a			
	4a	resistance to weathering	sodium sulfate soundness	ASTM D5121, D5240	*Evaluate rate of weathering*	Record weathering of rock minerals and fabric	TO BE DEVELOPED
	4a,4b,4d	resistance to impact damage	Schmidt Hammer hardness	ASTM-C805; ISRM 1977a			
			Charpy impact	ASTM E23			
	3a	*Evaluate rock properties that affect inscription, including:*			*Evaluate durability of inscription*	measure losses in inscription depth and sharpness	TO BE DEVELOPED
		stable mineralogy	petrographic study	ASTM D294, C295; ISRM 1977c			
		mineral hardness	L.A. Abrasion	ASTM D5121, C535			
		matrix hardness	Schmidt Hammer hardness	ASTM C805; ISRM 1977a			
		inscribability	inscription trial	TO BE DEVELOPED			
Information Center		Configuration			Configuration		
	4b, 4c	*Evaluate structural design for stability under extreme load conditions, including*			none		
		strength in compression	compressive strength	ASTM C170; ISRM 1972b			
		response to bending	modulus of rupture	ASTM C99			
		strength in flexure	flexural strength	ASTM C880			
		tensile strength	splitting tensile strength	ASTM D3967; ISRM 1977b			
		response to loads	structural analysis	TO BE DEVELOPED			
			point load strength	ASTM D5731; ISRM 1985			
		Evaluate effects of sand deposition	Wind transport/ sedimentation model	TO BE DEVELOPED			
		Location			Location		
	4b, 4c	*Evaluate bearing capacity of selected and alternative foundation strata*	test drilling and sampling of soils	ASTM D1452, D1586, D1587 D3441, D5434, D5778, D6151	none		
			load test	ASTM D1194			
		Material Properties			Material Properties		
	4a	*Evaluate rock properties that affect durability, including:*	granite dimension stone standards	ASTM C615	*Durability*	use results of marker and buried room prototype tests	
		stable mineralogy	petrographic study	ASTM D294, C295; ISRM 1977c			
		density, weight	specific gravity	ASTM C97; ISRM 1972a			
		resistance to water penetration	absorption	ASTM C97; ISRM 1972a			
		resistance to weathering	sodium sulfate soundness	ASTM D5121, D5240			
		resistance to erosion	hardness	ASTM C805; ISRM 1977a			
	3a	*Evaluate rock properties that affect inscription, including:*			*Inscription*	use results of marker and buried room prototype tests	
		stable mineralogy	petrographic study	ASTM D294, C295; ISRM 1977c			
		mineral hardness	L.A. Abrasion	ASTM D5121, C535			
		matrix hardness	Schmidt Hammer hardness	ASTM C805; ISRM 1977a			
		inscribability	inscription trial	TO BE DEVELOPED			

MARKER SYSTEM	DESIGN CRITERIA Addressed by Test	SCREENING PHASE			LONG-TERM PHASE		
		TEST OBJECTIVE OR ISSUE	TEST OR ANALYSIS	REFERENCE OR STANDARD	TEST OBJECTIVE OR ISSUE	TEST OR ANALYSIS	REFERENCE OR STANDARD
Concrete		<u>Material Properties</u> *Evaluate properties that affect durability, including:*			*Evaluate durability*	Construct full-scale prototypes of concrete structures to be evaluated, then:	TO BE DEVELOPED
	4a	erosion resistance	sandblast abrasion	ASTM C418			
			mechanical abrasion	ASTM C779, C944			
			L.A. Abrasion	ASTM D5121, C535; ISRM 1977a			
			solid particle impingement	ASTM G76			
	4a	weathering resistance, water	chloride permeability	ASTM C1202	rate of weathering	Record weathering of concrete	TO BE DEVELOPED
			rapid freeze-thaw	ASTM C666			
			specific gravity, absorption	ASTM C642			
	4a	resistance to water erosion	liquid impingement erosion	ASTM G73	rate of erosion	Measure losses from exposed surfaces	TO BE DEVELOPED
	4a, 4c	material stability	petrographic analysis of concrete	ASTM C856			
	4a, 4b, 4 c	impact damage resistance	penetration resistance	ASTM C803			
			Charpy impact	ASTM E23			
	4a, 4 c	volume stability	shrinkage	ASTM C157			
	4a, 4c	chemical stability	alkali-silica expansion	ASTM C1293			
	4a, 4b, 4c	thermal stability	coefficient of thermal expansion	Corps of Engineers CRD C39-81			
		Evaluate properties that affect strength, including:					
	4b, 4c	compressive strength	compressive strength	ASTM C39			
	4b, 4c	flexural strength	flexural strength	ASTM C78			
	4b, 4c	strength	elastic modulus	ASTM C215			
	4a	density, water penetration	specific gravity, absorption	ASTM C642			
	4b, 4c	splitting tensile strength	splitting tensile strength	ASTM C496			
	4b, 4c	point load strength	penetration resistance	ASTM C803			
Ceramics and Plastics		<u>Material Properties</u> *Evaluate properties that affect durability, including:*			*Evaluate durability*	Construct full-scale prototypes of ceramic or plastic structures to be evaluated, then:	TO BE DEVELOPED
	4a	erosion resistance	sandblast abrasion	ASTM C418			
			mechanical abrasion	ASTM C779, C944			
			L.A. Abrasion	ASTM D5121, C535; ISRM 1977a			
			solid particle impingement	ASTM G76			
	4a	weathering resistance, water	chloride permeability	ASTM C1202	rate of weathering	Record rate of weathering	TO BE DEVELOPED
			rapid freeze-thaw	ASTM C666, ASTM C1026			
			specific gravity, absorption	ASTM C642, ASTM20			
	4a	resistance to water erosion	liquid impingement erosion	ASTM G73			
		resistance to UV radiation	concentrated sunlight (plastics)	ASTM D4364, ASTM D4141	rate of erosion	Measure losses from exposed surfaces	TO BE DEVELOPED
	4a, 4c	material stability	hardness	ASTM E3, ASTM E92, ASTM E140, ASTM D2583 (plastics)			
	4a, 4b, 4 c	impact damage resistance	penetration resistance	ASTM C803			
			Charpy impact	ASTM E23			
	4a, 4 c	volume stability	shrinkage	ASTM C157, ASTM D756			
	4a, 4c	chemical stability	alkali-silica expansion	ASTM C1293			
	4a, 4b, 4c	thermal stability	coefficient of thermal expansion	Corps of Engineers CRD C39-81			
		Evaluate properties that affect strength, including:					
	4b, 4c	compressive strength	compressive strength	ASTM C39			
	4b, 4c	flexural strength	flexural strength	ASTM C78			
	4b, 4c	strength	elastic modulus	ASTM C215, ASTM C1161, ASTM E9			
	4a	density, water penetration	specific gravity, absorption	ASTM C642			
	4b, 4c	splitting tensile strength	splitting tensile strength	ASTM C496			
	4b, 4c	point load strength	penetration resistance	ASTM C803			

MARKER SYSTEM	DESIGN CRITERIA Addressed by Test	SCREENING PHASE			LONG-TERM PHASE		
		TEST OBJECTIVE OR ISSUE	TEST OR ANALYSIS	REFERENCE OR STANDARD	TEST OBJECTIVE OR ISSUE	TEST OR ANALYSIS	REFERENCE OR STANDARD
Metals and Metal Alloys		<u>Material Properties</u>					
		*Evaluate properties that affect **durability**, including:*			***Evaluate durability***	Construct full-scale prototypes of metallic structures to be evaluated, then:	TO BE DEVELOPED
	4a	erosion resistance	sandblast abrasion	ASTM C418			
			mechanical abrasion	ASTM C779, C944			
			atmospheric corrosion	ASTM G50			
			L.A. Abrasion	ASTM D5121, C535; ISRM 1977a			
			solid particle impingement	ASTM G76	rate of weathering	Record rate of weathering	TO BE DEVELOPED
	4a	weathering resistance, water	chloride permeability	ASTM C1202			
			rapid freeze-thaw	ASTM C666			
			specific gravity, absorption	ASTM C642			
	4a	resistance to water erosion	liquid impingement erosion	ASTM G73	rate of erosion	Measure losses from exposed surfaces	TO BE DEVELOPED
	4a, 4c	material stability	hardness	ASTM E3, ASTM E92, ASTM E18, ASTM E140			
	4a, 4b, 4 c	impact damage resistance	penetration resistance	ASTM C803			
			Charpy Impact	ASTM E23			
	4a, 4 c	volume stability	shrinkage	ASTM C157			
	4a, 4c	chemical stability					
	4a, 4b, 4c	thermal stability	coefficient of thermal expansion	Corps of Engineers CRD C39-81			
		*Evaluate properties that affect **strength**, including:*					
	4b, 4c	compressive strength	compressive strength	ASTM C39			
	4b, 4c	flexural strength	flexural strength	ASTM C78			
	4b, 4c	yield strength	yield strenght	ASTM E8, ASTM E9			
	4b, 4c	strength	elastic modulus	ASTM C215			
	4a	density, water penetration	specific gravity, absorption	ASTM C642			
	4b, 4c	splitting tensile strength	splitting tensile strength	ASTM C496			
	4b, 4c	point load strength	penetration resistance	ASTM C803			
Berm Components							
Berm Foundation		<u>Material Properties</u>			<u>Material Properties</u>		
	4a, 4b, 4c	*Evaluate properties that affect **foundation performance** including:*			*Continue to monitor **test berm** for:*		
		soil identification and stratification	drilling, logging, and sample collection	ASTM D1452, D1586, D1587, D2488, D6151, D6169, D4220, D5434			
		soil classification	grain size analysis	ASTM D421, D2217, D422, D1140, D2487			
		plasticity	Atterberg limits	ASTM D4318			
		dispersivity	dispersivity test	ASTM D4221, D4647			
		matrix stability	collapse potential test	ASTM D5333			
			shrink/ swell , expansion tests	ASTM D4546, D4829			
		settlement potential	one-dimensional consolidation test	ASTM 2435			
		in-situ density	test berm field penetration tests	ASTM D1586, D3441, D5778			
			test berm nuclear density tests	ASTM D6031, D5195			
		actual settlement and bearing failure	Install and measure settlement plates at test berm foundation surface	TO BE DEVELOPED	settlement and bearing failure	settlement plates at foundation surface and inclinometers	TO BE DEVELOPED

