Department of Energy
Carlsbad Field Office
P. O. Box 3090
Carlsbad, New Mexico 88221

16 MAY 2002

Mr. Frank Marcinowski
Office of Radiation and Indoor Air
Environmental Protection Agency
Center for Federal Regulation
Arial Rios Building
1200 Pennsylvania Avenue. N. W.
Washington, D. C. 20460

Dear Mr. Marcinowski:

This letter is to request approval from the Environmental Protection Agency (EPA) of a proposed change in the schedule to submit detailed plans and drawings on the passive institutional controls (PICs) permanent marker prototype designs for the Waste Isolation Pilot Plant (WIPP). This request provides a proposed revised schedule and the justification to support the schedule change. The new schedule will allow the Department the additional time needed to refine the permanent marker design and testing program. Also we will be testing a set of potential markers that more closely resemble the final permanent marker design. We believe this delay is necessary in order to ensure effective testing of the permanent marker designs in the time period specified in Condition 4 of WIPP's EPA certification.

Our evaluation of the EPA WIPP Docket A-93-02 containing the compliance baseline has determined that this delay does not differ significantly from the information in the most recent compliance application. Additionally, we are providing two notebooks. Each one contains reasons for the proposed change in schedule, a proposed new schedule for the permanent marker testing program activities, and three supporting documents.

If you have any comments or questions, please contact Mr. Harold Johnson at (505) 234-7349.

Sincerely,

Dr. Inés R. Triay
Manager

Enclosure

cc: w/o enclosure
H. Johnson, CBFO
S. Casey, WTS

0202973

CBFO:ORC:HJ:VW:02-1106:UFC:5400

MAY 16 2002

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Carlsbad Field Office
P. O. Box 3090
Carlsbad, New Mexico 88221

CORSPDNCE ID
CBFO:ORC:HJ
CORSPDNCE/UFC #
02-1106:UFC:5400
CONCURRENCE
RTG. SYMBOL
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5/8/02
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Passive Institutional Controls – Permanent Marker Test Program Proposed Schedule Change

Introduction

In 1996, the Department of Energy submitted plans to the Environmental Protection Agency on the construction of permanent markers [DOE/WIPP 1996-2184, Compliance Certification Application (CCA)]. These markers provide a major contribution to the passive institutional controls (PICs) system that will warn future generations of the potential threat of the waste buried 2150 feet below the surface. The proposed system of PICs also includes archiving of documents containing information about WIPP, and distribution of awareness triggers. The focus of this change request is the schedule for the permanent marker designs.

The permanent marker conceptual design identified in Appendix PIC of the CCA, was developed from the insights of several planning and strategy teams representing a multidisciplinary approach. These teams evaluated potential scenarios and produced key concepts to warn future generations about the dangers of the radioactive waste buried nearly a half mile below the surface. The combined efforts resulted in the designs and strategies for implementing the permanent marker system, as approved in the Certification Final Ruling [FR, May 18, 1998]. The DOE position, at the time this information was submitted, stated that the designs were still concepts, and not the intended final designs. The EPA, agreed that the designs were not fully mature, and requested that the DOE provide more information confirming that the proposed permanent marking system could be successfully emplaced once the repository was sealed. In response, the DOE-Carlsbad Area Office submitted a plan and schedule showing how the conceptual designs would evolve into an effective final system of designs. This schedule listed activities that would be performed during the 35-year operational period and after site closure.

Change Request

In response to Condition 4 of the EPA certification, a new schedule is being developed to accelerate the design, testing, and emplacement of the permanent marker system. Since the schedule for the proposed approach differs from the schedule for permanent marker design and testing submitted in conjunction with the CCA, the DOE is seeking EPA agreement to update the schedule to reflect the proposed changes. This change in schedule is being requested for the following reasons:



- Portions of the permanent marker system originally conceptualized (e.g. the granite monuments) are impractical, thus more suitable designs must be engineered

- Materials studies conducted since WIPP was certified suggest that substitution of different materials other than those originally proposed for use in the permanent marker system could decrease the cost of the system without compromising performance (see section entitled *Completed Activities*)

- Condition 4 (of the EPA Final Certification Decision) requires the fabrication and emplacement of the final permanent markers as soon as practical after WIPP closure.

DOE's previous schedule allowed a longer time for testing after closure and prior to fabrication to capture a wide range of potential weathering impacts. In consideration of a shortened testing duration, DOE's plan for testing the permanent markers needs to be realigned to ensure adequate testing and evaluation of the long-term performance of the system of markers can be accomplished. A condensed testing period dictates that design changes and material substitutions be made, if warranted, before long-term testing begins so that the prototype design being tested bears as close a resemblance as possible to the final design.

- Finally, DOE plans to re-examine whether the all of the components of the permanent marker system proposed in the CCA are needed. The redesign effort could produce a less elaborate system of permanent markers that is still adequate to meet the requirements.

The primary objectives of this test program are to maximize the effectiveness of the designs and to devise a permanent marker system that continues to meet the requirements of the EPA regulations. The schedule related to the permanent markers program, as submitted in connection with the CCA, is provided in Table 1 along with a revised listing of the proposed completion dates. The schedule for the modified Permanent Markers Testing Program completes all testing activities by 2033, so the markers can be installed as soon as possible after site closure.

DOE does not propose that any of the activities in Table 1 be cancelled or significantly altered. The proposed changes are specific to completion dates. Thus, it is the opinion of DOE that these proposed schedule changes do not constitute a "significant change" as described in Title 40 CFR Part 194.4(b)(3). The changes are being pursued to ensure that the Permanent Marker Testing Program produces useful results that will yield more effective designs, within the required timeframe.

DOE anticipates having the detailed plans and drawings ready to submit to EPA by the end of 2007. Reasons for this delay are explained in the next section, entitled *Future Activities*. If the testing program results in material substitution or changes the permanent marker system design, such changes will be provided to the EPA with the 2007 Annual Change Report submittal.

Table 1. Activities Related to the Implementation of the Permanent Markers Program

Activity	Reference Event	Original Timeframe	Current Status	Proposed Timeframe
Stone Monument Survey	1st 5 years of operations	1999-2004	Completed	N/A
Identification of suitable source material	1st 5 years of operations	1999-2004	Pending changes to design and material selection	2007
Submit plans for the test marker system	1st CRA Submittal	2003	Proposed change to submit prior to 2nd CRA	2007
Construct and test berm and test markers	2nd 5 years of operations	2004-2009	Pending proposed change and testing program	2008
Monitor performance of test berm and test markers	After construction	2007-2083	Pending proposed change and testing program	2009 – until closure
Test comprehension of marker messages submittal of testing plans to EPA	4th CRA submittal	2018	No change	N/A
Develop final design of markers	Upon termination of testing program	2083-2090	Final design to be submitted with the final CRA	2033 (anticipated)
Finalize Translated Messages	Prior to building of final permanent markers	N/A	Finalized messages will be submitted with the final CRA	2033 (anticipated)

Future Activities

As referred to in Table 1, the information on PICs-permanent markers (provided to the EPA in 1997) contained a schedule of activities to be performed prior to the construction of the permanent markers, or implementation of the other PICs.

Based on comments from the EPA, the Department believes it needs to take an expedited approach to the testing of the permanent markers. The initial testing program will analyze the candidate materials, evaluate human cognition factors, and utilize computer modeling for long-term weathering impacts and major impact events (e.g. earthquakes, 100-year floods, etc.). Such modeling will most likely have to be updated and enhanced as the actual design is produced.

Once permanent marker designs are specified and configured within a computer modeling program, DOE can perform an analysis of the current design, incorporate modifications of materials and/or design, and perform analyses of alternative design approaches. Based on the alternative schedule, the final long-term test plans and designs should be ready in 2007. At that time, DOE will decide whether to build full-scale or reduced-scale prototypes of the markers for long-term testing. Table 2 presents a schedule of planned activities for the proposed test

program. DOE has based the revised Permanent Marker Testing Program on the assumption that the proposed changes can begin in January 2003.

Table 2. Schedule of Activities for the Permanent Markers Testing Program

Activity	Duration (months)	Expected Completion
Computer Modeling (several phases)	40	2008
Cognition Experimentation	14	2004
Material Testing	9	2003
Bench Scale Design	62	2006
Design Evaluation and Determination	30	2006
Long Term PM Program Plan	12	2007
Final Design of Scale Models of Prototype (Option 1)	21	2007
Final Design of Full Scale Models of Prototype (Option 2)	12	2007
Completion of Prototype Construction	37	2011
Long Term Test Program (to begin after construction)	241	2031

Completed Activities

Results from activities completed since 1998 support the proposed changes within this request. As committed to in a response to the EPA's request for additional information (EPA Air Docket A-93-02, Item II-I-07, DOE, 1997) the DOE has followed through on examining issues related to the final design of the permanent markers. In late 2000, the DOE Carlsbad Area Office completed the following: 1) surveyed monuments within a wide radial distance from WIPP; 2) examined materials chosen for the permanent marker conceptual designs; and 3) produced a plan for the Permanent Marker Testing Program. The monument survey, materials analysis, and testing plan are summarized in following paragraphs.

Monument Survey

Originally, the DOE committed to performing a survey of monuments within a 150-mile radius of the WIPP facility to evaluate the environmental effects on various types of granite. However, due to the lack of comparable archeological sites with structures constructed from rock or granite, the survey area was extended to include any sites within New Mexico or Texas containing compatible archeological information. The focus was to gather data that could be used to improve the design of the permanent markers containing granite or other rocks with a climate and elevation similar to that at WIPP.

As the southwest portion of the country contains very few ancient dwellings constructed of long lasting materials, it was determined that the best information could be gathered from the messages left behind. The messages inscribed or pecked into the rock surface are often called "petroglyphs." Site selection criteria were established to ensure that the most useful information could be obtained from each visit.

The criteria limited eligibility to sites:

- that provide inscriptions on durable rocks;
- that contain inscriptions at least 600 years old;
- at elevations able to support piñon and juniper trees, but low enough that temperatures and moisture are comparable to the climate projected for the WIPP; and
- that have not undergone major restoration

At each site, information on the inscriptions was recorded. This included the rock type, physical features, depth and width of inscription, estimated inscription age, and any other information that could provide qualitative significance. Results of these surveys can be found in the contractor report entitled, Permanent Markers Monument Survey [WIPP UN001208, John Hart & Associates, 2000]. Conclusions reached from this survey support the need for testing and refining the design and selection of proper materials for the permanent marker system.

Materials Analysis

The materials proposed for use in the berm or the other permanent markers have come under a great deal of scrutiny. For example, the use of mined salt as a core material in the berm is subject to validating that the core will not be exposed to elements that could degrade the soluble halite. Even if this is proven likely, the use of the salt material is dependent on meeting performance requirements (such as those from the American Society of Testing Materials, ASTM) to qualify as an adequate material for berm construction. An analysis of the various candidate materials was performed and published in the report Permanent Markers Materials Analysis [WIPP UN001206, John Hart & Associates, 2000]. Results of the analysis support future testing and provide recommendations on the types of tests that might lead to the most practical information. It is expected that the testing of the candidate materials will provide quantitative information for selection of final construction-grade materials.

Testing Plan

The Department has issued a programmatic plan to guide the process of moving from a conceptual design to a final design. The Permanent Markers Testing Program Plan [DOE/WIPP 00-3175, DOE 2000] examines system components and ensures that adequate materials and designs are engineered for the long-term testing phase. This Plan will serve as an upper-level decision guide for the long-term testing program, and will be updated through out the life of the program.

Copies of these three documents have been provided as part of this change request.



Contractor Report

Permanent Markers Materials Analysis

Waste Isolation Pilot Plant
Carlsbad, New Mexico



August 31, 2000

Contractor Report

Permanent Markers Materials Analysis

Waste Isolation Pilot Plant
Carlsbad, New Mexico

August 31, 2000

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1.0 Introduction

The U.S. Department of Energy (DOE) is implementing a program of passive institutional controls (PICs) for the Waste Isolation Pilot Plant (WIPP) in response to U. S. Environmental Protection Agency (EPA) regulations 40 CFR 191.14(c) (EPA, 1993) and 40 CFR 194.43 (EPA, 1996) and in accordance with the EPA Certification Decision (EPA, 1998). The purpose of the PICs program is to minimize the potential for inadvertent human intrusion into the repository by documenting the dangers of the repository and by permanently marking its location. The EPA regulations specify that radioactive waste disposal systems must be designated by multiple PICs including permanent markers, long-term records and "other PICs."

The DOE Carlsbad Area Office (CAO) has prepared a PICs implementation plan to facilitate the overall PICs program. The PICs implementation plan is supported by three additional "lower tier" documents, each corresponding to one of three elements that comprise the overall PICs program. These documents are:

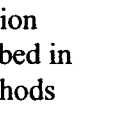
> Passive Institutional Controls Records Management Implementation Plan,
> Passive Institutional Controls Awareness Triggers Implementation Plan, and the
> Passive Institutional Controls Permanent Markers Implementation Plan.

This report supports the third of these three plans by documenting assessments of marker materials included in the reference design and as well as potential alternative materials.

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

- Large Surface Markers
- Small Subsurface Markers
- Berm
- Buried Storage Rooms
- Information Center

The permanent markers will be constructed of materials that will be selected through an evaluation process. Candidate materials identified in the Compliance Certification Application (CCA) (DOE, 1996) reference designs will be evaluated against performance criteria described in the Permanent Markers Implementation Plan. The evaluations will be performed using methods identified in the Permanent Markers Testing Program Plan.



Information obtained from literature reviews is provided in this report and has been used to refine the evolving candidate materials lists. The literature review also provides information supporting preliminary evaluations of the candidate materials. This information also is of value in planning laboratory and field tests that will provide additional information necessary to make final marker materials selections.

1.1 Study Objectives

Many materials, both natural and man-made, have been suggested over the years for consideration as permanent markers. It is neither feasible nor desirable to test all of these materials; much information exists to support preliminary materials recommendations. The results of this literature review support determinations of the materials that most likely satisfy the design and performance requirements for each marker system and warrant testing to confirm their selection. The objectives of this literature review are:

- to identify materials that could be suitable for each marker system,
- to evaluate these materials based on information available in the literature and from expert opinion,
- to recommend materials that appear to be best suited for specific marker applications, and
- to identify tests most appropriate for the screening phase of the testing program.

1.2 Study Methods

The work represented in this report was performed primarily as a literature review using information available through printed media (technical journals, text books, research reports), electronic media (worldwide web sites), and technical expert consultation. Inquiries were made to materials vendors concerning the availability of their materials and specifics pertinent to the material properties. Consultants and researchers with materials expertise assisted in directing the research and suggesting alternative materials and identifying those properties most important to marker performance.

1.3 Report Organization

Material design criteria are described in Section 2.0 of this report. Although already discussed in the Permanent Markers Implementation Plan and Permanent Markers Testing Program Plan, the material design criteria are repeated in this section to provide the reader with an overview

understanding of the objectives for the permanent markers. The materials specified in the PICs reference design and the material properties relevant to permanent marker performance are identified in Section 3.0. Alternative materials that have been identified both before and during this literature review are described in Section 4.0. Section 5.0 presents the analysis of materials vis-à-vis the design criteria and the comparison between candidate materials for each marker component. The last section of the report, Section 6.0, provides conclusions and recommendations for the first level of material selection and testing in the screening phase of the permanent markers testing program.



2.0 Material Design Criteria

The draft Permanent Markers Implementation Plan (August 31, 1999) documents the design bases for the permanent markers; the design bases consist of performance objectives and performance criteria. The performance criteria are as follows:

- Alert a visitor to the existence of the site,
- Convey a warning of danger,
- Inform the visitor about the nature and degree of danger, and
- Endure in form and function for the longest time possible.

The first three of these performance criteria relate to the form and message conveyed by the markers and are affected in part by the ability of the marker materials to be detected and inscribed. However, the fourth performance criterion relates directly to the marker materials, in particular the durability, strength, and intrinsic value of materials. To satisfy the performance criteria, design criteria have been established (see Section 3.1.3 of the implementation plan), and some of these design criteria apply to the markers materials. Specifically, the following material design criteria are identified in the implementation plan.

(1c) - To alert the visitor to the existence of the site, the material must be obviously anomalous with respect to the natural features (i.e., materials) of the site. The marker material must be detectable.

(3a) - To inform a visitor about the degree and nature of the danger, markers must be able to be inscribed with symbols and letters. For the purposes of this report, this concept is called "inscribability."

To endure in form and function for the longest time possible, marker materials must be:



(4a) - as resistant as possible to chemical and physical weathering, dissolution, and erosion. The marker material must be durable.

(4b) - able to withstand all foreseeable extreme natural conditions including earthquake, wind, flood, and fire. The marker material must be durable and strong.

(4c) - able to remain stable in form, location, and position. The marker material must be durable and strong.

(4d) - able to resist vandalism. The marker material must be durable.

(4f) - lacking in economic value to be of no interest for scavenging and salvage. The marker material must have low intrinsic value.

Material properties and associated aspects (detectability and inscribability) as related to the design criteria will be explained in the following subsections. It is apparent from the design criteria that durability is the most important property required for the markers materials.

2.1 Durability

Durability is the ability of a material to resist destruction by a number of different forces or mechanisms. Therefore, durability is not a single property but rather a composite of several properties, the combination of which varies with the materials and their intended applications. In general, durability of any candidate marker material is a combination of composition and texture, density, hardness, toughness, erosion resistance, and weathering resistance. The importance of each of these durability properties varies from one marker application to another and from material to material.

Composition and Texture - Composition, or the chemical and mineralogical makeup, is fundamental to material durability. Composition affects the chemical stability of the material and its response to thermal and mechanical stresses, regardless of the other macroscopic properties of the material. Texture is the relationship between crystals or grains within the material, the micro-fabric. Texture affects the amount of surface area per unit volume of material, which may be important in determining how a material will fracture, its strength, and its rate of weathering.

Density - Density is the mass per unit volume of a material. For a solid of a single composition, density also indicates the amount of porosity in the material; i.e., the difference between the specific gravity of the material constituent and the density of the material mass is the pore space in the material. In solids composed of more than one constituent, density indirectly reflects the composition of the material; for any given porosity higher density indicates heavier elements in the material's composition. Therefore, density must be evaluated in the context of both composition and porosity. In general, denser materials are harder and more resistant to weathering and erosion.



Hardness - Hardness is the resistance of a material to penetration of its surface. It is an important durability property because hardness is needed to resist vandalism, accidental impacts, and erosion. However, in the context of this report, hardness is used specifically in reference to resistance to instantaneous, high-energy impact; resistance to erosive forces is considered separately. Hardness is measured differently for rock and concrete than for completely man-made materials such as ceramics and polymers, and each type of hardness testing has its own scale of measurement.

Toughness - Toughness is the resistance of a material to extension of a crack, in effect the opposite of brittleness. It is an important property of ceramics, composites, alloys and other man-made materials that are essentially homogeneous and isotropic, but is not usually used in reference to rock or concrete.

Erosion Resistance - Resistance to erosion may be viewed as a type of hardness, but in this study erosion resistance refers to resistance to mechanical abrasion by fluids (water and air) or by solids suspended in fluid, an ongoing or intermittent process rather than an instantaneous impact event. This distinction is particularly meaningful for heterogeneous materials like rock and concrete, where erosion can work at the crystal or particle level to differentially loosen or remove durable larger particles from a less resistant fine-grained matrix. Several types of abrasion tests can be used, depending on the material to be tested.

Weathering Resistance - In the context of this report, weathering is limited to ongoing or intermittent processes other than erosion that involve a chemical or a mechanical breakdown of the material in place. Chemical weathering includes oxidation, hydration, dissolution and any other process that involve changes in the composition, solubility, or phase of matter. Mechanical weathering includes freeze/thaw, shrink/swell or other cyclic alterations that induce fracturing, disaggregation, or volume changes in the material. Chemical and mechanical weathering processes are so commonly interactive that they are addressed under one heading for this report. Resistance to weathering is a composite of properties that maintain the chemical composition and fabric of the material. Exfoliation is a particular type of weathering process in which thin sheets of rock successively split away from the rock mass in a manner resembling an onion skin. The process is attributed to differential expansion and contraction of the minerals within the depth below rock surface affected by diurnal temperature changes (Whitten and Brooks, 1972).

2.2 Strength

Strength is resistance to nonrecoverable strain, measured by the stress needed to cause a specified amount of yield (yield strength) or rupture (ultimate strength). The type of strength important for any marker depends on the intended function of the marker and the types of loads that it must sustain. Strength is a critical property only for those marker components that must support loads other than their own weights, specifically, the berm and the walls and roof of the information center and the buried storage rooms. All other markers, including the large surface markers, have only their own weights to support and only relatively minor externally imposed stresses.



In the berm structure, the strength of soil or rock material after it has been compacted (mechanically densified) is important in resisting compression (manifested as settlement) and shear stresses due to the weight of overlying materials and cyclic shear stresses due to earthquake-induced ground motion. The deeper the soil or rock layer within the berm, the higher the stresses imposed and the strength required.

The walls and roofs of the information center and the buried storage rooms will be required to carry stresses imposed by the weight of the materials themselves as well as externally imposed loads from wind or overburden as well as earthquakes. Both compressive strength and flexural strength of wall and roof materials must be adequate to carry the maximum expected loads with a substantial factor of safety.

Strength is tested by methods that induce the type of stress (e.g., compressive, tensile) that the material is expected to experience. Although each test for a type of stress is similar from one material to the next, there is a specific test procedure and apparatus for each type of material. However, for all marker materials, compressive strength testing will be needed, using the relevant procedures for unconfined, uniaxial loading conditions, the conditions that will prevail in the marker environments.