MARKER SYSTEM	DESIGN CRITERIA Addressed by Test	SCREENING PHASE			LONG-TERM PHASE		
		TEST OBJECTIVE OR ISSUE	TEST OR ANALYSIS	REFERENCE OR STANDARD	TEST OBJECTIVE OR ISSUE	TEST OR ANALYSIS	REFERENCE OR STANDARD
Salt or soil core		<u>Material Properties</u> *Evaluate properties that affect*			<u>Material Properties</u> *Continue to monitor test berm for:*		
	4a, 4b, 4c	***structural performance*** *including:* compaction and density	grain size analysis	ASTM D421, D422, D2487	structural failure and settlement	inclinometer and settlement plate measurements	TO BE DEVELOPED
			maximum compacted density	ASTM D698, D1557, D4253, D4254			
			test berm in-place density	ASTM D1556, D2922, D3017			
		compacted strength	uniaxial compressive strength	(Existing SNL test data for salt)			
		creep rate	creep tests	(Existing SNL test data for salt)			
		consolidation and settlement	uniaxial consolidation	ASTM D2435			
			test berm inclinometers, settlement plates	TO BE DEVELOPED			
	4a, 4b, 4c	*Evaluate properties that affect* ***durability:*** porosity	specific gravity, compacted density	ASTM D5550, D698, D1557	long-term dissolution of salt	periodic surveys of salt core using: ground penetrating radar surveys	TO BE DEVELOPED
		hydraulic conductivity	permeability	ASTM D2434		cone penetrometer	ASTM D3441, D5778
		solubility at field density	soluble salt content, leachability	ASTM D4542, D5744		in-place density measurements	ASTM D5195, D6031
Caliche		<u>Material Properties</u> *Evaluate properties that affect*			<u>Material Properties</u> *Continue to monitor test berm for:*		
	4a, 4b, 4c	***structural performance*** *including:*	drilling, logging, and sample collection	ASTM D1452, D1586, D3550, D2488, D6151, D6169, D4220, D2937			
		mineral composition	petrologic examination	ASTM D294, C295; ISRM 1977c			
		compaction and density	grain size analysis	ASTM D2217, D422			
			maximum compacted density	ASTM D698, D1557, D4253, D4254	structural failure	inclinometer deformations	TO BE DEVELOPED
			test berm in-place density	ASTM D1556, D2922, D3017, D4564			
		resistance to weathering	sodium sulfate soundness	ASTM C88, D5240			
		Evaluate properties that affect performance as ***seepage barrier:*** particle size distribution	grain size analysis	ASTM D2217, D422			
		capillarity	moisture tension	ASTM D2325			
		hydraulic conductivity	permeability	ASTM D2434			
		seepage rate	test berm measurement with neutron probe	ASTM D5220	seepage rate	neutron probe	ASTM D5220
		resistance to water penetration	absorption	ASTM C127, C97; ISRM 1972a		psychrometer measurements	TO BE DEVELOPED
Riprap		<u>Material Properties</u> *Evaluate rock properties that*			<u>Material Properties</u> *Continue to monitor test berm for:*		
	4a-d	*affect* ***durability***, *including:*	evaluation methodologies	ASTM D4992			
		stable mineralogy	petrographic study	ASTM D294, C295; ISRM 1977c			
		density, weight	specific gravity	ASTM C127; ISRM 1972a			
		effects of wetting/ drying	wet/ dry durability	ASTM D5312			
		effects of freeze/ thaw	freeze/ thaw durability	ASTM D5313			
		resistance to water penetration	absorption	ASTM C127; ISRM 1972a			
		resistance to weathering	sodium sulfate soundness	ASTM D5240	rate of weathering	Visually observe and record weathering of rock	TO BE DEVELOPED
		resistance to impact damage	Schmidt Hammer hardness	ASTM C805; ISRM 1977a			
		resistance to erosion	L.A. Abrasion	ASTM C535	erosion	Perform visual observations and manual measurements	NRCS and IECA procedures

MARKER SYSTEM	DESIGN CRITERIA Addressed by Test	SCREENING PHASE			LONG-TERM PHASE		
		TEST OBJECTIVE OR ISSUE	TEST OR ANALYSIS	REFERENCE OR STANDARD	TEST OBJECTIVE OR ISSUE	TEST OR ANALYSIS	REFERENCE OR STANDARD
Soil		Material Properties			Material Properties		
	4a, 4b, 4c	*Evaluate properties that affect **structural performance** including:*	drilling, logging, and sample collection	ASTM D1452, D1586, D1587, D2488, D6151, D6169, D4220, D420, D3550	*Continue to monitor test berm for:*		
		soil classification	grain size analysis	ASTM D421, D2217, D422, D1140 D2487, D4221			
		plasticity	Atterberg limits	ASTM D4318			
		swell/ shrink potential	shrink/ swell , expansion tests	ASTM D4546, D4829			
		compaction	maximum compacted density	ASTM D698, D1557, D4253, D4254			
			optimum moisture content	ASTM D698, D1557			
			test berm in-place density	ASTM D1556, D2922, D3017	structural failure	inclinometer and survey point measurements	TO BE DEVELOPED
		dispersivity	dispersivity test	ASTM D4221, D4647			
		settlement	uniaxial consolidation	ASTM D2435	settlement	inclinometer and survey point measurements	TO BE DEVELOPED
	4a, 4b, 4c	*Evaluate properties that affect **water infiltration and retention**:*					
		particle size distribtuion	grain size analysis	ASTM D421, D2217, D422, D1140, D2487			
		hydraulic conductivity	permeability	ASTM D2434	increases in water content	neutron probe	ASTM D5220
		capillarity	moisture tension	ASTM D3152, D2325			
		infiltration potential of soil	field infiltration tests	ASTM D3385			
	4a, 4b, 4c	*Evaluate properties that affect **erosion**:*					
		particle size distribution	grain size analysis	ASTM D421, D2217, D422, D1140, D2487			
		dispersivity	dispersivity test	ASTM D4221, D4647			
		static stability	slope stability analysis	Simplified Bishop Method	slope deformation	inclinometer and survey point measurements	TO BE DEVELOPED
		stability during earthquake	pseudostatic stability analysis	Simplified Bishop Method			
		settlements	consolidation test	ASTM D2435	settlements	inclinometer and survey point measurements	TO BE DEVELOPED
		erosional stability	erosion resistance soil loss and allowable shear calc	ASTM D5852 RUSLE, USCOE (1970)	soil loss and rill formation	visual observations and manual measurements	NRCS and IECA procedures
		resistance to biointrusion	resistance to roots and animals	TO BE DEVELOPED	resistance to biointrusion	visual observations and manual measurements of burrow and root depths and concentrations	TO BE DEVELOPED
Berm Structure		Configuration			Configuration		
	4b, 4c	*Evaluate factors that affect **structural stability**:*			*Continue to monitor test berm for:*		
		static stability	static slope stability analysis	Simplified Bishop Method	XYZ deformations	inclinometer and survey point measurements	TO BE DEVELOPED
		stability during earthquakes	pseudostatic slope stability analysi	Simplified Bishop Method			
		settlements	consolidation test	ASTM D2435	settlements	inclinometer, survey point, and settlement plate measurements	TO BE DEVELOPED
		all of the above	**test berm** with inclinometers, settlement plates, and survey points	TO BE DEVELOPED			
	4a, 4b, 4c	*Evaluate factors that affect **erosional stability**:*					
		erosional resistance	erosion resistance soil loss and allowable shear calc	ASTM D5852 RUSLE, USCOE (1970)	erosion	visual observations and manual measurements	NRCS and IECA procedures
		resistance to biointrusion	resistance to roots and animals	TO BE DEVELOPED			
		all of the above	**test berm** with visual observations and manual measurements	TO BE DEVELOPED		visual observations and manual measurements of burrow and root depths and concentrations	TO BE DEVELOPED
		Evaluate effects of sand deposition	Wind transport/ sedimentation model	TO BE DEVELOPED			

MARKER SYSTEM	DESIGN CRITERIA Addressed by Test	SCREENING PHASE			LONG-TERM PHASE		
		TEST OBJECTIVE OR ISSUE	TEST OR ANALYSIS	REFERENCE OR STANDARD	TEST OBJECTIVE OR ISSUE	TEST OR ANALYSIS	REFERENCE OR STANDARD
Magnets		Configuration			Configuration		
		Evaluate factors that affect					
	1a,1b 1c, 4g	***detectability:***					
		pattern shape	optimal pattern	TO BE DEVELOPED	none		
		orientation	optimal alignment magnet	TO BE DEVELOPED			
		pattern density	optimal number of magnets	TO BE DEVELOPED			
		all of the above	air/ground magnetometer survey	TO BE DEVELOPED			
		Location			Location		
		Evaluate factors that affect					
		detectability:			none		
	1a, 1b, 1c; 4a-e	depth	air/ground magnetometer survey	TO BE DEVELOPED			
	1a, 1b 1c, 4d, 4e	spacing	air/ground magnetometer survey	TO BE DEVELOPED			
		Material Properties			Materials		
		Evaluate factors that affect			*Evaluate for* ***durability***		
		durability:			*including:*	Fabricate, energize and	
	4a, 4b, 4f	composition	optimal metallurgy	TO BE DEVELOPED		install prototype magnets, then	
	4a	corrosion resistance	(later)	TO BE DEVELOPED	corrosion rates	recover and measure mass loss	TO BE DEVELOPED
		Evaluate factors that affect					
		detectability:					
	1a, 1b, 1c	magnetic intensity	intensity measurements	ASTM A977			
	4b, 4c	longevity of magnetism	magnetism decay rate	ASTM A977	demagnetization	periodic magnetometer surveys	TO BE DEVELOPED
	1a,1b	magnetic field	field shape measurements	ASTM A977	detection range	periodic magnetometer surveys	TO BE DEVELOPED
	1a, 1b, 1c, 4b, 4c	all of the above	air/ground magnetometer survey	TO BE DEVELOPED			
		Evaluate ***detectability*** *of*					
	1a, 1b, 1c	demagnetized prism	air/ground magnetometer survey	TO BE DEVELOPED			

Footnote 1. Design criteria are listed below under performance criteria headings:

1. To alert the visitor to the existence of the site, markers must be:
    a. readily detected from all directions and means of intrusion
    b. detectable directly by human senses and by indirect remote sensing methods
    c. obviously anomalous with respect to the natural features of the site

2. To convey a warning of the danger to a visitor, markers must be:
    a. identifiable as conveying a warning
    b. able to convey danger independent of the language of the visitor

3. To inform a visitor about the degree and nature of the danger, markers must be:
    a. able to be inscribed with symbols and letters
    b. contain sufficient information about the site and its dangers to dissuade intrusion and should be identifiable within the first four levels of understanding [as discussed in the Compliance Certification Application (CCA), Appendix PIC]
    c. state the information in enough different languages that at least one of them will likely be familiar to the visitor
    d. display the information so that it is readily discovered without the need for more than surficial intrusion into the site

4. To endure in form and function for the longest time possible, markers must be:
    a. as resistant as possible to chemical and physical weathering, dissolution, and erosion
    b. able to withstand all foreseeable extreme natural conditions including earthquake, wind, flood, and fire
    c. able to remain stable in form, location and position
    d. able to resist vandalism
    e. able to minimize risk of casual removal
    f. lacking in economic value to be of no interest for scavenging and salvage
    g. sufficiently redundant to meet performance criteria despite some loss in numbers or form

3.1 Screening Phase

The screening phase will contain those tests and analyses that do not depend on time-related factors such as the necessary number and locations of Large Surface Markers. Many test issues can be addressed in the screening phase, which is expected to last three to five years. Every marker system will be tested during the screening phase, as described below.