2.3 Inscribability

As used in this study, inscribability includes any means of imposing symbols and letters into the marker material. Inscription by carving or sandblasting into a rock surface is the usual method, as envisioned in the reference design, but for the materials analysis the term is used much more broadly. The only constraint is that the messages and symbols required by criterion 3a (see Section 2.0) must be placed into the material, not just applied to the surface. Tests for inscribability will need to try to create inscriptions using actual inscription methods and equipment.

2.4 Detectability

The detectability criterion applies to all markers, by definition, but it is important in materials selection only for those markers that will be buried. Small subsurface markers must be easily recognizable as anomalous when they are uncovered by excavation. Magnets or electromagnetic telltales must be detectable with aboveground magnetic detectors. Radar reflectors must produce a clearly distinct radar anomaly on airborne radar surveys. All other markers must be identifiable by the human eye, a requirement more dependent on configuration than on material of construction.



2.5 Intrinsic Value

Any object that exists in a remote location without active maintenance or security is subject to removal. Large size and weight are obvious deterrents to removal of permanent markers, but if the value of the marker or its material is great enough, it should be expected that someone will be motivated to use any means available to remove the marker intact or in pieces. Therefore, the best deterrent to removal is to use materials that have low intrinsic value. Material value can be readily determined from existing and projected market costs.

3.0 Reference Design Materials

Reference designs for the permanent markers systems are presented in the CCA. Some of the reference designs are more developed than others, with one or more materials proposed. The opportunity exists within the framework of the CCA for review of the reference designs and materials selection with opportunity to propose alternatives as the design review process advances. This section presents an evaluation of the reference materials in relation to the design criteria. Other factors assessed include material availability, transportation and construction logistics, and relative cost. Although cost is not a factor in the selection of materials during the initial screening stage, it is reasonable to consider the relative cost of materials at this point so that materials having extremely high costs without commensurate benefit can be eliminated or given lower priority in future evaluations.

3.1 Granite

Granite is the reference-design material of construction for the large surface markers, information center, and buried storage rooms. Granite was suggested in part because of its history of use in monument construction, its apparent strength and durability, and its availability from several operating quarries around the country.

3.1.1 Granite Properties



Granite is an intrusive igneous rock with visible, well-formed mineral crystals (phaneritic texture) composed of quartz, sodium and potassium feldspars, biotite and accessory minerals. These minerals crystallize from the parent magma in the latter stages of slow cooling, making them more stable in surface environments than minerals that form at higher temperatures in the earlier stages of cooling. Crystals are fused together tightly, leaving very little porosity. The phaneritic texture provides less surface area exposed to weathering and erosion, compared to finer grained materials.

The following descriptions and values are related to material properties and are representative of granite from various sources.

- Density – Granites vary in density depending on composition but have average specific gravity of 2.7 and bulk density of 165-170 pcf (Carmichael, 1989).
- Hardness – The L-hammer hardness of granite ranges from 37 to 100 (dimensionless units). Although this range is wide, it compares favorably with the hardness of other rock types (Carmichael, 1989).

- Strength – Uniaxial compressive strength of granite ranges from 17,000 psi to 104,500 psi (Carmichael, 1989).

- Weathering Resistance – Indices of weathering resistance of granite include porosity and absorption. Fresh granite typically exhibits low values of each, less than 2% and less than 1%, respectively (Cold Springs Granite, 2000; Franklin and Dusseault, 1989). Although these values indicate high resistance to weathering of granite fragments, the phenomenon of exfoliation is widely observed in granitic rock masses.

- Inscribability – Given the widespread use of granite as an ornamental and monument material with inscriptions, there is no need to test its inscribability. The relevant question is the relative ease of inscription of granite versus other materials.

- Detectability – Detectability for granite and other nonmetallic materials is dependent primarily on marker size and configuration (not relevant to this study) but also on readily visible contrasts in color, composition and texture between the marker material and surrounding materials. Such contrasts can be evaluated through experimentation or field studies.

- Intrinsic Value – Monument-quality granite is more valuable than most rock and clearly more valuable than rock commonly found at the surface in southeastern New Mexico.

3.1.2 Use of Granite

Granite is an obvious material choice for the large surface markers and also for small subsurface markers because of its hardness and strength, availability, and history of use in similar applications. However, exfoliation could be a serious problem for the large surface markers, causing loss of the inscription in the rock surface.

Use of granite for large surface markers and for the wall and roof panels of the information center and buried storage rooms is problematic for logistical reasons. The size of the panels presents a challenge to the quarry operator to cut, finish, handle, load and ship large slabs without damage or without activating incipient fractures. Even though the panels would be cut from large blocks of granite that visibly seem to contain no fractures, the rock may contain incipient fractures. The rock fabric is weaker and more susceptible to failure along these fractures.

It is unlikely that large slabs of granite used to construct walls and roof panels would be free of these invisible incipient fractures. These fractures would substantially reduce the strength of the load-bearing panels and the ability of the roof panels to sustain bending movement. Consequently, either a redesign of the buildings is needed to reduce required dimensions and

structural loads or other materials should be considered for the load-bearing components.

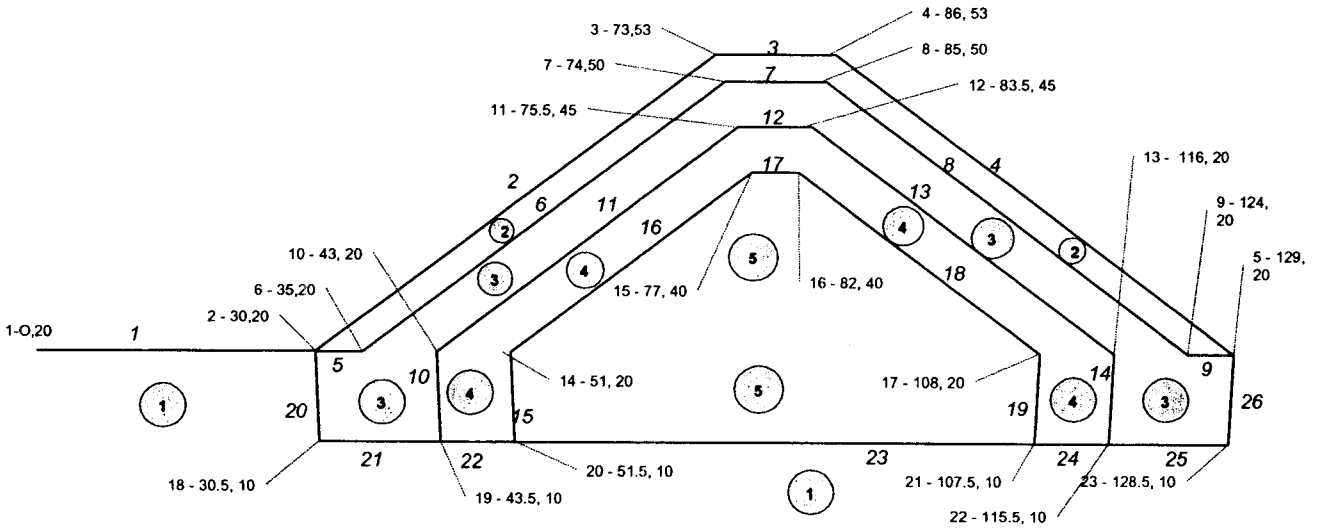
3.2 Local Earth Materials

The reference design for the berm calls for it to be constructed of crushed salt, native soil, caliche, and rock from sources on or near the WIPP site. The crushed salt, presently stockpiled on site, was excavated to form the underground workings at repository level. Native soil is the natural soil of the WIPP site consisting of sand, silt, and some clay. Caliche occurs at shallow depth across the WIPP site and surrounding lands. Rock in the berm will be used for erosion protection so it must be durable; such rock is not found on the site but sources are located within 100 miles of the site. Each of these materials has been evaluated for their proposed use in construction of the berm. The material evaluations are presented in the following subsections.

3.2.1 Salt

The salt excavated from the underground workings consists primarily of halite (sodium chloride) with some potassium salts and anhydrite (calcium sulfate). Salt was included in the reference design to use a material already available in a large quantity at the WIPP site and otherwise not commercially valuable. However, halite is very soluble and has low strength. Sandia National Laboratories (SNL) tested compacted crushed salt to determine its properties for use as backfill material in the underground workings (SNL, 1999). The SNL studies determined that salt permeability was extremely low, about 10^{-17} cm/sec, under laboratory test conditions of 145 psi confining pressure, dry density of 130 pcf (or about 90 % of the theoretical maximum), and porosity of 10-12 %. These results would appear to support a prediction that a salt core in the berm would be functionally impermeable and not susceptible to penetration and consequent dissolution by water. However, the laboratory test conditions are ideal and much different from those that could be achieved in the field using heavy earth working equipment. Typically, field-compacted earth materials can be compacted to densities of up to about 75% of theoretical maximum, or about 98 pcf for salt, leaving porosities of at least 25% (Terzaghi et al, 1996). The confining pressure of the salt core in the finished berm would be 8-25 psi, much less than that used in the Sandia tests. Consequently, a salt core would be less dense and more permeable than would be predicted based on the Sandia results.

Long-term performance criteria 4a and 4c (see Section 2.0) require the berm to be durable and stable; i.e., to be long lasting and structurally sound. To predict the structural performance of compacted crushed salt in the core of the berm, as proposed in the reference design, stability analyses were performed using the computer code SB Slope (Geosystems, 1994). Results of these analyses are illustrated on Figures 1 and 2. The stability analyses predict that the reference-design berm with its salt core would be unstable (factor of safety of less than 1.0 against slope failure by rotational displacement) under both static and pseudostatic (earthquake of 0.1g peak



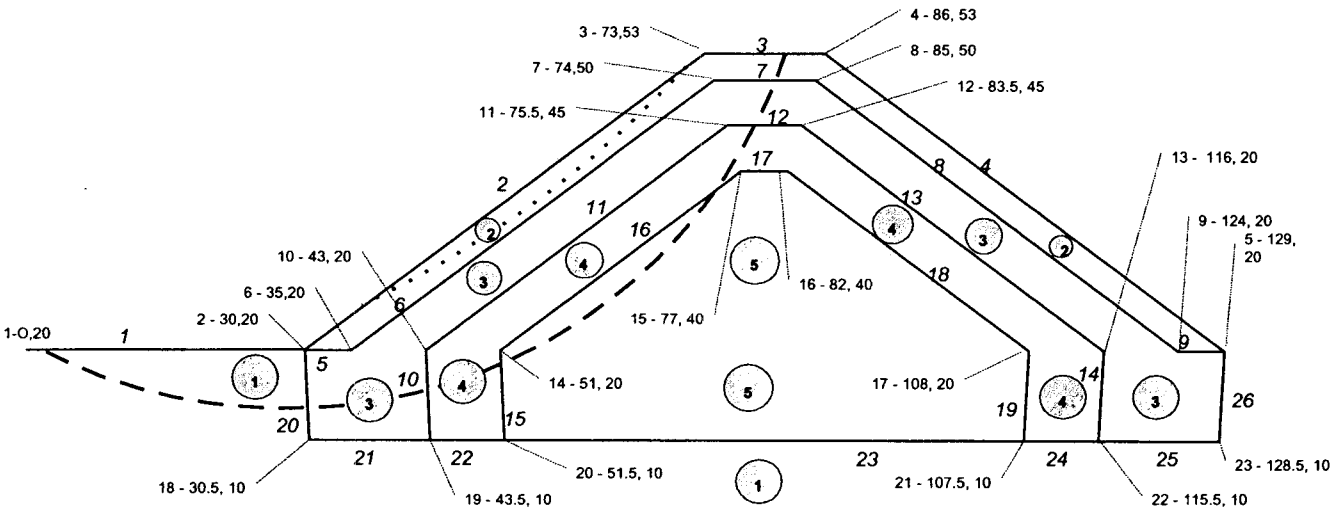
	SOILS	UNIT WT. PCF	FRICTION ANGLE	COHESION PCF
1	NATIVE SOIL	110	25	0
2	SOIL/RIPRAP	140	30	110
3	RIPRAP	107	35	0
4	CALICHE	135	30	0
5	SALT	112	11	110

POINT	X	Y
1	0	20
2	30	20
3	73	53
4	86	53
5	129	20
6	35	20
7	74	50
8	85	50
9	124	20
10	43	20
11	75.5	45
12	83.5	45
13	116	20
14	51	20
15	77	40
16	82	40
17	108	20
18	30.5	10
19	43.5	10
20	51.5	10
21	107.5	10
22	115.5	10
23	128.5	10

LINE	L	R	SOIL
1	1	2	1
2	2	3	2
3	3	4	2
4	4	5	2
5	2	6	3
6	6	7	3
7	7	8	3
8	8	9	3
9	9	5	3
10	10	19	3
11	10	11	4
12	11	12	4
13	12	13	4

LINE	L	R	SOIL
14	22	13	3
15	14	20	4
16	14	15	5
17	15	16	5
18	16	17	5
19	21	17	4
20	2	18	1
21	18	19	1
22	19	20	1
23	20	21	1
24	21	22	1
25	22	23	1
26	23	5	1

Figure 1 - Material And Configuration Parameters Of Reference Design berm



. . . . FAILURE SURFACE WITH LOWEST FACTOR OF SAFETY (0.76) UNDER STATIC LOAD CONDITIONS

— — FAILURE SURFACE THROUGH CORE WITH LOWEST FACTOR OF SAFETY UNDER STATIC LOAD CONDITIONS – 0.88 WITH SALT CORE, 1.27 WITH SOIL CORE

Figure 2 - Reference Design Berm Stability Analysis

ground acceleration) load conditions. The calculated minimum factor of safety for a failure surface through the salt core is 0.88 for static load conditions and would be even lower with earthquake loading. The likely failure surface passes partly through the salt core (Figure 2). If the side slopes of the berm are reduced to a 0.33 grade (3H: 1V) as shown in Figure 3, the pseudostatic factor of safety is still too low, 0.92 (Figure 4). In the reference-design configuration where soil is used in place of salt (see Figure 2), factors of safety are substantially higher, 1.27 for soil core versus 0.88 for salt core, clearly demonstrating that salt lacks the strength needed in the core of the berm. The safety factor with a soil core and 0.33 grade is 1.54 under static load conditions.

Another factor that influences the structural performance of the berm is settlement. All non-indurated earth materials are subject to settlement, generally resulting from densification of material. In typical earthfill construction practice, earth materials are mechanically compacted to increase the fill density, increasing its strength and minimizing its settlement potential. If a fill material is soluble, dissolution can create voids that not only reduce the material mass strength but also make the material susceptible to additional settlement. Such settlement can be non-uniform and large enough to increase the fill's susceptibility to erosion, intrusion by burrowing animals, and structural failure.

3.2.2 Native Soil

The native soils at the WIPP site consist of sand, silt and clay derived from weathering of local rock, alluvial deposition from small streams, and from more recent deposition of windblown sediments. The predominant soil type varies from place to place across the WIPP area but fine sand in low vegetation-stabilized dunes is distributed across the undeveloped portions of the site.

The following italicized text, excerpted from Chapter 2 of the CCA, describes the area soils:

> *Soils of the region have developed mainly from Quaternary and Permian parent material. Parent material from the Quaternary System is represented by alluvial deposits of major streams, dune sand, and other surface deposits. These are mostly loamy and sandy sediments containing some coarse fragments. Parent material from the Permian System is represented by limestone, dolomite, and gypsum bedrock. Soils of the region have developed in a semiarid, continental climate with abundant sunshine, low relative humidity, erratic and low rainfall, and a wide variation in daily and seasonal temperatures. Subsoil colors are normally light brown to reddish brown but are often mixed with lime accumulations (caliche) that result from limited, erratic rainfall and insufficient leaching.*
>
> *A soil association is a landscape with a distinctive pattern of soil types (series). It normally consists of one or more major soils and at least one minor soil. There are three soil associations within 5 miles (8.3 kilometers) of the WIPP site: the Kermit-Berino, the Simona-Pajarito, and the Pyote-Maljamar-Kermit. Of these three associations, only the Kermit-Berino soil series has been mapped across the WIPP site by Chugg et al. (1952, Sheet No. 113). These are sandy soils developed on eolian material. The Kermit-Berino soils include active dune areas. The Berino*

soil has a sandy A horizon; the B horizons include more argillaceous material and weak-to-moderate soil structures. A and B horizons are described as noncalcareous, and the underlying C horizon is commonly caliche. Bachman (1980, 44) interpreted the Berino soil as a paleosol that is a remnant B horizon of the underlying Mescalero. Rosholt and McKinney (1980, Table 5) applied uranium-trend methods to samples of the Berino soil from the WIPP site area. They interpreted the age of formation of the Berino soil as 330,000 ± 75,000 years.

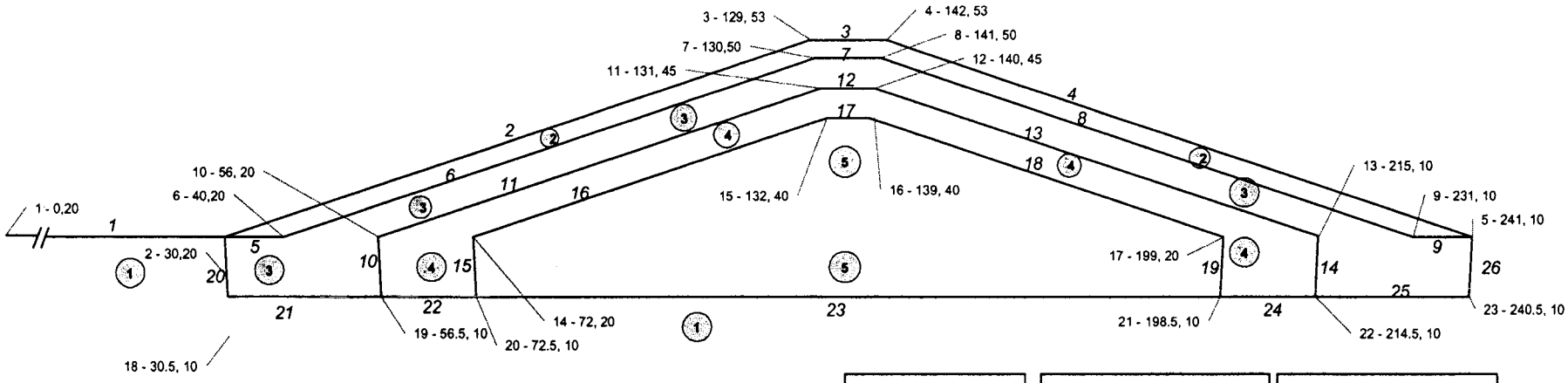
Generally, the Berino Series, which covers about 50 percent of the site, consists of deep, noncalcareous, yellow-red to red sandy soils that developed from wind-worked material of mixed origin. These soils are described as undulating to hummocky and gently sloping (0 to 3 percent slopes). The soils are the most extensive of the deep, sandy soils in the Eddy County area. Berino soils are subject to continuing wind and water erosion. If the vegetative cover is seriously depleted, the water-erosion potential is slight, but the wind-erosion potential is very high. These soils are particularly sensitive to wind erosion in the months of March, April, and May, when rainfall is minimal and winds are highest. These soil characteristics are a consideration for the design of long-term passive controls such as monuments and markers (see Appendix PIC, Section III).

The Kermit Series consists of deep, light-colored, noncalcareous, excessively drained loose sands, typically yellowish-red fine sand. The surface is undulating to billowy (from 0 to 3 percent slopes) and consists mostly of stabilized sand dunes. Kermit soils are slightly to moderately eroded. Permeability is very high, and, if vegetative cover is removed, the water-erosion potential is slight, but the wind-erosion potential is very high.

When used as construction materials in the berm, these soils can be selectively excavated, blended and compacted to achieve any necessary structural properties. The in-place density and cohesion of the native soil will govern its behavior as a foundation material for the permanent markers. These properties are subject to some improvement through procedures such as compaction, consolidation grouting, and other ground improvement procedures. However, it is unlikely that any structural loads imposed by permanent markers would necessarily be greater than the allowable bearing capacity of the in-place soils without improvement of their original properties. The native soil excavated for construction of the berm may be manipulated in various ways to increase strength, including blending of soils, selectively wasting of weaker soils, and additives. After the soils are placed, they can be moisture-conditioned and compacted to achieve close to their maximum potential densities and strengths.

No highly compressible soils or shallow ground water conditions exist within the area of permanent marker placement. Therefore, dewatering or artificial consolidation of compressible or collapsible soils should not be necessary. The design of the berm can be modified in various ways to accommodate the native soils found within the immediate vicinity of the berm.