3.1.1 Large Surface Markers

The reference design for the Large Surface Markers is two rectangular arrays, one with 16 markers on the perimeter of the repository footprint and the other with 32 markers on the perimeter of the Controlled Area. Granite has been identified in the reference design as the preferred rock type but other rock types will be considered. Based on the applicable design criteria (second column in Table 1), the tests objectives are evaluation of:

- Configuration - Visibility of the marker and its inscriptions
- Location - Number and locations of the markers
- Material Properties - Durability of the marker, strength, inscription durability, inscribability, and bearing capacity of the marker foundation

3.1.1.1 Configuration

The reference design for the Large Surface Markers consists of two members, an elongated four-sided prism that connects by a mortise-and-tenon connection to a truncated pyramid base. The base foundation is 17 feet below ground surface and the top extends to 25 feet above ground surface. Inscriptions will be placed on both members. For the Large Surface Markers to satisfy the design criteria, they must be visible to the eye as an anomalous feature in the natural landscape, and the above-ground inscriptions must be visible to anyone approaching the markers close enough to examine them with the unaided eye.

To evaluate the visibility of the Large Surface Markers, a *full-scale mock-up* of a marker will be constructed and installed at one of the planned marker locations. The mock-up need not be constructed of granite or other rock material, but the inscriptions will be engraved into a surrogate material and placed on the mock-up at the above-ground position described in the reference design.

Once in place, the mock-up marker will be tested for visibility with a method that establishes the distance at which a person with normal vision approaching the site will first notice a Large Surface Marker. This test will be performed in conjunction with the location test, described below. The test will employ people who have no involvement with WIPP, no specific training for visual observations, and no knowledge of the objective of the test.

The configuration design elements that affect visibility and to be resolved in this test are marker shape and height. A marker must be tall enough to be visible above the surrounding terrain and vegetation, and its shape must contrast sharply with natural terrain and vegetation features. The recorded responses of the observers will be used to evaluate whether the design height and shape satisfy the design criteria in terms of visibility.

3.1.1.2 Location

The location and number of the Large Surface Markers need to be sufficient so that there is a noticable pattern to the locations of the markers. To achieve this level of awareness, at least one marker must be visible from any direction of approach, and at least two other markers must be visible from the location of any marker. In this test, the full-scale mock-up marker used to evaluate configuration will be used, and at least two additional full-scale mock-ups will be installed to each side, for a total of not less than five mock-up markers. The additional mock-ups may be made of any material, probably wood framing with plywood sides painted to resemble granite, and will be maneuverable enough to be relocated easily.

To conduct the test, the wooden mock-ups will be positioned initially at the reference-design interval distances from the configuration mock-up. Observers like those used in the configuration test will be positioned at the configuration marker site and asked to look around for any anomalous objects. If one or more other markers are seen the observer will be taken to the location of the other marker and will repeat the same observation. If at least two other markers are seen from one marker location, the distance between markers will be incrementally increased, and the test repeated, until adjacent markers are too far apart to be seen.

The location design elements that affect marker visibility, if shape and height are kept constant, are distance between markers and positions of markers. The data recorded will include distance between markers and maximum height of vegetation between markers. From this, the lowest angle of line of sight to the next visible marker will be calculated, and the maximum distance for visibility of any marker from the adjacent markers will be determined.

The terrain in the area of WIPP is characterized by scattered sand dunes. Wind-blown sand associated with active dune building and migration could accumulate in the wind shadow of the Large Surface Markers and near the Large Surface Markers located leeward of the Berm. In extreme conditions of sand deposition, the Large Surface Markers might be buried in sand. To assess this possibility, a wind-borne transport and sedimentation model, to be developed during the screening test phase, will be run. If model results indicate a reasonable likelihood that the Large Surface Markers could be buried in their reference design locations, alternative locations may be selected.

3.1.1.3 Material Properties

Although durability of the Large Surface Markers is affected somewhat by the configuration of the marker, the material properties are most important to durability and will be the basis for selection of the type of rock or other material to be used. Strength will also be important if tenon or other fitted connections are used to join the two pieces of the marker. Because the Large Surface Markers will be exposed to the full range of climatic conditions that occur at the WIPP site, durability (both material and inscription) and strength parameters are critical to their long-term performance.

The parameters of *material durability* include mineralogy, density and weight, and resistance to weathering, impact damage, water penetration, and erosion. These are the parameters that affect durability of riprap, for which a variety of tests have been developed and are widely accepted by government agencies like the U.S. Bureau of Reclamation, the Army Corps of Engineers, and the U.S. Nuclear Regulatory Commission. These tests include petrographic study, specific gravity, sodium sulfate soundness, Schmidt Hammer hardness, absorption, and Los Angeles (LA) abrasion. Standards have been developed by the American Society for Testing and Materials (ASTM) and the International Society for Rock Mechanics (ISRM) that address all of these tests, and the relevant standards are identified for each test in Table 1. Also, the tests are briefly described in Appendix A.

In general, if rock is used to construct the Large Surface Markers, the petrographic study should determine that there is less than 10 percent micaceous mineral content, at least 30 percent quartz, and no weathering products such as clays. A durability score of at least 80 percent should be attained by the combined scores of specific gravity, absorption, soundness, and hardness.

The reference design calls for a mortise-and-tenon connection between the base and upper sections of the large marker. This design puts complete reliance on the *strength* of the tenon to resist separation of the two sections by rotational or sliding movements. Sliding is opposed by the shear resistance between the two sections, a function of the weight of the upper section and the angle of friction along the common surfaces, both of which are high, as well as the shear strength at the base of the tenon. Rotational movement (which could occur under extreme wind loads, differential movements in response to earthquakes, or impacts from heavy equipment) is more likely. To oppose differential rotation, some combination of compressive strength, tensile strength, and point load strength will have to be mobilized in the tenon. For this reason all three strength parameters will be tested using the procedures listed in Table 1.

The Large Surface Markers will be inscribed with symbols and text that will convey warnings about the site. Because of the differences in rock hardness and texture, *inscribability* and *inscription durability* will vary between rock types. Rock properties that are expected to affect inscribability (including mineralogy, mineral hardness, and matrix hardness) will be assessed by the same tests used for marker durability. *Inscribability* will be directly determined by attempting to inscribe the same symbols and text on several candidate marker materials. The attempts will be made using the same methods and craftsman on each material. The inscriptions will be examined for sharpness, depth and any damage to the rock fabric using procedures to be developed.

Inscription durability will be evaluated during the screening phase and the long-term test program. For screening evaluations, inscribed blocks will be subjected to the sodium sulfate soundness test to record losses in inscription depth and sharpness. These test results will be useful in preliminary selection of rock types and in final design of inscriptions.

The reference design for the Large Surface Markers will weigh approximately 105 tons. This load will exert a total pressure of about 3281 pounds per square foot (psf) [22.79 pounds per square inch (psi)] and a net additional pressure of about 1240 psf (8.61 psi) on the earth below the base. This pressure is substantially higher than any previous earth pressure at the foundation level. If the supporting (foundation) strata are unable to bear this load, foundation failure will occur and the marker will abruptly settle or tilt, and possibly overturn. Therefore, the *bearing capacity* of the marker foundation must be evaluated.

Procedures commonly used in soils and foundation engineering are available for this testing and evaluation and are listed in Table 1. At selected locations of the Large Surface Markers, test drilling and soil sampling will be used to characterize foundation conditions to the depth of influence of the marker load. Based on evaluation of these investigations, load tests will be conducted at selected marker locations. The number of load tests conducted will be sufficient to cover the range of foundation conditions identified by test drilling and will concentrate on the weakest or otherwise most problematic conditions. Results of the load tests will determine the upper limit for ground pressures with a substantial factor of safety; if the load tests indicate inadequate bearing capacity, a change in marker design or foundation depth or location, or both, would be indicated.

At the conclusion of screening tests on Large Surface Markers, it is expected that no unresolved issues related to configuration or location will remain and no tests associated with these issues are expected to be needed in the long-term test program. However, several material properties cannot be fully evaluated during the screening phase and will require additional effort in the long-term phase. These include observations and measurements of rates of weathering, resistance to erosion, evidence of fracturing, inscription durability, and foundation performance.

3.1.2 Small Subsurface Markers

The reference design for the Small Subsurface Markers is a disk having a diameter of nine inches fabricated from a variety of materials. These disks are to be placed at random locations and various depths in the shallow subsurface of the WIPP repository footprint, within the Berm, and in the four shafts. Granite, aluminum oxide, and fired clay have been identified as potential materials of fabrication but other rock types and other materials may be proposed for consideration. Based on the applicable design criteria, the tests objectives are evaluation of:

- Configuration - Detectability of a single marker
- Location - Number and positions of markers
- Material Properties - Durability, inscribability, and inscription durability

3.1.2.1 Configuration and Location

The purpose of the small buried markers is to alert and warn anyone who may drill into or excavate the soil within the WIPP footprint. Therefore, the Small Subsurface Markers must be *readily detectable* and *clearly anomalous* in the soil profile. To test whether the reference design meets these criteria, two field tests will be conducted. A number of marker mock-ups, made of the selected rock or another material, will be buried in the ground at a test site of at least one acre size. Surface disturbances will be remediated as much as possible. When no visual clue of the burial locations is left, a ground-penetrating radar (GPR) survey will be conducted to determine if the marker is of sufficient size and has sufficiently contrasting properties to be identifiable by GPR.

For the second test, an excavation contractor with no knowledge of the markers or the purpose of the work will be contracted to excavate the test site to a depth at least equal to the depth of the deepest test marker. Contractor personnel will be observed to record their responses to markers encountered during this blind excavation test. This testing will likely take place somewhere other than the WIPP site to avoid any understanding that the potential contractor may have regarding the purpose of the WIPP. Also, the excavation contractor will be requested to excavate the site in a manner consistent with drill-site pad preparation and/or road construction.

These two tests address both marker configuration and locations; the two issues are inseparable for the Small Subsurface Markers. If the Small Subsurface Markers are not large enough to be detected by GPR or during excavation, the size may have to be increased. If, regardless of size, the markers are not readily identified as anomalous, other shapes or material compositions may be needed. If the markers are noticed but the number of markers excavated does not draw close attention, the number of buried markers may have to be increased.

3.1.2.2 Material Properties

For the Small Subsurface Markers, *durability* and *inscribability* are the primary design issues. Because these markers are buried, erosion resistance is not expected to be of concern for the durability of the Small Subsurface Markers; natural erosional processes are not expected to unearth the markers. Therefore, if the Small Subsurface Markers are made of the same material as the Large Surface Markers, the material tests conducted for the latter will provide all information needed to evaluate Small Subsurface Markers material properties, and no separate tests will be needed. However, if a different material, such as metal, metal alloy, or ceramic, is used for the Small Subsurface Markers, a separate test program will be conducted to evaluate mineralogy, density, mineral and matrix hardness, resistance to water penetration and weathering, and inscribability and inscription durability. The test developed for inscribability of Large Surface Markers will be used on Small Subsurface Markers, as well.