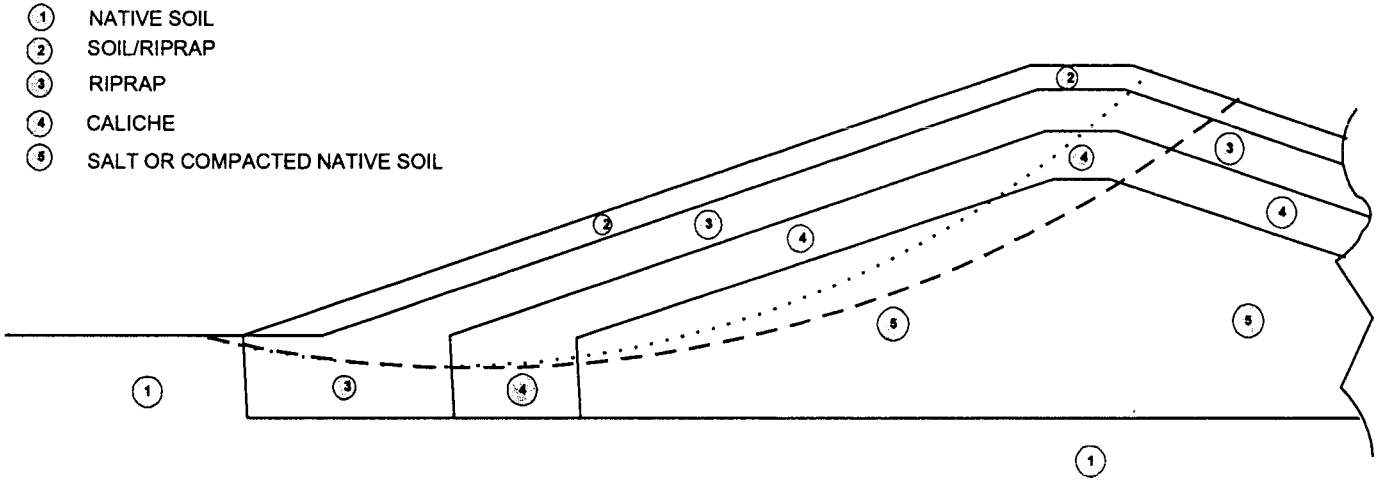
SOILS		UNIT WT. PCF	FRICTION ANGLE	COHESION PCF
1	NATIVE SOIL	110	25	0
2	SOIL/RIPRAP	140	30	110
3	RIPRAP	107	35	0
4	CALICHE	135	30	0
5	SALT	112	11	110

POINT	X	Y
1	0	20
2	30	20
3	129	53
4	142	53
5	241	20
6	40	20
7	130	50
8	141	50
9	231	20
10	56	20
11	131	45
12	140	45
13	215	20
14	72	20
15	132	40
16	139	40
17	199	20
18	30.5	10
19	56.5	10
20	72.5	10
21	198.5	10
22	214.5	10
23	240.5	10

LINE	L	R	SOIL
1	1	2	1
2	2	3	2
3	3	4	2
4	4	5	2
5	2	6	3
6	6	7	3
7	7	8	3
8	8	9	3
9	9	5	3
10	10	19	3
11	10	11	4
12	11	12	4
13	12	13	4

LINE	L	R	SOIL
14	22	13	3
15	14	20	4
16	14	15	5
17	15	16	5
18	16	17	5
19	21	17	4
20	2	18	1
21	18	19	1
22	19	20	1
23	20	21	1
24	21	22	1
25	22	23	1
26	23	5	1

Figure 3 - Alternative Berm Design Material And Configuration Parameters With 3:1 Sideslopes



M

. . . . FAILURE SURFACE WITH LOWEST FACTOR OF SAFETY OF 1.27 UNDER STATIC LOAD CONDITIONS, 0.92 UNDER EARTHQUAKE LOADING - *COMPACTED SALT CORE*

— — FAILURE SURFACE WITH LOWEST FACTOR OF SAFETY OF 1.54 UNDER STATIC LOAD CONDITIONS, 1.12 UNDER EARTHQUAKE LOADING - *COMPACTED NATIVE SOIL CORE*

Figure 4 - Alternative Berm Design Stability Analysis With 3:1 Sideslopes

3.2.3 Caliche

Caliche occurs in and near the WIPP site at shallow depths. Several developed caliche borrow pits are within reasonable haul distance of the WIPP site, and some caliche borrow pits could be developed in or near the locations of the permanent markers. The CCA and other project documents discuss the characteristics of the native caliche in some detail. The following italicized text is from Chapter 2 of the CCA:

> *The Mescalero caliche is an informal stratigraphic unit apparently first differentiated by Bachman in 1974, though Bachman (1973, 17, 27) described the caliche on the Mescalero Plain. He differentiated the Mescalero from the older, widespread Ogallala caliche or caprock on the basis of textures, noting that breccia and pisolitic textures are much more common in the Ogallala caliche. The Mescalero has been noted over significant areas in the Pecos drainage, including the WIPP area, and it has been formed over a variety of substrates. Bachman (1973) described the Mescalero as a two-part unit: (1) an upper dense laminar caprock and (2) a basal, earthy-to-firm, nodular calcareous deposit. Machette (1985, 5) classified the Mescalero as having Stage V morphologies of a calcic soil (the more mature Ogallala caprock that occurs east of the WIPP site reaches Stage VI).*
>
> *Bachman (1976, Figure 8) provided structure contours on the Mescalero caliche for a large area of southeastern New Mexico, including the WIPP site. From the contours and Bachman's discussion of the Mescalero as a soil, it is clear that the Mescalero is expected to be continuous over large areas. Explicit WIPP data are limited mainly to boreholes, though some borehole reports do not mention the Mescalero. The unit may be as much as 10 feet (3 meters) thick.*

The caliche materials may be blended to improve their strength and compaction characteristics, or non-caliche soil materials may be added to the caliche for this purpose as well. Other than the differences in composition between caliche and native soil, the density and strength of compacted caliche should be similar to those properties of compacted native soil. However, the handling of caliche will probably be complicated by the great variability in the natural density and hardness of the material in its undisturbed condition. Excavating and processing caliche will probably take more effort and cost more per cubic yard than similar handling of native soil.



3.2.4 Riprap

Rock for riprap is not available within or in close proximity to the WIPP site; however, durable rock sources are known to exist within about 100 miles of the WIPP site, especially in the Guadalupe Mountains. Possible rock types that may be considered for riprap include limestone, basalt and other extrusive igneous rocks, and well-indurated sandstone.

The design of the berm sideslopes (gradient, length) can be varied to accommodate the available riprap rock. The most readily available and least costly rock might not be sufficiently durable to protect side slopes of a certain configuration. In such a case, the side slopes can readily be flattened to a lower gradient, trading off the cost of additional earthwork against the higher cost of importing more durable rock from more distant sources.

3.3 Metals and Metallic Alloys

Various metals and metal alloys have been proposed in the markers reference designs. Characteristics of those proposed are described in the following subsections.

3.3.1 Strontium Ferrite

The reference design material for the buried magnets is strontium ferrite. Although not specifically identified as such in the reference design, the particular material that would most likely be used for magnets is strontium hexaferrite ($SrO\text{-}6Fe_2O_3$). This material makes a hard permanent magnet that has high resistance to demagnetization, high remanence, coercivity, and saturation flux density, as well as low initial permeability. The most important properties of strontium hexaferrite are cohesivity and "energy product." The energy product is representative of the energy required to demagnetize the permanent magnet. A large external field is required to demagnetize strontium hexaferrite. Strontium hexaferrite exhibits a strong magnetization after a magnetic field has been applied and removed and is stable even if a certain strength of demagnetizing field is reapplied. The advantages of strontium hexaferrite over other magnetic counterparts include high coercivity and low permeability, low specific gravity, multipolarity on one surface, and the ability to be mixed with plastic and rubber to form magnets (Collins and Hirschfeld, 2000a).

3.3.2 Stainless Steel



Stainless steel has been identified as one of two alternative materials of construction in the reference design for the radar reflectors. The reference design does not specify what particular type of stainless steel is intended; there are, in fact, several types that might be used. Stainless steel 316 and 317 have some of the best long-term durability properties. These are austenitic stainless steels with less carbon or added nitrogen for increased strength. Stainless steel 316 has high corrosion resistance and is resistant to mild oxidizing and reducing chemical environments.

Stainless steel 317 has higher molybdenum content than stainless steel 316, increasing its resistance to corrosion. However, if the radar reflectors are enclosed within a corrosion-resistant coating or protective shell, high corrosion resistance may be unimportant. In this case, stainless steel 304 may be preferable because of its lower cost. Table 1 lists some of the properties of two stainless steels and Inconel.

Table 1. Comparison of Properties and Costs of Reference Design Radar Reflector Metals

Materials	Density (g/cm3)	Hardness (Rockwell)	Tensile Strength (MPa)	Yield Strength (Mpa)	Percent Elongation	Thermal Expansion (μm/m*K)	Cost ($/lb.)
Stainless Steel 316	7.8	79	579	290	50	16.0	2.50-3.00
Stainless Steel 317	7.8	85	621	276	42.5	16.2	NA
Inconel 625	8.4	190	930	517	42.5	11.5	14-17

Any type of stainless steel should perform satisfactorily in terms of its reflectivity of radar energy. There has been no distinction drawn between the several stainless steels or between stainless steel and other metals with respect to radar reflectivity.

3.3.3 Inconel

Inconel (61Ni-21Cr-9Mo-3.6Nb) has also been identified in the reference design as a material that could be used in the construction of radar reflectors. Inconel 625 is commonly used in chemical processing equipment, aerospace and marine engineering, pollution-control equipment, and nuclear reactors. It is a nickel-chromium-molybdenum alloy with an addition of niobium that acts with the molybdenum to stiffen the alloy's matrix and provide high strength without extensive heat treatments. The alloy is able to withstand a wide variety of corrosive environments; the combination of nickel and chromium provides resistance to oxidizing conditions, and the combination of nickel and molybdenum provides resistance to reducing conditions. The alloy is especially resistant to pitting and crevice corrosion.

3.3.4 Other Metals

Both titanium and hastealloy (hastelloy) are mentioned in the reference design as metals that could be used in the small subsurface markers. Titanium is used in alloys, principally with iron where high strength, corrosion or temperature resistance, or light weight are important. The reference design does not name any specific alloys containing titanium.

Hastelloy is a family of Nickel base superalloys (35+ variations), all of which are relatively expensive (Leslie Chom, ASM International, personal communication, July 21, 2000). Hastelloys



are used primarily for highly corrosive, oxidizing and reducing environments. The properties of Hastelloy C-2000 are representative of the group:

- Compostion - 23% chromium, 16% molybdenum, 1.6% copper, >1% carbon and silicon, balance nickel
- Density - 8.50 g/cm3
- Mean coefficient of thermal expansion - 6.9 μm/m
- Tensile strength - 758 MPa for 0.5 in. thickness

It also has superior pitting and crevice corrosion resistance. Hastelloy can be formed into sheets, bars and plates as well as wire and tube (ASM, 1996).

3.4 Other Materials

Quartz, Lanthanumborate glass, ceramics, and polyethylene are mentioned in the reference design as possible materials for small subsurface markers. Quartz is a mineral with a hardness of 7 on the Moh's Scale, making it as hard as any windblown sand. However, crystalline quartz would be difficult to inscribe and would have to be specially fabricated to create sizes sufficient for the markers.

3.4.1 Lanthanumborate

Lathanumborate glass is a "glass precursor" developed by Owens Corning for the DOE's Savannah River Company containing lanthanum and borate (Peter McGinnis, Owens Corning, personal communication, July 21, 2000). No other information on this material was found through this literature review.