All issues related to Small Subsurface Markers configuration and location should be resolved during the screening phase, and no tests for them will be needed in the long-term test program. Some issues regarding material properties will require more time for adequate evaluation, including rate of weathering and inscription durability. These issues will be addressed in the long-term phase, as well.

3.1.3 Buried Storage Rooms

The reference design includes two Buried Storage Rooms constructed of rock slabs for the floor and roof and rock panels for the walls and interior partitions. One room will be buried at a depth of 20 feet below ground surface and the other at natural grade within the Berm structure. All structural connections are intended to be slotted, without connectors. The test objectives include evaluation of:

- Configuration - Structural stability under extreme load conditions
- Location - Detectability
- Material Properties - Durability , strength, and inscribability

3.1.3.1 Configuration

Structural stability is a function of both configuration and material properties. Assuming the material properties are adequate, structural stability will depend on the shapes and dimensions of the structural elements, their connections, and on the loads imposed on them. With nothing but slotted connections between walls, roof, and floor, the room will lack the stiffness to resist large moments and rotational deformation. Therefore, structural stability must be developed through the stiffness of the earth backfill around and above the room. The backfill earth pressure and dynamic loads from construction activities and earthquakes must be carried by the wall panels and roof slab which will experience compressive and tensile stresses, flexure and bending moments. At connecting points, high point loads may develop.

Rock, including granite, typically has high compressive strength but much lower tensile strength and tends to display brittle rupture in bending. Consequently, the testing program will include determination of compressive and tensile strength, modulus of rupture and flexural strength, and point load strength. When the results of these tests are available, structural analysis will be performed to predict the behavior of the buried room under static and dynamic load conditions. Testing methods are listed in Table 1.

3.1.3.2 Location

Inscriptions on other markers will provide information on the locations of the Buried Storage Rooms. However, to satisfy the applicable design criteria 1a (readily detected from all directions and means of intrusion), 1b(detectable directly by human senses and by indirect remote sensing methods), and 1c (obviously anomalous with respect to the natural features of the site), it is necessary to be able to detect the Buried Storage Rooms without benefit of the inscription information. To this end, and for the purpose of long-term structural testing, a full-scale prototype buried room will be constructed at one of the two design locations, and a set of surveys will be conducted to determine the detectability of the room using several remote sensing survey methods. These surveys will include GPR, seismic reflection, and seismic refraction. For the seismic surveys, frequencies and geophone spacing commonly used in oil and gas exploration will be used initially to see if these deep-looking methods can detect a shallow anomaly. Subsequently, shallow-looking methods will be used to confirm detectability. The survey results will be used to select the actual depth of the Buried Storage Rooms.

3.1.3.3 Material Properties

In addition to the tests described above under the configuration discussion (strength and modulus), the material properties important to the performance of the Buried Storage Rooms are the same as those for the Small Subsurface Markers. In order for the strength and modulus tests to be conducted, extensive core and slab preparation will be necessary. Once these tests are completed, the broken fragments will be used for the durability tests.

At the completion of the screening phase tests for the Buried Storage Rooms, important configuration issues will remain that will be addressed in the long-term phase. In particular, the long-term stability of the prototype room will be monitored. Material properties that are time-dependent, such as the rate of weathering and inscription durability under actual field conditions, will also be evaluated in the long-term program.

3.1.4 Information Center

The reference design includes an above-ground structure consisting of four walls and seven interior panels founded at five feet below grade. The interior sides of the walls and the interior panels are inscribed with text and pictographs. All structural elements are to be granite slabs. The test issues related to the design criteria include:

- Configuration - Structural stability and effect of sand deposition
- Location - Bearing capacity of designated and alternative foundation strata
- Material Properties - Durability , strength, and inscribability

3.1.4.1 Configuration

As in the case of the Buried Storage Rooms, strength of materials and configuration are closely connected design issues of the Information Center that require testing and evaluation. The lack of stiff, shear-resistant connections of the structural elements places greater reliance on the material properties of the rock from which the structural elements are formed. Specifically, compressive and tensile strength, modulus of rupture and flexural strength, and point load strength will determine whether the reference design configuration will work. The tests performed to determine those properties for the Buried Storage Rooms structural analysis will be used to support the structural analysis of the Information Center, as well. A prototype of the Information Center will not be included in the screening phase.

The size and shape of the Information Center may cause wind-blown sand to accumulate within the structure and on its leeward side. Burial by sand is a possibility, so the same model developed to assess sand deposition around the Large Surface Markers and the Berm will also be used to assess the potential for sand to bury the Information Center. If this appears likely, some redesign of the center may be indicated.

3.1.4.2 Location

The Information Center will be located is the geometric center of the repository footprint. The shallow soil conditions in this area are well known from site investigations and construction of the WIPP surface facilities. If existing information is sufficient to determine the bearing capacity of the soils at foundation depth, no additional site investigations or tests will be needed. If the existing information is not adequate, additional test drilling and sampling will be performed. If necessary thereafter, a load test will be performed to determine safe bearing pressures at the design location.

3.1.4.3 Material Properties

The same material property issues that will be tested for the Large Surface Markers and the Buried Storage Rooms will be important regarding the Information Center. No additional or separate tests will be needed unless a material is selected for the Information Center that is different than that used in the Large Surface Markers and the Buried Storage Rooms. Relevant tests will include those to determine durability, strength, and inscribability and will include petrographic study, specific gravity and absorption, sodium sulfate soundness, Schmidt Hammer hardness, L.A. abrasion, and an inscription trial, as appropriate.

The screening phase of testing should resolve all configuration and location issues. As with the other marker systems that depend on long-term changes in material properties, durability of the material and the inscriptions will have to be evaluated in the long-term testing phase. However, this evaluation will rely on the results of tests on Large Surface Markers, Small Subsurface Markers, and the Buried Storage Rooms; no separate tests will be needed for the Information Center.

3.1.5 Berm

The reference design for the Berm includes an earthfill structure, rectangular in plan and approximately 2700 feet by 2250 feet with a height above ground surface of 33 feet, a 13 foot wide crest and nominal side slopes of 1.3H: 1V. The base of the Berm will be founded at a depth of 10 feet below natural grade. The Berm components include the foundation, a salt core, a caliche zone, a riprap zone and a soil/riprap zone. The test issues related to the design criteria include:

- Material Properties - Foundation performance, structural performance, durability, water infiltration and retention, and erosion
- Configuration - Structural stability, erosional stability, and effects of sand deposition

3.1.5.1 Berm Component Material Properties

Material properties considerations related to the various components of the Berm are described in the following sections.

3.1.5.1.1 Berm Foundation

The reference design calls for the Berm to be built on a foundation of natural soil and/or caliche at 10 feet below natural grade, apparently to have a uniformly dense bearing surface and to accommodate subgrade drainage outlets at intervals along the Berm. Because the Berm location is set to define the footprint of the WIPP waste-emplacement area, and the configuration of the foundation is by definition a flat surface defined in plan by the shape and location of the Berm structure, there are no location or configuration issues to be addressed in the test program. The sole test issue to be addressed concerns the material properties that affect *foundation performance.*

The performance of the foundation is a function of the material properties of the soil and/or rock underlying the foundation horizon. The properties that determine foundation performance are strength as measured by bearing capacity, soil texture stability, and settlement potential. These properties will be determined by test drilling and sampling at selected locations along the alignment of the Berm, followed by laboratory testing of samples for grain size analysis and plasticity (Atterberg limits), dispersivity, collapse potential, shrink/swell potential, and settlement potential (one-dimensional consolidation). During the test drilling, field penetration (cone penetrometer) tests will be performed to determine in-place density of subgrade soils at depth, and nuclear density tests will be performed on in-place surficial soils. If conditions warrant, other density-measuring methods may also be used.

The results of these test will be used to predict the long-term performance of the subgrade soils as the foundation of the Berm. Actual foundation performance evaluation requires construction and monitoring of a test berm, which will occur during the field stage of the screening phase with monitoring continuing into the long-term phase.

3.1.5.1.2 Salt Core

The Berm reference design specifies that the core of the Berm will be constructed of crushed salt excavated from the WIPP underground. Salt is soluble and is generally not used as a structural fill material. Therefore, the *structural performance* and *durability* are material property issues that must be addressed in the test program.

The structural performance of compacted crushed salt must be evaluated in the context of the expected stress environment. In the reference design, the deepest layer of compacted salt will be placed at a depth of about 43 feet below the highest part of the Berm, and the vertical stress at that level should be in the range of 4000-5600 psf. Because rock salt displays plastic deformation (creep) at high sustained stress levels, it will be important to determine how much the compacted crushed salt could deform at the design stress levels, and if those deformations would compromise the structural performance of the Berm. Sandia National Laboratories has performed extensive rock mechanics testing on both intact and crushed salt samples, so it is expected that those tests results will adequately address the issue of creep and that no additional creep testing will be required.

Tests on crushed salt and soil (because soil may be used as an alternative to salt) will be performed to measure compaction characteristics using test methods that are generally used for soils engineering and quality control of earthwork construction. Grain size analysis will be performed to determine which compaction test methods will be most appropriate, then tests will be performed to determine the maximum compacted density. Compacted samples will then be subjected to uniaxial consolidation tests to determine the potential for settlement that is not creep-related. During the construction of the test berm, in-place density of compacted salt will be measured using one or more field density test methods.

The durability of compacted salt, especially as it is affected by solubility, is the primary issue to be addressed in the test program.[2] It is expected that the potential for dissolution and rate of dissolution will be dependent in part on the hydrologic properties of the compacted salt. The primary hydrologic properties, porosity and hydraulic conductivity, will be tested. Solubility at compacted density will also be tested.

The results of the material properties tests in the early part of the screening phase will be used to predict if a salt core can be expected to be a durable structural element of the Berm. If the prediction is that it will not, a design change will be indicated before the test berm is constructed. If the prediction is positive or uncertain, a salt core will be included in some part of the test berm. In the latter case settlement points and inclinometers will be installed in the salt core and monitored, and periodic surveys of the core will be conducted throughout the test berm program into the long-term test phase.

3.1.5.1.3 Soil

The type of soil to be used and its source are not identified in the design, but it is reasonable to expect that on-site soils will be used if suitable. During the site exploration and design activities of the WIPP surface facilities, soil test drilling and sampling were conducted and samples were tested. Records of that work will be examined and relevant information will be used to characterize the soils that could be used in the Berm. The following test program is based on the assumption that all necessary soils information must be generated in this program; useful existing information from previous testing may, in fact, reduce or modify this program.

Soil will be combined with riprap to form the outermost zone of the Berm, according to the reference design. Therefore, the soil must be able to maintain its strength, volume and position indefinitely, requiring it to have properties that are not substantially affected by changes in moisture and temperature, by erosional forces, or by weathering. The properties of soil that are important to its use in the Berm are those that affect *structural performance, water infiltration and retention,* and *erosion.* After review of existing data, the soil material test program will begin with test drilling, logging, and sampling of potential borrow sources of soil. Soil samples will be tested for grain size and Atterberg limits to establish soil classifications and plasticity indices. For evaluation of structural behavior, candidate soils will be tested for maximum compacted density and optimum moisture content, shrink/swell potential, dispersivity, and settlement potential. Water infiltration and retention potential, expressed in terms of hydraulic conductivity and capillarity, will be evaluated from grain size analysis, permeability tests and

[2]Initial analysis indicate that salt may be a poor choice as a core material for the berm (John Hart and Associates, P.A., 2000). These initial analysis indicate that a berm built with a salt core would be unstable under both static and pseudostatic (earthquake) conditions.

moisture tension tests. Susceptibility to erosion will be determined through grain size analysis, erodibility and dispersivity tests.

The test berm will provide the opportunity to test the properties of the soils as placed and compacted under full-scale conditions. Field in-place density and moisture content of soils will be measured immediately after construction and at periodic intervals during the remainder of the screening phase and into the long-term phase. Other material properties will also require long-term evaluation, including infiltration rates and increases in water content, and long-term erosion rates measured by soil loss and rill formation.

3.1.5.1.4 Riprap

In the reference design, riprap will be used with soil to form the outermost zone of the Berm and will be used by itself to form the next lower zone. In both applications, the primary function of the riprap is protection of the underlying zones from erosion. Consequently, *durability* is the most important property of rock used for riprap. In the screening phase of the test program, potential rock types and sources of riprap will be identified and evaluated initially for stable mineralogy based on petrographic study. Candidate rock will then be tested for durability characteristics including density (specific gravity) and absorption, wet/dry and freeze/thaw durability, and other appropriate tests. A combined durability score of at least 80 percent will be required for rock to be acceptable for use as riprap.

The selected riprap rock type(s) will be used in the construction of the test berm. Visual observations of riprap durability, including weathering and erosion, will be documented during the screening phase but will continue throughout the long-term test phase.

3.1.5.1.5 Caliche

In the reference design, caliche will be used to construct the zone of the Berm directly above the salt core and below the riprap zone. In this position the caliche will have two important functions: its *structural performance* will contain the salt core and provide strength to the entire Berm, and it will provide the final *seepage barrier* protecting the salt core against dissolution. The primary source of the caliche will probably be located on or near the WIPP site but has not been identified. Therefore, the initial effort in the caliche screening will be to locate potential sources and perform a test drilling and/or test pit program including logging and sample collection.

Because the caliche will be placed and compacted using earthwork equipment and earthmoving methods, its structural and seepage barrier performance will depend on how well the broken caliche can be compacted. For this reason, standard soil testing parameters used for earthfills will be used in the test program including grain size analysis, maximum compacted density, and in-place density of caliche placed in the test berm. Although not directly exposed at the surface, caliche in the Berm must be able to withstand weathering processes that operate subsurface, so sodium sulfate soundness testing will be performed on caliche samples. Seepage barrier performance will be evaluated initially in the laboratory by grain size analysis, moisture tension, and permeability tests. In the test berm program, changes in moisture content, measured by neutron probe and possibly by psychrometers, will provide a means of determining actual seepage rates in the caliche zone.

Predictions of structural and seepage barrier performance of the caliche based on testing in the early part of the screening phase will be followed by monitoring during the long-term phase. In addition to the neutron probe or psychrometer measurements of moisture content changes over time, the structural performance of the caliche will be monitored by inclinometers installed in the test berm, from which measurements of XYZ deformations will be taken periodically.

3.1.5.2 Berm Structure

The preceding section addressed the material properties issues of the Berm. This section addresses the test issues important to the Berm *structure*, all of which are affected by Berm materials but are limited to configuration issues for the purpose of the test program plan. With the importance of material properties kept in mind, the important configuration issues of the Berm are *structural stability* and *erosional resistance*. Both are affected by the overall size and shape of the Berm as well as the size and shape of the individual zones of the Berm. The Berm and its component zones have side slopes of about 1.3H:1V. The salt core is up to 30 feet thick, the caliche and riprap zones are about five feet thick, and the soil/riprap zone is about three feet thick. Structural failure or excessive deformation of any lower zone will affect the stability of an overlying zone. Conversely, erosional breach of any overlying zone will increase risk of erosion to an underlying zone.

Using material parameters developed by testing of Berm component properties, slope stability of the reference design configuration will be analyzed using a computerized version of the Simplified Bishop Method of slope stability analysis. This method is a limiting equilibrium form of analysis in which the Berm slope is modeled as a set of vertical slices, each analyzed as a free body with applied forces. The free-body forces of the slices are summed to find the total driving force and the total resisting force acting along a potential failure plane. In the computerized models, hundreds of potential failure surfaces can be analyzed quickly. Some form of this stability analysis is used in virtually every structural analysis of earthfill slope stability. As previously noted in Section 3.1.5.1.2 of this report, initial analysis of a modeled salt-core berm based upon the reference design has shown that such a berm would likely be unstable (John Hart and Associates P.A., 2000).

Settlements are also a potential mechanism for structural deformations and instability of the Berm. Settlements may originate below the Berm in the foundation soils or in the Berm itself, through consolidation of compressible soil (densification) or loss of mass due to dissolution. If wet fine-grain soils exist at shallow depth below the Berm, settlement by consolidation of those soils is possible. One dimensional consolidation tests on suspect soils and on compacted salt will be conducted to assess consolidation-settlement potential. The potential for dissolution-induced settlement will depend on the results of tests on the salt core material; those results will provide the parameters for estimating settlements caused by dissolution in the salt core.

Erosion of the Berm will be a function of the length and gradient of the Berm slopes and the erosional resistance of the materials at the slope surface. Tests for erosional stability of slope materials will provide the erosion resistance parameters that will be used in analyses of annual soil loss rates, using the Revised Universal Soil Loss Equation (RUSLE), and in analyses of resistance to shear stresses under design runoff conditions using a variety of calculation methods based on Corps of Engineers (1970) procedures.

These analyses of structural and erosional stability will be used to confirm or revise the reference design of the Berm. However, they are predictive methods only. A test berm will be constructed in the field stage of the screening phase of the markers test program, after the laboratory tests of Berm component materials have been completed. The test berm will be designed during the screening phase to test at full scale the materials and configurations selected for the Berm design. The test berm will be built to full design height and width; it will be long enough to accommodate the combinations of materials and configurations identified for field testing during the early part of the screening phase. Included in the test berm will be:

- Inclinometers - Installed vertically through the Berm at locations on the crest and slopes, to measure XYZ deformations

- Survey points - Placed on the surfaces of the Berm to measure XYZ displacements, including slope movements and settlements

- Measurements of erosion rates and patterns - Using methods endorsed by the Natural Resource Conservation Service and the International Erosion Control Association, including visual observations and manual measurements.

- Inspections of biointrusion of the Berm - Biointrusion by either roots or burrowing animals could increase infiltration and compromise surface resistance to erosion. Biointrusion will be monitored by visual observations and manual measurements using methods to be developed.
- Measurements of water content changes in the zones of the Berm - Using neutron probes or psychrometers, this information will be used to evaluate actual infiltration rates

- Surveys of salt core integrity - Using ground-penetrating radar, cone penetrometer, or cross-hole geophysical methods

- Observation of riprap weathering - Using visual methods and measurements of particle sizes on a regular grid pattern

These field observations conducted on the test berm will be started in the screening phase but will be continued into the long-term test phase.

The height and shape of the Berm will contribute to deposition of wind-blown sand on the leeward side of the Berm crest. Over time the accumulated sand might be sufficient to cover the leeward slopes and the ground downwind of those slopes. The wind transport and sedimentation model described under the Large Surface Markers section will be run to predict the rate and extent of sand deposition associated with the Berm. The results could affect the final location of the Berm or other markers near the Berm.

3.1.5.3 Magnets

In the reference design, strontium ferrite magnets, 3.0 x 1.5 x 1.5 feet in size, will be placed in the Berm. Magnetization is to be strong enough to be detectable at 300 feet above the magnet and to have longevity comparable to the numbers of years required for intrusion protection. The design at this time is conceptual only, leaving many issues to be addressed in the test program including:

- Configuration - Pattern shape, pattern density, and orientation
- Location - Depth and spacing
- Material properties - Durability and detectability

3.1.5.3.1 Configuration

The reference design calls for placing the magnets in clusters in the Berm. Because the configuration of the clusters can influence the magnetic signature of the cluster, either enhancing or subduing it, the *pattern shape, orientation* and *density* of various cluster arrangements will be evaluated. Several pattern shapes, each containing various trial magnet orientations and cluster densities, will be set up at ground surface, and magnetic intensity will be measured from several directions and distances from the cluster.

3.1.5.3.2 Location

The location of magnets within the Berm should protect the magnets from exposure by erosion, limiting exposure to weathering (corrosion), and yet should also provide the strongest possible magnetic signature above ground surface. The cluster configuration(s) with the greatest intensities in the configuration tests will be tested with the cluster buried in the test berm or other earthfill at various depths. The tests conducted for the configuration issues will be repeated using several combinations of cluster *depth* and *spacing* to determine which produces the greatest magnetic signature while also providing adequate protection from erosion or removal by man.

Most of the design issues for magnets will be addressed during the screening test phase. However, two time-dependent issues affecting the magnets, corrosion rates and demagnetization, require long-term testing. Corrosion rates and demagnetization will be measured periodically during the long-term phase. Demagnetization is expected, but the steel prism of the magnet may still be detectable by magnetometer survey; this will be evaluated during the periodic magnet surveys.

3.1.5.3.3 Material Properties

The design criteria for the magnets require them to be *durable* enough to survive the performance period and to be *detectable* for that entire period. Buried in the Berm, the magnets will be subjected to variable moisture conditions in an oxidizing environment, which may cause corrosion. Corrosion is the only process likely to threaten the physical *durability* of the magnets, so the composition and corrosion resistance need to be evaluated during the screening test program.

The question of composition has to address the optimal metallurgy for both corrosion resistance and magnetization. Tests for both of these properties will be developed early in the screening phase. For the magnets to be detectable they must have magnetic intensities great enough to be readily detected, their magnetism must have the greatest possible longevity, and their magnetic fields must have shapes such that the individual fields can overlap and reinforce the magnetic field of the arrays, if possible.

For screening test purposes, several scaled-down replicas of the design magnet will be made and subjected to measurements of intensity and field shape. Magnetism decay (demagnetization) rate will also be measured. Also, these magnets will be buried in the test berm, one at each of several trial depths, to measure magnetic intensity at various distances from and heights above the test berm.

It is likely that nonmagnetized steel prisms or other shapes buried in the Berm will be readily detected by magnetometer. A field survey of an array of nonmagnetized steel prisms will be conducted, and the results will be compared to the surveys of the trial magnets.