3.4.2 Polyethylene

Polyethylene is soft plastic that can be formulated for a wide variety of uses and, therefore, to have a wide range of properties. According to ASTM D-3550-84, typical primary properties are:

- Density - 0.941-0.955 g/cm3
- Tensile strength at yield - 21 Mpa
- Flexural modulus - 758 Mpa
- Impact strength - >12 ft.lbs/ in.
- Hardness (Shore D) - 65
- Coefficient of thermal expansion - 0.778 x 10^{-4} in./in./ °F



Polyethylene is readily molded into many shapes and holds even very small symbols and letters, a fact evident in the profusion of bottles, caps and other common imprinted objects. High density polyethylene (HDPE) is widely used as material for pipe and liners for both acidic and alkali liquids; it is chemically stable over a wide pH range. Polyethylene warrants further consideration as a material of construction for the small subsurface markers.

3.4.3 Ceramics

Ceramics are a large group of materials composed of inorganic nonmetallic substances. No specific ceramic is identified in the reference design. The group is too large to address completely; a few specific ceramics are identified and described later in this report as alternative materials.



4.0 Alternative Materials

This review includes an initial examination of a wide variety of materials that may be considered for use either in addition to or in place of materials identified in the reference design. The identification and evaluation of alternative materials focuses primarily on the physical properties and expected performance of the alternative materials, but also considers the availability of such materials, the logistics of obtaining them and transporting them to the WIPP site, and the relative costs of these materials versus those identified in the reference design. Alternative materials evaluated in this study include rock types other than granite, concrete, other metals and metallic alloys, ceramics, and polymers.

4.1 Rock Other than Granite

Several rock types other than granite have been identified as likely to have durability, inscribability, and strength comparable to or better than granite. The initial list of alternative rock types includes basalt, well-indurated sandstone, quartzite, and limestone. Limestone, however, has been discarded from consideration because of its composition (calcium carbonate), which is susceptible to dissolution under even mildly acidic conditions. It is impossible to predict the long-term air quality and potential for acid rain over the service life of the permanent markers. Therefore, the potential for dissolution of the surface features of limestone in that period of time is considered to be too great to give limestone further consideration. Quartzite has also beeen discarded from consideration because of its relative scarcity and because it is difficult to quarry and inscribe due to its extreme hardness.

Transportation cost for rock from sources outside southern New Mexico and west Texas is expected to be an important discriminating factor when selecting alternative rock types. Accordingly, the evaluation of alternative rocks was limited to those that occur at ground surface within 200 to 300 miles of the WIPP site.

4.1.1 Basalt

Basalt is an extrusive volcanic rock that is widely distributed throughout the southwest and, in particular, in the south central and southwest parts of New Mexico, within reasonably short haul distance of the WIPP site. Basalt is composed of sodic feldspars and mafic minerals, those that are on the earlier-crystallizing end of the Bowen Reaction Series. Although these minerals are less stable at ground surface than those that crystallized later in the series, they can be viewed as stable in the relatively short period of performance of the permanent marker system versus the geologic scale of time in which these minerals are commonly referred to as less stable. The hardness of the minerals in basalt is comparable to the hardness of most of the minerals in granite; therefore, basalt should be at least as readily inscribed as granite.

The physical properties that affect durability of basalt compare favorably to those of granite. The density of basalt varies from 130 pcf to 187 pcf (2.08 to 3.0 g/cm^3), reflecting the influence of vesicles (gas-produced voids) on the density of basalt. Because of these voids or holes, vesicular basalt is unsuitable for use in any marker that is inscribed. Non-vesicular basalt will have densities near the upper end of this range as well as compressive strength of up to 104,500 psi and Schmidt L-hammer hardness of 49-85, similar to granite (Carmichael, 1989). Non-vesicular basalt has porosities below 2%, just like granite (Franklin and Dusseault, 1989).

Basalt is evidently at least as erosion resistant as granite in the environment of the southwest, as demonstrated by the persistence of the basalt cap rocks on mesas and elsewhere within New Mexico. In addition basalt is drab and relatively unattractive, and that combined with its widespread occurrence makes it economically less valuable and less attractive to would-be scavengers than granite. The results of a recent survey of petroglyphs (John Hart and Associates, P.A., 2000a) show that very old petroglyphs of Archaic age (1000-6000 years old) are well preserved in basalt in several locations in environments similar to that of the WIPP site. The inscriptions of these petroglyphs were very shallow but have endured for up to several thousand years without observable deterioration.

4.1.2 Well-indurated Sandstone

There is a wide variety of rocks appropriately called sandstone that occur in the southwest. Some of these sandstones are very soft and crumble easily when squeezed or struck; others are extremely hard because they have been lithified in a way that has cemented the sand grains in a tight, durable matrix (well-indurated). Sandstones like this occur in the southwestern quadrant of New Mexico, within reasonable distance from the WIPP site. They also form resistant cap rocks on mesas and have been inscribed by Archaic Indians in several locations in New Mexico, leaving petroglyphs that are up to 6000 years old, readily visible and exhibit little deterioration over that period of time. Some of these petroglyphs are in environmental settings that are more severe with respect to weathering and erosion than the environment of the WIPP site.

Well-indurated sandstone has physical properties at the upper end of the wide ranges recorded for all sandstones, with values similar to granite. Compressive strength, up to 142,000 psi, can be as good as, or even better than, that of granite. Densities of well-indurated sandstone higher than those of granite, up to 207 pcf, have been measured, but L-hammer hardness tends to be lower than for granite, up to 56 (Carmichael, 1989).

4.1.3 Other Potential Alternative Rock Types



The extent of this study has not enabled the investigators to examine all potential candidate rock types that might occur within reasonable proximity of the WIPP site. However, several other rock types are known to occur in southern New Mexico and west Texas that could be examined for possible inclusion as alternative rock types. These include rhyolite and andesite. Both of these are fine-grained igneous rocks that exhibit properties very similar to those of basalt.

4.2 Concrete

In the reference design, the potential use of concrete is limited to the encasement of the radar reflectors. However, the opportunity is left open for other uses, including the material of construction for the large surface markers, the buried storage rooms, and the information center. Widespread examples of crumbling concrete in our modern infrastructure contribute to legitimate concerns about the use of concrete for any applications requiring extreme longevity. However, there are well documented examples in the historic record of concrete used in ancient times that remains intact and durable to the present. If the historic record is used as a reference and recent advances in concrete technology are considered, alternative concrete designs may be developed that have the potential for satisfying the performance criteria.

4.2.1 Concerns About Concrete

Examples of crumbling concrete and failed structures made of concrete are well known to everyone. While few would dispute the strength of concrete as a construction material, many people have legitimate concerns that concrete is not adequately durable to last the thousands of years expected of the permanent markers. There are many causes for the short service life of some concretes, including unsuitable aggregate materials, improper ratios of constituents, contaminated cement, poor workmanship and placement, and insufficient curing times. The last of these causes is frequently the result of construction schedule imperatives that place a priority on removing forms from concrete pours as quickly as possible. Accelerators are often added to concrete mix to obtain an initial set as quickly as possible, which can contribute to the long-term low durability of concrete. The circumstances of construction of the WIPP permanent markers (e.g., unlimited time available for set and cure) offer opportunities to avoid important causes of concrete deterioration.

4.2.2 History of Concrete

Over the course of this study, the literature was reviewed to find descriptions of concrete and cementiceous materials that, in general, have lasted for long time periods. The record is surprisingly strong in this regard.

One of the earliest uses of a cementiceous material is a lime-plastered floor found in the village of Yiftahel in Israel. The site has been determined by carbon-14 dating to be approximately 8850 years old. The floor consists of a base layer and a thin finish layer. The primary constituent of both layers is calcite, with minor amounts of quartz. The base layer was determined to have a compressive strength of 34 Mpa (4930 psi), and the finish layer has a compressive strength of 45 Mpa (6525 psi). Although this floor did not contain aggregate like that used in modern structural concrete, its compressive strength is comparable to that of modern structural concrete in similar applications (John Hart and Associates, P.A., 2000b).

A calcium sulfate-based mortar was used as a cementiceous material and crack filler in open spaces in pyramids in Egypt constructed 4500 years ago. The main constituents are gypsum, anhydrite, calcite, argillaceous limestone, and quartz sand. The gypsum was heat-treated and possessed pozzolanic properties due to the breakdown of clay to amorphous aluminosilicates (John Hart and Associates, P.A., 2000b).

On the Greek island of Rhodes at the ancient city of Kamiros, a water tank was constructed of concrete approximately 3000 years ago. The concrete used in the water tank is a mixture of aggregates consisting of siliceous gravel, granular intermediate calcareous aggregates and fine-grained calcareous aggregates plus volcanic earth and lime as a binder, creating low porosity and good water tightness. The tank remains intact today (John Hart and Associates, P.A., 2000b).

The history of the Roman Empire contains a record visible today of the advanced state of Roman concrete technology. The city of Caesaria in Israel on the shores of the Mediterranean contains a breakwater consisting in part of concrete continually subjected to salt water since around 10 BC. The concrete is made of fieldstone rubble, red clay and lime. In Italy, several Roman aqueducts built nearly 1800 years ago and located as close as 150 meters from the sea still remain intact and functional. These structures were continuously subjected to salt water spray and cycles of wetting and drying. Both the Coliseum completed in AD 82 and the Pantheon completed in AD 128 contain large amounts of concrete. Despite containing no reinforcement, the Pantheon dome is in good condition. The aggregate used in the concrete in the Pantheon ranges from heavy basalt in the foundations through brick and tuff in the upper walls to pumice in the top of the dome (John Hart and Associates, P.A., 2000b).

The Roman Empire constructed nearly 53,000 miles of roads throughout Europe and the Middle East; by comparison, the U.S. Interstate Highway system consisted of 42,000 miles in 1995. The typical Roman road construction design included four courses. The next-to-bottom course, or nucleus layer, was about one foot thick and was made of concrete with small gravel and coarse sand mixed with hot lime and water (Steiger, 1995). Whenever possible, the concrete mix consisted of lime mixed with volcanic rock or sand called pozzolana, named after the place where it was first found, the town of Pozzuoli near Mt. Vesuvius. The pozzolana contained aluminum silicate ash, erupted from the volcano, from which silica was readily liberated by caustic alkalies such as calcium hydroxide. Silica combined with the lime to form a solid cementing material that could harden in water. Pozzolanic materials are still used in many applications to this day (John Hart and Associates, P.A., 2000b).



In Meso-America, the Mayans developed a concrete that has lasted approximately 900 years. In the ancient city of El Tajin in Mexico, the Mayans constructed a concrete roof in which the main components were calcite and quartz with other mineral composites which participated in the pozzolanic reactions. The concrete has been analyzed and found to contain 15% soluble silica, 15% aluminum, 56% lime, and 20% anhydrous cementiceous material, with a pozzolanic index of 0.42, indicating that silica and alumina mobilization is quite substantial. Compositions of this type are commonly known as pozzolanic concrete (John Hart and Associates, P.A., 2000b).

Very recently in Hawaii, a foundation slab was constructed for a temple planned to last for at least 1000 years. The design specifically excluded the use of reinforcing steel. To achieve the high strength and durability required, a high volume fly ash (HVFA) concrete was designed. In this type of concrete, half or more of the cement in the mix is replaced with fly ash. According to the designer, Dr. E. K. Mahta (1999), fly ash concrete is much more durable than normal concrete because it totally eliminates temperature cracking due to its low heat of dehydration and slow cure time. The slab reached a strength of 1000 psi in three days and 3000 psi in three weeks, and the slab is expected to reach 6000 psi strength in a few years (Mahta ,1999).