3.1.5.4 Radar Reflectors

Radar as a terrain exploration tool has been recognized in the reference design as one means by which the location of the WIPP may be discovered. The radar imagery anticipated in the reference design would be by a ground-scanning airborne device, for which a pattern of reflectors buried in the Berm will indicate something anomalous. For this result to be assured, several issues must be addressed in the screening test program:

- Configuration - Reflector shape and size
- Location - Reflector pattern and depth of emplacement
- Material properties - Reflectivity and durability

3.1.5.4.1 Configuration

Configuration of the radar reflectors, specifically *shape* and *size,* has a major effect on their detectability. The reference-design reflector is a trihedron composed of three mutually perpendicular planes. The arrangement of three perpendicular planes is a fundamental requirement for maximum reflectivity and, therefore, needs no testing. However, the shape and size of the planes and of the total reflector will be evaluated for optimal reflectivity for the desired detection range and for the expected radar frequencies. Tests and evaluations will be developed in consultation with the Radar Reflectivity Laboratory (RRL), Naval Air Warfare Center, Point Magu, California.

3.1.5.4.2 Location

The ability of the radar reflectors to convey the message of an anomaly depends on the contrast between the natural, or background, reflections and those of the reflectors. The reflectors must create a reflection image that is stronger than that from any background or individual reflector and distinctly different in form. Consequently, *reflector patterns* and *depth of emplacement* within the embankment are important design issues that must be tested. In the reference design, radar reflectors are to be grouped in clusters of four, with clusters spaced 300 feet apart within the Berm. Four reflectors are to be placed underground around the buried room within the Controlled Area, as well.

The shape and dimensions of the clusters, the number of reflectors per cluster, and the orientation of the reflectors will be evaluated to select the combination of these variables that produces the strongest reflection at the desired distance and frequency. The RRL will provide testing of these variables in scaled-down laboratory tests to be developed jointly with WID program management. Depth of emplacement will be evaluated in these tests, as well, using various depths of soil over the model reflectors to measure the attenuation effects of soil.

Once the laboratory tests conducted in the initial stage of the screening test phase have produced results that support selection of reflector materials, configurations and locations, a field test will be conducted in the subsequent field stage of screening tests using full-scale reflectors positioned at those locations and in those configurations selected from laboratory tests at RRL. The field test will include airborne radar scans using state-of-the-art ground scanning radar searching for one or more individual reflectors and reflector clusters. Further refinements in design will be made based on these field tests. In the long-term test phase, only the durability issues, specifically corrosion resistance, will need to be addressed.

3.1.5.4.3 Material Properties

The reference design specifies that each reflector will be made of a metal (stainless steel or incolnel) that has excellent radar-reflective properties. Therefore, the ability of the metal to reflect optimally will be influenced more by the finish on the metal surfaces than by the metal composition. Tests or technical evaluations based on previous research will be used to select the metal compositions that will also take the necessary surface finish to produce the best reflectivity. The radar reflectors will require some protective covering to inhibit corrosion and guard the metal surfaces against abrasion and other damage during emplacement in the Berm; tests or evaluations of candidate protective materials will also be performed.

For both the metal composition and the surface finish, *durability* over the long-term is critical. Durability will be a function of both the *corrosion resistance* and *strength* of the reflectors themselves and of their protective materials. It will be important for the durability of the reflectors that they are structurally strong enough to be handled and buried without bending or warping. The reflectors material must also resist corrosion both in the presence of soil, water and air but also in contact with the protective material. Therefore, the reflector material must be evaluated for both structural characteristics (flexural strength, rigidity) and for chemical characteristics that affect corrosion. Tests and evaluations will be developed in consultation with the RRL early in the screening test phase for these issues, including the effects of concrete and possibly other protective materials on the attenuation of radar reflections.

3.1.6 Concrete

The only application for concrete described in the reference design is for encasement of radar reflectors; however, the test program will evaluate concrete in a broader context of potential use in the marker systems. Concrete will be considered as an alternative material to rock in the Large Surface Markers, the Small Subsurface Markers, the Buried Storage Rooms, and the Information Center because concrete materials can be formed to any shape desired, a major advantage over cutting, transporting and handling large pieces of rock. In addition, the installation of inscriptions can be accomplished by placing the characters on the concrete forms instead of having to sandblast inscriptions into a polished rock surface

All test objectives for concrete concern the durability and strength of various, yet to be specified, concrete mixes. Concrete will be tested during the screening phase for strength and durability in both the laboratory stage and field stage. If screening tests results are favorable for these properties, concrete testing will continue into the long-term phase.

The durability of concrete is dependent upon several physical factors:

- Permeability - Lower permeability reduces the infiltration into concrete of water and other materials that may be detrimental and thereby reduces deterioration. By proper mixture design and placement, very low permeability may be achieved in the field.

- Strength - Higher strength concrete is more capable of resisting abrasion and erosion at the surface. The strength may be designed over a wide range.

- Chemical Stability - Binders such as Portland cement other materials must be chemically compatible with other components, including aggregates and additives, and the operating environment. By properly selecting materials, these incompatibilities may be eliminated. Some binders other than Portland cement may have significant advantages over Portland cement from a chemical stability viewpoint and warrant consideration. These are normally not considered in concrete construction because the setting or curing times are longer than normal construction schedule will permit

If durability and strength of concrete remain questionable throughout the screening phase, the concept of a sacrificial surface layer may be considered. In this concept, the surface layer may be lost to weathering, erosion, or abrasion yet the structure itself will continue to function as planned. This is because multiple inner layers would have the same inscriptions as those on the outer layer. The loss of the outer layer would reveal the messages on the inner layer.

To add strength to concrete, several types of reinforcement may be evaluated. In standard concrete structure design, steel reinforcing is used to sustain tensile loading. However, longevity of steel reinforcement is uncertain. Designs that reduce tensile loading on the concrete materials to acceptable levels can be used to eliminate reinforcing steel. In addition, significant tensile capacity may also be achieved by the use of discrete reinforcing systems other than steel rebar. These consist of discrete fibers uniformly distributed throughout the concrete matrix. The fibers may be steel, plastic, ceramic or other materials. Fiber-reinforced concrete exhibits significant post-cracking strength capacity and dramatically increased toughness and abrasion resistance.

Pozzolanic materials will also be evaluated. Some concrete made during Roman times with natural pozzolanic materials used as binders have survived very well over very long time periods. A drawback of pozzolanic materials is their slow rate of curing and strength gain. For permanent markers, these binders may be acceptable because curing time is not limited by other project considerations.

3.2 Long-Term Phase

The majority of permanent marker test issues will be addressed and largely resolved in the screening phase, so only those issues with time-dependent factors will be left for long-term testing. This phase will begin at a different time for each marker, starting at the point where only the time-dependent factor(s) of test issues remain to be addressed. This point could be as soon as one year from the beginning of the screening phase for some markers (like the magnets) to as long as five years for the Buried Storage Rooms or Berm. Expected long-term testing requirements are discussed by marker system in the following sections.

3.2.1 Large Surface Markers

The test issues that are time-dependent for the Large Surface Markers involve durability and foundation performance. Although a battery of screening tests will be run to measure durability parameters, the results of these tests are predictive and need confirmation by observations and measurements of actual rates of weathering, resistance to erosion, evidence of fracturing, and inscription durability over decades of time. Weathering and erosion of the inscriptions over time are critical to large marker performance. The methods of observation and measurement will be developed before the start of the Large Surface Markers long-term phase, based in part on the results of the screening phase tests. They will include protocols for objectively observing phenomena that indicate weathering, fracturing and erosion of the prototype marker surface and for quantifying those observations in a consistent and reproducible manner. Emphasis will be placed on imaging techniques, such as multispectral or hyperspectral imagery, that minimize or eliminate operator bias and variability.

Although one or more load tests during the screening phase will provide essential information on which to predict large marker foundation performance, long-term observations of the prototype marker foundation will be important to either confirm the predicted behavior or to support design modifications. Differences between load test predictions and long-term performance of the foundation could arise from several causes including consolidation of underlying clay strata or dissolution of evaporitic minerals in the subsoils. Survey points will be placed at several vertical and horizontal locations on the prototype marker and surveyed periodically from fixed control points placed beyond the influence of any marker testing activities. The surveys will measure the changes in XYZ coordinates of the survey points, and the composite differential movements will reveal any settlements or tilting of the large marker. Excessive movements will trigger reevaluation of marker base design, selected foundation horizon or both.

3.2.2 Small Subsurface Markers

Small Subsurface Markers performance over time is dependent on rate of weathering and inscription durability, both of which will be predicted by screening tests but must be verified in the long-term phase. Prototype Small Subsurface Markers buried in the subsurface will excavated, one at a time, over the long-term test phase at intervals to be selected at the conclusion of the screening phase. Each excavated marker will be examined using the same methods selected for evaluating durability of the Large Surface Markers. The results are expected to indicate what period of time the buried markers can be expected to retain legible inscriptions, and what design revisions to inscriptions or rock type might be needed.

3.2.3 Buried Storage Rooms

Concerns about long-term durability of Buried Storage Room rock panels and their inscriptions are the same as those described above for the Small Subsurface Markers and will be tested in the long-term phase in the same way. Specifically, at one or more times during the long-term field test, the prototype Buried Storage Room will be excavated to a depth to permit entry for observations of the rate of weathering of the rock and the durability of inscriptions. In addition, instrumentation including convergence and strain gauges will be installed on the buried room walls and roof and will be monitored remotely at ground surface to observe structural performance throughout the long-term phase. When the prototype room is excavated for weathering observations, the instrumentation measurements will be confirmed by manual measurements, and faulty instruments will be replaced. The results of these long-term tests will support decisions about rock and inscription durability and stability of the buried room design.

3.2.4 Information Center

Tests conducted during the screening phase should resolve all configuration and location issues related to the design of the Information Center. Durability of the material and the inscriptions will be evaluated in the long-term testing phase; however, results of long-term marker and Buried Storage Room tests will be sufficient to support conservative estimates of both durability and structural stability of the Information Center. Therefore, no long-term tests of the Information Center will be needed.

3.2.5 Berm

Long-term tests related to the various Berm components are described in the following sections.

3.2.5.1 Berm Foundation

Tests on the Berm foundation conducted in the screening phase will be sufficient to determine the bearing capacity and physical properties of the Berm foundation. However, settlement predictions based on consolidation tests should be confirmed by long-term monitoring of actual settlements. This will be accomplished as part of the test berm program by installing settlement plates during construction at the foundation surface, with risers extended to the test berm surface as construction progresses. Through the rest of the screening phase and into the long-term phase, periodic survey measurements of the top of the riser will be performed to track any foundation settlements over time.

3.2.5.2 Berm Materials

The tests needed to select Berm materials or to evaluate their properties will be performed during the screening phase. Tests to assess the long-term behavior of Berm materials will be performed in conjunction with tests of the Berm structure, described below.

3.2.5.3 Berm Structure

A test berm will be constructed during the field stage of the screening test phase. By the time the test berm is constructed, the components materials will have been thoroughly tested for those properties that will most affect their behaviors as structural elements of the Berm. The test berm will provide a means of measuring how these elements behave individually and as parts of the whole structure. Some of this behavior is time-dependent; e.g., settlement, dissolution, and erosion. Therefore, the long-term test phase will continue the monitoring measures started in screening phase. They will include:

- Inclinometer measurement
- Survey points monitoring
- Measurements of erosion
- Inspections of biointrusion
- Measurements of water content changes
- Surveys of salt core integrity
- Observation of riprap weathering

The data collected during the test berm monitoring program, beginning at construction and extending through the long-term test phase, will be used to refine the test berm design to optimize durability and structural stability. This might result in changes in materials or configuration of the Berm should such changes be determined to enhance the service life of the actual Berm.

3.2.5.4 Magnets

Considerable uncertainty exists regarding both the physical durability of the magnet material and the longevity of its magnetization. Both of these issues will be addressed in the screening program, but neither can be completely resolved within the time frame of that program. Therefore, corrosion rates and demagnetization will be measured periodically during the long-term phase. At time intervals to be established during the screening phase, magnets will be scanned by magnetometer from the ground surface to measure and record the strength of the magnetic fields. At the same time, selected magnets will be excavated to measure the amount of corrosion and to directly measure the amount of magnetism remaining. Gradual demagnetization is expected, but the steel prism of the magnet may still be detectable by magnetometer survey; this will be evaluated during the periodic magnet surveys.

3.2.5.5 Radar Reflectors

All test issues regarding the radar reflectors are expected to be addressed satisfactorily during the screening phase except the issue of corrosion. To evaluate corrosion of the encased radar reflectors over time, one reflector of each encasement type will be excavated periodically and examined for corrosion. Both the encasing protective material and the radar reflector metal will be evaluated. The results are expected to demonstrate which encasing material is most durable itself and which best protects the reflector metal.

3.2.6 Concrete

The durability of concrete in its several possible applications in the permanent marker system is the central issue in the decisions about where it can be used, if at all, in place of rock or as a protective covering of the radar reflectors. Durability tests performed in the screening phase will be valuable in ruling out concrete if it fails to attain a composite score of at least 80 percent. However, if concrete in one or more formulations passes the durability screening tests, its long-term durability remains to be demonstrated. To test concrete durability over time, full-scale prototypes of possible concrete markers or protective applications will be constructed and placed in locations on the site close to those of their permanent counterparts. A full-scale Large Surface Marker made of concrete will be constructed near the prototype Large Surface Marker made of rock. In addition, Small Subsurface Markers made of concrete will be buried near those made of rock, and a cluster of concrete-encased radar reflectors will be buried in the test berm. Observations of weathering and erosion will be made using the methods developed for the rock markers. If the durability of concrete is evaluated to be comparable to that of rock, concrete may be substituted for rock in the permanent markers.

3.3 Design Alternatives

The current reference designs of the permanent markers are primarily conceptual, lacking the level of engineering analysis necessary to develop final designs. The test program offers the opportunity for, and forces the performance of, the detailed analyses and engineering needed to develop the designs to the final level. Part of the process of advancing the design is the identification and assessment of design alternatives. Reasonable alternatives will be tested at the same time as the reference designs to ensure selection of the best design in the most timely and efficient manner.

At the time of the preparation of this test program plan, several alternatives to elements of the reference design have been identified. These include the following:

- Rock for Large Surface Markers, Small Subsurface Markers, Buried Storage Rooms, and Information Center - Several rock types, including quartzite, andesite, rhyolite, and well-cemented sandstone, may be equal to or better than granite.
- Other alternatives for Small Subsurface Markers - Other alternative materials have been proposed including various metals, plastics, glass, and ceramics.
- Large Surface Markers configuration - The proposed mortise-and-tenon connection may be very expensive or difficult to make and could be structurally inadequate, indicating the need to consider simpler, stronger connections between

the two parts of the marker.

- Buried Storage Rooms configuration - With large dimensions of panels and slotted connections, the Buried Storage Rooms may be difficult to build so that they are structurally sound. Free-standing, self-supporting elements may be better.

- Salt core - The long-term durability and structural integrity of a salt berm is problematic; a design without a salt zone will be evaluated.

- Berm slopes - The reference design slopes are very steep, which means that they may not be stable structurally or erosionally. Flatter slopes will be considered.

- Magnets - Detection of the site by magnetometer survey might be achieved more practically with a basalt-filled trench in a pattern that would be recognized as anomalous.

These and other design alternatives will be examined during the screening phase of the test program. The test plan for each will be integrated with tests on reference designs.

4.0 Test and Analysis Plans

The testing and analyses described in the previous section will be performed in conformance with written detailed testing and analysis plans. Testing and analysis work will not begin until a test or analysis plan specific to that activity has been written and approved by the cognizant CAO manager. As appropriate, tests and analyses that pertain to multiple marker systems but are similar in nature will be addressed by a single test or analysis plan.

The testing and analysis process will comply with and be controlled by the application of relevant portions of the CAO *Quality Assurance Program Document* (CAO-94-1012, Rev. 3) (QAPD). Sections of the QAPD that are of particular relevance to the development of the test and analysis plans include Section 2, Performance Requirements, Section 5, Scientific Investigation Requirements, and Section 6, Software Requirements.

As specified in Section 2.1.2 of the QAPD, the detailed test and analysis plans must identify the following:

1. The responsibilities of the organizations affected by the test of analysis plan;

2. Technical, regulatory, quality assurance, or other program requirements;

3. A sequential description of the work to be performed, including any allowance for out-of-sequence processing;

4. Quantitative or qualitative acceptance criteria sufficient for determining that activities were satisfactorily accomplished;

5. Prerequisites, limits, precautions, process parameters, and environmental conditions;

6. Any special qualification and training requirements;

7. Verification points and hold points;

8. Methods for demonstrating that the work was performed as required (such as provisions for recording inspection and test results, check-off lists, or sign-off blocks); and

9. Identification and classification of QA records to be generated by the implementing procedure.

The QAPD also includes provisions specific to the performance of scientific investigations (QAPD Section 5). Portions of Section 5 that are of particular relevance to the development of the detailed test and analysis plans include:

- QAPD Section 5.1, Planning Scientific Investigations. This section includes multiple relevant requirements:

  A. Variables that affect interrelated scientific investigations shall be identified and controlled appropriately in each related investigation.

  B. The intended use of the data shall be documented before collection as part of the planning for data processing. Any alternate use of the data shall be evaluated for appropriateness and the justification for use shall be documented.

  C. Planning shall consider the compatibility of data processing with any conceptual or mathematical models used at each applicable stage.

  D. The technical adequacy of procedures for conducting scientific investigations and their implementation shall be reviewed and approved by qualified persons other than those who prepared the procedures. Changes to procedures for conducting scientific investigations shall be reviewed and approved in a manner commensurate with the original procedure.

  E. Development activities used to establish new methods or procedures for conducting scientific investigations shall be documented. The results of developmental testing shall be reviewed for adequacy and approved by qualified persons prior to implementation of the procedures for data collection.

  F. Planning shall be coordinated with organizations providing input to or using the results of the investigation.

  G. Planning shall include the establishment of acceptance criteria for data quality evaluation, to assure that the data generated are valid, and satisfy documented requirements for the following characteristics, as appropriate: data precision; data accuracy; data representativeness; data comparability; and data completeness.

H. Planning shall include the identification of known sources of error and uncertainty as well as any input data that are suspect or whose quality is beyond the control of the performing organizations.

- QAPD Section 5.2, Performing Scientific Investigation. Provisions of this section relevant to the development of the detailed test and analysis plans include:

A. Scientific investigations shall be performed in accordance with requirements documented in test plans, procedures, and scientific notebooks.

B. If deviation from test standards or the establishment of specially prepared test procedures is deemed appropriate (e.g., no nationally recognized test standards exist), the modified or new test procedures shall be documented in sufficient detail to be repeatable, and shall be justified, evaluated, and approved by the cognizant technical organization.

C. Scientific notebooks shall contain, as a minimum:

1. a statement of the objective and description of work to be performed or reference to an approved plan that describes the work;
2. the method(s) used;
3. identification of the samples;
4. the measuring and test equipment used;
5. a description of the work performed and the results obtained, the names of individuals performing the work, and dated initials or signature, as appropriate, of individuals making the entries;
6. a description of changes made to methods used, as appropriate; and
7. the potential sources of uncertainty and error in test plans, procedures, and parameters that must be controlled and measured to assure that tests are valid.

D. Scientific results shall be periodically reviewed, by a qualified individual, to verify that there is sufficient detail to retrace the investigation and confirm the results, if feasible, or repeat the investigation and achieve comparable results without recourse to the original investigator.

E. Practices, techniques, equipment, and manual or computerized methods used to obtain and analyze data shall be verified to assure they are technically sound, and have been properly selected. Controls shall be established for these processes to ensure that they are properly implemented, including controls to prevent tampering.

F. Data collection and analysis shall be controlled by procedures of sufficient detail to allow the processes to be repeated. Where appropriate, quality control checks shall be performed, using recognized methods such as replicate, spike, and split samples; control charts; blanks; reagent checks; replication of the methods used to obtain the results; or alternate analysis methods.

G. Test media (e.g., fluids), when used, shall be characterized and controlled in accordance with test procedures.

H. Scientific notebooks and technical implementation documents shall be maintained as QA records.

- QAPD Section 5.3.1, Data Identification and Usage. Relevant requirements of this section include:

A. All data shall be recorded so that they are clearly identifiable and traceable to the test, experiment, study, or other source from which they were generated. Identification and traceability of the data shall be maintained.

B. The method of data recording (e.g., scientific notebooks, log books, data sheets, or computerized instrumentation systems) shall be controlled to avoid data loss and permit data retrievability. Controls shall be established to ensure that data integrity and security are maintained wherever data are stored. Controls shall prescribe how specific types of data will be stored with respect to media, conditions, location, retention time, security, and access. Data shall be suitably protected from damage and destruction during their prescribed lifetime and shall be readily retrievable.

C. Data transfer and reduction controls shall be established to ensure that data transfer is error free (or within a prescribed permissible error rate); that no information is lost in transfer; and that the input is completely recoverable. Data transfer and reduction will be controlled to permit independent reproducibility by another qualified individual. Examples of data transfer include: copying raw data from a notebook into computerized data form or copying from computer tape to disk.

D. Data that are determined to be erroneous, rejected, superseded, or otherwise unsuited for their intended use shall be controlled to prevent their inadvertent use. Controls shall include the identification, segregation, and disposition of inadequate data. The basis for the disposition of erroneous data shall be justified and documented.

E. All processes which change either the form of expression or quantity of data, values, or number of data items (data reduction) shall be controlled by prescribed methods that allow for the validation of the conversion process.

F. Data collection and analysis shall be critically reviewed and questions resolved before the results are either used or reported. Uncertainty limits shall be assigned to the data prior to their use.