It is evident from this historical record that the potential durability for cementiceous materials and concrete cannot be judged by the experience of most modern concrete design and construction practices that emphasize volume and speed of placement and early strength at the sacrifice of durability. This is not necessarily the case with all modern concretes, however. Brown (1987) tested two samples of Roman concrete approximately 1900 years old, two samples of Mayan concrete approximately 600 years old, and a referenced sample of modern-day concrete. The samples were subjected to freezing in air and thawing in water, and weight losses were recorded after each freeze-thaw cycle. Brown found that Roman concretes virtually disintegrated after 18-29 cycles. One of the Mayan samples lasted 79 cycles; the other lasted the entire test of 150 cycles with 28% loss. The reference modern-day samples survived the entire 150 cycles with only 6% loss. Brown concluded that even the successful ancient concretes would have suffered substantial deterioration in harsher climates represented by the cyclic freeze-thaw testing, whereas modern concretes can be designed for specific environmental conditions.

4.2.3 Alternative Concrete Design

The combination of historic lessons and modern technology indicate that it may be possible to create a concrete that will be sufficiently strong and durable to last a very long time at the WIPP site, perhaps 10,000 years or longer. Durability is dependent on several factors – permeability, strength, and chemical stability (McKeen, 2000). Low permeability is desirable to reduce, as much as possible, infiltration of water and other mobile materials from infiltrating the concrete. High strength gives the concrete greater capability to resist abrasion and erosion. Chemical stability is needed to prevent or reduce the risk of reactions between incompatible constituents in the mix that could lead to deterioration of the concrete over time. All three of these factors can be optimized by the selection of the proper materials, optimal proportions, and mixing and placement procedures that are designed specifically for the mix and the intended application.



The permanent markers program provides an ideal set of circumstances to use concrete in the most optimal way. Specifically, pace of construction, cure times, and removal of forms are not important considerations in the construction of permanent markers and may be planned to provide the longest cure time needed to obtain optimal durability. Forms can be kept in place and accelerator additives can be avoided in the construction of the permanent markers, allowing the

concrete to cure slowly and gain strength gradually, thereby providing the greatest likelihood that the concrete will gradually develop the desired properties.

For the WIPP permanent marker applications, a high-volume fly ash (HVFA) concrete mix appears to be the most appropriate for the achievement of the performance objectives. This type of concrete may also be used in place of granite or other rock in most or all of the other applications for which granite is the reference material. The HVFA concrete would consist of ASTM Class F fly ash as the pozzolanic material that will substitute for a portion of the Portland cement in the mix. The aggregates should be selected to be as stable and non-reactive as possible. The recommended proportions and typical physical properties of such mixes are listed in Table 2 and Table 3, respectively.

Table 2. Typical Mix Proportions for High Volume Fly Ash Concrete [1]

Component	Fly Ash Content		
	Low	Medium	High
Water (kg/m^3)	115	120	110
Type I cement (kg/m^3)	125	155	180
Class F fly ash (kg/m^3)	165	215	220
Coarse aggregate (kg/m^3)	1170	1195	1110
Fine aggregate (kg/m^3)	800	645	760
Air-entraining (ml/m^3)	200	200	280
Superplasticizer (kg/m^3)	3.0	4.5	5.5

1. Source: McKeen, 2000



Table 3. Typical Physical Properties of a Medium Strength Mix HVFA Concrete [1]

Property	Age (days)	Values	
		(MPa)	(psi)
Compressive Strength	1	8±2	1160±290
	7	20±4	2900±580
	28	35±5	5070±725
	91	43±5	6240±725
	365	55±5	8000±725
Flexural Strength	14	4.5±0.5	650±73
	91	6±0.5	870±73
Splitting Tensile Strength	28	3.5±0.5	500±73
Young's Modulus	28	35±2	5.1×10^6
	91	38±2	5.5×10^6
Drying shrinkage strain	448	$500\pm50, \times 10^{-6}$ [2]	
Specific creep strain	365	$528\pm40, \times 10^{-6}$ [2]	

1. Source: Bilodeau et. al, 2000.
2. Dimensionless

4.3 Metals and Metallic Alloys

The metals identified in the reference design, strontium ferrite for magnets and both stainless steel and Inconel for the radar reflectors, appear to be appropriate for the designated uses. Additional metals and alloys may also be considered.

Monel K-500 (66Ni-29.5Cu-2.7Al-0.6Ti) is widely used for pump shafts, oil well tools, and instruments, doctor blades and scrapers used in ceramic tape casting, springs, valve trim, fasteners, and marine propeller shafts. It is a precipitation-hardenable nickel-copper alloy with high strength and excellent corrosion resistance in a range of media, including sulfuric acid and alkalis. Inscription of Monel K-500 would be the easiest and least expensive of all the metals considered (Collins and Hirschfeld, 2000a; 2000b). Therefore, Monel K-500 might be considered for the small subsurface markers and for inscribed message plates that could be embedded in another structural medium for any of the other message-bearing markers.

Barium hexaferrite is an alternative to strontium ferrite for magnets. It is one of the most widely used materials for permanent magnets and magnetic recording media (hard disks, floppy disks, and video tapes). It has excellent chemical stability and exhibits a stronger coercive force (H_{cf}) than strontium hexaferrite. However, strontium hexaferrite has a higher coercivity (H_c), remanence (Gauss), and energy product $(BH)_{MAX}$. The properties of these two ferrites are compared in Table 4 (Collins and Hirschfeld, 2000a; 2000b).

Table 4. Properties of Ferrite Materials for Magnets [1]

Properties	Strontium Ferrite ($SrO\text{-}Fe_2O_3$)	Barium Ferrite ($BaO\text{-}6Fe_2O_3$)
Density (g/cm^3)	5.11	5.28
Thermal Expansion ($\mu m/m*K$)	~18	18
Coercivity (H_c)	3150	3000
Coercive Force (H_{cf})	3590	3650
Remanance (Gauss)	3550	3200
Energy Product $(BH)_{MAX}$, (MGOe)	3.0	2.5
Flux Density (Gauss)	1730	1600
Curie Temp. (°C)	460	450

1. Source: Collins and Hirschfeld, 2000a; 2000b.

4.4 Ceramics

Ceramics are a group of very versatile materials, some of which offer advantages over rock, concrete, metals or polymers for several marker applications. Most oxides, nitrides, carbides, and other "ides" fall into the class of materials called ceramics. Advantages of ceramics compared to metals and polymers include an excellent combination of properties such as high hardness, high melting temperature, good erosion and wear resistance, good corrosion resistance and relatively low cost. However, ceramic materials, being composed of inorganic nonmetallic substances, characteristically are brittle and fracture with little or no deformation, in contrast to metals that yield and deform. Much research is being done to develop ceramics that will not fracture in a brittle manner, which occurs when a crack rapidly travels through a material with no ductile deformation of the adjacent material. A number of other compounds may be added in varying amounts to enhance strength, density, oxidation and corrosion resistance, toughness and machinability. The use and manufacture of ceramics began about 7000 B.C. and, due to the chemical and mechanical stability of ceramics, they are among the most well-preserved man-made materials in existence today (Collins and Hirschfeld, 2000a; 2000b).

Several modern ceramic materials may be well suited for use as marker materials, specifically aluminum oxide (alumina-Al_2O_3), aluminum oxide-zirconium oxide composite (alumina-zirconia-

Al_2O_3-ZrO_2), and aluminum oxide-yttrium oxide-tetragonal zirconium oxide polycrystalline composite (alumina-yttria-tetragonal zirconia polycrystal-Al_2O_3-Y-TZP) robocast silicon nitride (Si_3N_4), Si_3N_4 with silicon carbide (SiC) whisker addition, SiC-10 wt.% (Al_2O_3+Y_2O_3) (Collins and Hirschfeld, 2000a; 2000b). Properties of these ceramics are listed on Table 5.

Table 5. Properties of Ceramics [1]

Ceramic Material	Density (g/cm^3)	Vickers Hardness (GPa)	K_{Ic} Toughness ($MPa*m^{1/2}$)	Thermal Expansion [2] ($K^{-1}*10^6$)	Bend Strength (MPa)
Alumina Al_2O_3 (0-2% porosity)	3.9	20.5	3.8	7.9	700
Alumina-Zirconia 80 wt.% Al_2O_3 20 wt.% ZrO_2	4.2	16.5	6.5	8.5	500
Alumina-yttria tetragonal zirconia polycrystal (Y-TZP) Al_2O_3 2 mol. % Y_2O_3 20 mol % ZrO_2	4.5	16.0	7.4	>8.5	620
Robocast Si_3N_4	3.2	14.7	NA [3]	3.2	740
Si_3N_4-20 vol % SiC	3.1	~14.7	7.5	3.2	710
SiC–10 wt.% (Al_2O_3 +Y2O3)	3.2	25	7.0	4.9	625

1. Source: Collins and Hirschfeld, 2000a; 2000b
2. At room temperature
3. Information not available

4.4.1 Alumina

Alumina occurs naturally as the mineral corundum, which is better known as the gem-quality crystals ruby and sapphire. Alumina is widely used as a cutting tool material as well as an electronic and insulating ceramic. It has been the basis for insulator applications for the last 55 to 65 years. It is widely used in the manufacturing of automobiles as a cutting tool for repetitive machining on metals. Other applications include the manufacture of porcelain, alumina laboratory ware, crucibles, metal casting molds, high-temperature cements, wear-resistant parts (tiles, seals, etc.), sandblast nozzles, armor, medical components, abrasives, and refractories (Collins and Hirschfeld, 2000a; 2000b).

Alumina has excellent mechanical, thermal, and chemical properties such as high hardness and excellent wear resistance, low porosity, and high temperature strength and chemical stability. In addition, a dense body of strongly bonded alumina is comparatively easy to prepare through conventional ceramic processing methods. Due to alumina's high hardness and brittleness, silicon carbide, boron carbide, or diamond tooling are required for inscription, which can be costly (Collins and Hirschfeld, 2000a; 2000b).

4.4.2 Alumina-Zirconia

Although alumina is superior as a wear resistant material, it lacks a great degree of toughness. However, improvements may be realized by adding ZrO_2. Zirconia has long been used as a ceramic because of its refractory nature. It is commonly employed as a thermal barrier coating over the surface of superalloy gas turbine engine components. In addition, it is employed as oxygen sensors in automobiles, resistance heating elements, and single crystal gemstones. Alumina-Zirconia composite materials have high toughness and strength, with moderate hardness. The lower hardness of the Al_2O_3-ZrO_2 material, compared to single component polycrystalline alumina, is more than compensated by the fact that the toughness is greatly increased by zirconia addition. The addition of ZrO_2 toughens the Al_2O_3 matrix by mechanisms of microcracking and stress-induced transformation. There is a distinct difference in the material toughness and strength based on the volume-fraction of zirconia present in the composite. According to a volume fraction zirconia in alumina matrix study performed by Green et. al (1989) all of the measured toughness results passed through a maximum with increasing volume fraction of zirconia. Consequently, an alumina-zircona composite with approximately 75% tetragonal and 25% monoclinic zirconia particles would give the best erosion resistance of this composite material. The alumina-zirconia composite requires silicon carbide or boron carbide tooling for inscription (Collins and Hirschfeld, 2000a; 2000b).