- QAPD Section 5.3.2, Data Validation. Relevant data validation requirements include:

A. Validation methods shall be planned and documented. The documentation shall include the acceptance criteria used to determine if the data are valid.

B. All applicable data collected shall be validated. Validation shall include the following:

1. the relevant documentation is reviewed to evaluate the technical adequacy, the suitability for the intended use, and the adequacy of the QA record;
2. the results of the data review shall be documented; and
3. the reviewer shall be independent of the collection activities.

C. Data validation shall be controlled to permit independent reproducibility by another qualified individual.

D. Data considered as established fact by the scientific and engineering community, such as engineering handbook data, critical tables, etc., do not require validation.

When scientific and engineering software is used in implementing testing and analysis activities for the permanent markers program, the use of the software will be subject to relevant portions of Section 6 of the QAPD, Software Requirements. Portions of Section 6 of the QAPD that are of particular relevance to the development of the detailed test and analysis plans include:

- Section 6.2.1, Inventory of Software;
- Section 6.2.3, Software Quality Assurance;
- Section 6.3, Software Procurement;
- Section 6.5, Software Development and Life Cycle;
- Section 6.6, Software Verification and Validation;
- Section 6.7, Software Configuration Management; and
- Section 6.8, Documentation.

5.0 Evaluation of Testing and Analysis Results

An important aspect of the testing and analysis process is the manner in which test and analysis results will be evaluated. As described previously, specific tests and analyses are linked to individual marker systems and to the design criteria that apply to each marker system. To provide meaningful input to the determination of final markers systems designs, test and analysis results need to be linked to specific design criteria. These links are identified in Table1 and will be described in the detailed test and analysis plans.

The results of some tests and analyses may result in simple pass/fail determinations regarding the ability of a material selection, configuration, or location to satisfy a specific design criterion. In these cases, the pass/fail criteria will be defined in the detailed test and analysis plans.

In most cases, however, it is expected that test and analysis results will not provide a simple pass/fail answer. Instead, the results are expected to provide a relative indication of the extent to which a particular material selection, configuration, or location satisfies an individual design criterion.

An additional consideration in the design-selection process is that multiple design criteria apply to individual marker systems. Some aspects of an individual design may rank favorably in regard to some applicable design criteria, but less favorably in regard to other applicable design criteria. The ultimate objective of the design-selection process is to select those designs that show the highest level of satisfaction of all of the relevant design criteria.

6.0 Program Management

Key implementation activities and the general schedule for the performance of these activities are described in this section.

6.1 Implementation Activities

As describe in the preceding sections, the permanent marker test program will be conducted in two phases, the initial screening phase (1999-2005) and the long-term phase (2006-2093). The screening phase will have two stages, the laboratory stage and the field stage. The rationale for this overall program organization was described earlier in this document. This section describes the general sequence of tests, their interactions, and the approximate time lines for each test group so that a project control tool may be developed by which to manage the entire test program. The test program sequence is illustrated in Figure 5.

6.1.1 Screening Phase, Laboratory Stage

The laboratory stage is the initial stage of the test program. Its purpose is to *identify, test, and evaluate candidate marker materials* to provide the information needed to identify the most suitable materials for additional evaluation during the field tests. This stage is expected to take one to two years.

Key components of the laboratory stage will include:

- Earth Materials Testing - In this initial stage of the test program, laboratory tests will be conducted on candidate rock, salt, soil, riprap, and caliche materials. For each material to be tested, the initial task will be collection and evaluation of existing data. Based on these evaluations, sampling and testing programs will be developed for each material. Samples will then be collected and tested. The results of the tests will be used to select from the candidate materials and material sources those that are best suited to the requirements of the design criteria.

- Concrete Testing - At the same time as earth materials testing, the concrete laboratory test program will be conducted. A survey of available information will be used to select the cement types, aggregates, and additives that appear to be most likely to satisfy the material properties design criteria for protective materials for the radar reflectors and for alternatives to rock for the markers made of rock in the reference design. The selected mixes will be prepared and cast, allowed to cure completely, then tested. From the results of those tests, the mixes satisfying the properties criteria will be used to select mixes for subsequent use in casting mock-up or prototype markers for later field testing.

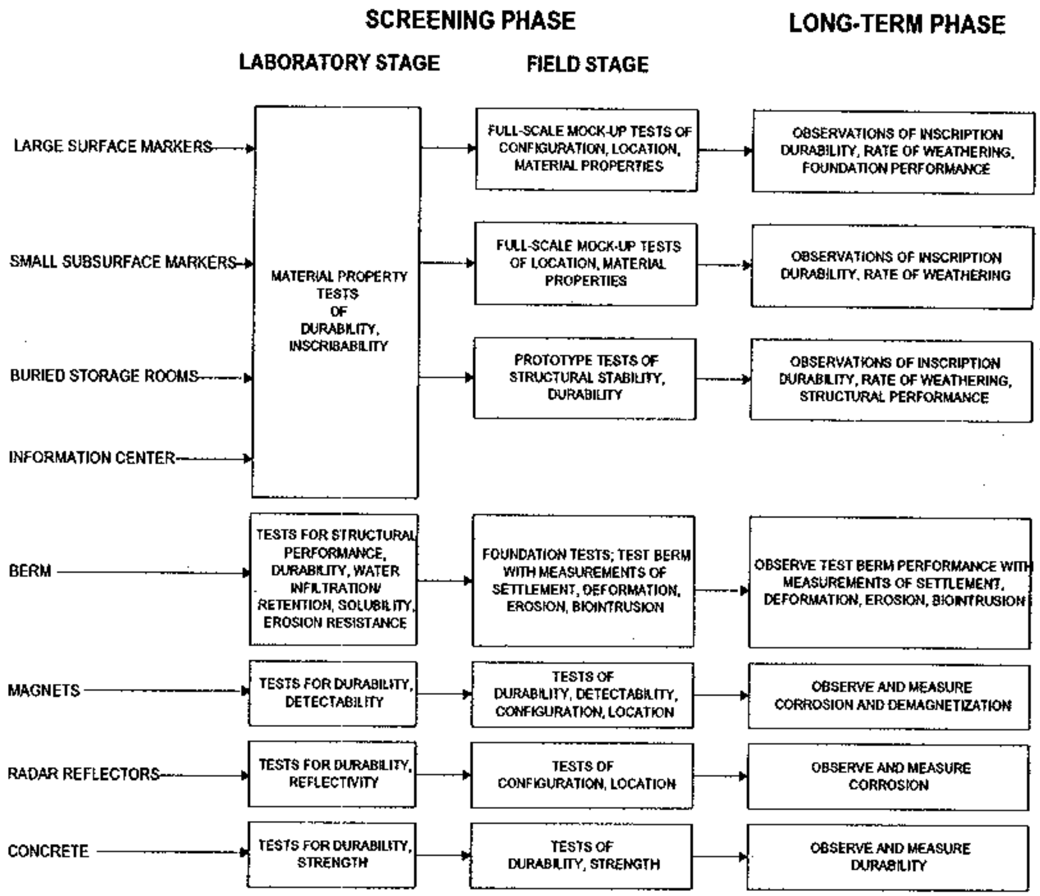

Figure 5. Permanent Markers Test Program Sequence

- Magnetic Material Testing - During the laboratory stage, candidate materials for making magnets will be identified first through a literature search. Those materials that are expected to have the optimal combinations of corrosion resistance and magnetism retention will be selected for testing. Castings will be made and magnetized for use in the field testing stage.

- Radar Reflector Material Testing - In conjunction with the RRL or another qualified laboratory, candidate reflector materials will be identified and evaluated for reflective properties and corrosion resistance. The latter tests will be performed by a qualified metallurgical laboratory. The material(s) displaying the best combination of these properties will be used to fabricate test targets for testing at RRL in several configurations that include concrete covering, concrete covering and soil, and concrete covering with soil and riprap. Results of these tests will be used to refine the design of the reflectors to be used in the field tests.

- Alternative Materials Testing - In addition to concrete, alternative materials will be considered for use in the marker systems. Although the alternative materials have not yet been identified, they could include epoxies, ceramics, composites or other man-made materials that might reasonably be expected to be durable over the long-term. During the laboratory stage, a search of the literature will be conducted, and likely candidate materials will be selected and tested as appropriate.

6.1.2 Screening Phase, Field Stage

The field stage is the second stage of the screening phase of the test program. Its purposes are to *test and evaluate reference marker configurations and locations* and to *test and evaluate selected materials under field conditions.* All tests in this stage will take place on or near the WIPP site. The field stage is expected to demonstrate the validity of reference designs, to reveal the design elements that require change, and to compare the performance of alternatives to reference design elements. This stage is expected to take at least three years.

6.1.3 Long-Term Phase

The long-term phase is the part of the test program in which time-dependent design issues will be addressed. It will begin at a different time for different tests, each beginning as a continuation of the observations and monitoring started in the field stage of the screening phase. Its purpose is to *provide the information needed to project marker performance far into the future.* If failures or inadequate performances are noted during this phase, a cycle of design revision and specific laboratory and field tests may be required. This phase will begin for each maker system differently, but in each case it should be a seamless transition from the field stage of the screening phase.

6.2 Program Schedule

Only a very general schedule of activities related to the implementation of the permanent markers program has been developed to date. It is important to note that activities relating to this schedule will overlap. For example, while some components may still be in the screening phase other components may be in the long-term testing phase. The following schedule illustrates the earliest possible implementation of activities.

Test plans are to be developed and finalized in 2001 and some test markers, including a test berm, are to be constructed in 2005. Field testing is to begin in 2004 and continue until 2083. Final designs will then be developed and construction will occur in about 2093. Status reports will be prepared at five year intervals or as need is determined.

7.0 Quality Assurance

The work performed in implementing the permanent markers program will be conducted in accordance with the applicable requirements of the DOE *Quality Assurance Program Document* (QAPD) (current versions) and applicable implementing documents. The QAPD contains requirements applicable to all work, items, and activities conducted in support of the CAO; applicability of requirements for implementation of the permanent markers program will be determined using a graded approach. Organizations supporting the CAO are required to use the QAPD in the performance of work that is important to safety and waste isolation. The CAO permanent markers program management is responsible for ensuring that the applicable QAPD requirements are contractually imposed on subcontractors doing work in support of the permanent markers program. The provisions of the QAPD are consistent with established national standards such as 10 CFR Part 830, *Nuclear Safety Management*, American Society of Mechanical Engineers NQA-1, *Quality Assurance Program Requirements for Nuclear Facilities,* DOE Order 414.1, *Quality Assurance*, and the DOE Organization EM-1 *Quality Assurance Requirements and Description.*

In addition, the M&OC has an established quality assurance (QA) program that meets the requirements of the QAPD. The requirements of this program will also be applied to permanent markers program implementation work performed by the M&OC, to the extent appropriate.

Provisions of the QAPD that apply to the development of detailed permanent markers test and analyses plans are identified in Section 4 of this program plan.

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