4.4.3 Alumina-Yttria-Tetragonal Zirconia Polycrystal



In alumina-zirconia ceramic composites with 100% tetragonal zirconia particles (TZP), the bending strength and fracture toughness are increased, and with addition of monoclinic zirconia particles the toughness is increased significantly but not the bending strength. Tetragonal zirconia polycrystal (TZP) plus Y_2O_3 added to Al_2O_3-ZrO_2 a durable, high strength, high toughness ceramic. Inscription of this material requires silicon carbide tooling (Collins and Hirschfeld, 2000a; 2000b).

4.4.4 Robocasted Ceramics

Three other ceramics - silicon nitride (Si_3N_4), Si_3N_4 with silicon carbide (SiC) whisker addition, and SiC with 10 wt.% (Al_2O_3+Y_2O_3) - can be made into marker components by robocasting. Robocasting is a free form fabrication process by which a dense ceramic is formed by computer

control. This process yields ceramics of near theoretical density formed directly from a CAD drawing to a finished part within 24 hours. Messages and symbols, made directly by this process without inscription, would be contained within and extend through the marker, not just reside at the surface (Collins and Hirschfeld, 2000a; 2000b).

These three materials demonstrate long time survival in severe elevated temperature, applied stress, and oxidizing environments. Si_3N_4 achieves better strength and fracture toughness than many materials because raising the sintering temperature when fabricating the material changes the grain morphology from granular to needle-like. Increased strength and toughness can also be realized by adding a second phase, such as SiC whiskers. Whiskers are short, discontinuous, rod- or needle-shaped single crystal fibers typically 0.1-3.0 μm in diameter and 5-200 μm in length. Because they are single crystals, they have extremely good strength properties. Whiskers improve material mechanical properties by increasing the flexural strength, fracture energy, and fracture toughness. Si_3N_4 with SiC whisker addition also has one of the lowest brittleness (B) index values. Due to the low brittleness value, Si_3N_4-SiC has excellent erosion resistance as well as excellent corrosion resistance. However, depending on the size of the SiC whisker, this material may be robocast, leaving no need for tooling (Collins and Hirschfeld, 2000a; 2000b).

Silicon carbide, SiC, doped with 10 wt. % (Al_2O_3+Y_2O_3), exhibits desirable properties such as high strength, moderate thermal expansion, a very high degree of erosion resistance due to its high hardness, and excellent corrosion resistance. With the addition of alumina and yttria as liquid-phase sintering additives, a high density SiC material can be made at relatively low temperatures (1850-2000°C). Of the 10 %-additives, a mixture of 25 % yttria with 75 % alumina yields the greatest strength. Silicon carbide is less expensive and more erosion resistant than Si_3N_4, making it somewhat more favorable. Silicon carbide requires diamond tooling for inscription or could be robocast (Collins and Hirschfeld, 2000a; 2000b).

The six ceramic materials described above have properties that make them attractive for use in the large surface markers, small subsurface markers, the information center and the buried storage rooms. Small subsurface markers can be made entirely from one or more of these, and the message panels of the others can be made of ceramic and then embedded in the structural components of these markers. Many combinations and configurations are possible and warrant further testing and evaluation.



4.5 Polymers

Polymers include a large number of materials, but the only one, other than polypropylene, that has been considered for use in the WIPP permanent markers is polyvinyl chloride (PVC). PVC is the most widely used plastic in terms of volume produced. It is used for low-cost piping (flexible and rigid), guards, ducts, tanks, fume hoods, insulative coatings, and corrosion resistant coatings applied to metals. Weak and strong acids and bases, salts, and water do not attack PVC. However, it is less resistant to some solvents and organic chemicals (ketones and chlorinated

hydrocarbons). Its total overall chemical resistance is second only to polytetrafluoroethylene (PFTE), which is more expensive than PVC. PVC is a lightweight material (density 1.5 g/cm^3) and has relatively high thermal expansion (17.0 $K^{-1}*10^6$). It also has low bending (tensile) strength, 96.5 Mpa or about 14000 psi (Collins and Hirschfeld, 2000a; 2000b). However, PVC has low cost and can be readily formed to produce nearly any desired size, shape and inscription, making it attractive for the small subsurface markers.

To improve material properties, composites of PVC and other materials such as fiberglass can be produced. These composites are stronger and lower cost than plain PVC. Fillers can be added to PVC to improve ultraviolet light resistance and increase hardness and impact resistance. Calcined clays and water-ground and precipitated calcium carbonates, with less than 3 μm particle size, are the most commonly used filler materials for PVC. Other fillers include silicas, mica, and talc. Clay has a greater stiffening effect on PVC than calcium carbonate, which results in greater hardness and tensile strength, and reduced elongation (Collins and Hirschfeld, 2000a; 2000b).

PVC itself does not have good ultraviolet radiation resistance. For the purpose of ultraviolet light resistance, the best UV screening pigment is carbon black. Typically, 1-3 % is sufficient for protection. UV stabilizers absorb light in the ranges damaging to plastic materials, thus screening the plastic from the effects of the sun's radiation. Nonetheless, fading and discoloration upon exposure to sunlight is difficult to predict on a long-term basis. The first sign of degradation is discoloration, leading to changes in the physical properties such as material embrittlement and loss of tensile strength (Collins and Hirschfeld, 2000a; 2000b).

4.6 Marker Coatings

Glazes or coatings can be used to encapsulate some markers to prevent absorption of water and/or other chemicals that initiate corrosion. Candidate coatings include vitreous enamel for the metal markers and ceramic glaze for the ceramic markers. All of these coatings have an abrasion resistance better than metals or polymers and can be made with a specific composition resistant to any particular corrosive environment present at the site. Glazes are strong in compression and weak in tension. Therefore, the coating must have a lower thermal expansion than that of the marker material so that the glaze is in compression and the marker surface is in tension. This is easily achieved in the fabrication process by proper material selection and by controlling the cooling rate after the coating has been applied to the substrate (Collins and Hirschfeld, 2000a; 2000b).



5.0 Analysis and Comparison of Materials

Findings and conclusions pertaining to materials selections for the permanent markers are provided in this section. These determinations are drawn from the information presented previously.

5.1 Rock Material

Geologic evidence and engineering experience support the use of rock for permanent markers that require durability and strength. A monument survey and other archeological support have documented the inscribability of some rock types and the durability of those inscriptions over thousands of years. Granite, as the reference design rock material of choice, is sufficiently strong and inscribable, given all the historic uses of granite in monuments and buildings, to support its selection for use in the large surface markers, the buried storage rooms, and the information center. However, there is legitimate concern about the durability of granite with respect to the process of exfoliation. Should exfoliation develop on granite, large surface markers and other applications exposed to the environment, the central purpose of the markers would be lost; i.e. the messages inscribed in the outermost layer of lettering would be lost completely as the exfoliation process progresses over time.

Basalt is also sufficiently durable and strong as well as apparently inscribable, based on archeological evidence as documented in the monument survey (John Hart and Associates, P.A., 2000a), to be considered for use in the large surface markers. However, due to the columnar and other regular jointing patterns common in basalt, it is unlikely that large slabs or monoliths of basalts can be quarried and finished for use in the permanent markers as they are presently designed. If basalt were to be used, the large surface marker design would likely have to be modified to incorporate multiple blocks as opposed to the present two-part reference design configuration. However, the abundance and close proximity of sources of basalt, as well as its very low intrinsic value, make it an attractive option among the rock types.

Well-lithified or indurated sandstone appears in several locations within reasonable hauling distance of the WIPP site. At these locations it occurs generally as caprock on mesas or other resistant topographic features. There are insufficient data on these specific sandstone formations to support more than conjecture about how readily available one or more of these sandstones might be for utilization in the WIPP permanent markers. However, the archeological evidence supports a conclusion that the sandstone is sufficiently durable and inscribable for consideration for use in the large surface markers, the buried storage rooms, the information center, and the small subsurface markers.



Both andesite and rhyolite have sustained petroglyphs in good condition for hundreds to thousands of years in environments comparable to that of the WIPP site (John Hart and Associates, P.A., 2000a). There are several locations within New Mexico from which rhyolitic

welded tuff as well as andesite might be obtained. There are no known test data on the strength and hardness of these rocks, however, and additional testing would be needed. They occur in resistant outcrops with substantial natural fracturing, implying that it would be difficult to quarry and prepare large monoliths or slabs from these rock types.

Other rock types such as limestone, quartzite, and other igneous rocks not described above might be used, but there is no reason to consider them further when the aforementioned rock types appear, on all levels, to be better and more readily available for use at the WIPP site.

5.2 Concrete

The evaluation of concrete performed in this study indicates that HVFA concrete should be further evaluated and tested for use in the large surface markers, small subsurface markers, the information center, and the buried storage rooms, as well as for protection or encapsulation of the radar reflectors. Concrete can be formulated with constituents in concentrations designed specifically for each application, making concrete as a material family much more versatile than rock materials. The record of ancient uses of concrete that remain in good condition at the present, as well as the advances in concrete technology in recent years, gives reason to believe that apparent frailties, i.e. lack of durability apparent in many civil works today, are more a function of the construction expedients used and priorities set for those facilities rather than any deficiency in concrete technology.

From the information available at this time, a high fly ash content concrete can be designed to have the durability, strength, and potentially the inscribability needed for use in the WIPP permanent markers. The relatively long period of time available for testing concretes in the laboratory and in the field prior to final decision and selection of marker materials provides an ideal opportunity to try one or more high fly ash content concrete mixes.

5.3 Local Earth Materials

A variety of earth materials that occur on or close to the WIPP site are available for use in the construction of the berm, including native soils and caliche. Salt, excavated from the WIPP underground works and stockpiled on site, is not a good material for use in the berm. Its solubility and low strength make it an unreliable material to form the core of the berm, and use at shallower locations in the berm, while structurally of less consequence, nevertheless would not be feasible because of the closer proximity to the infiltrating ground water and the resulting greater risk of dissolution.

Although there are no identified sources of durable riprap rock in close proximity to WIPP, there are sources sufficiently close to be considered in later materials testing and evaluation.

The design of the berm should be based on two considerations: (1) the functional requirements of the berm as a permanent marker system component; and (2) the physical properties of the most readily available earth materials. Native soils of any type including sand, silt, clay, and caliche can be used in a variety of combinations to construct the berm in a configuration that will be structurally stable and resistant to erosion over the required performance life of the marker system (10,000 years). Specifically, the side slopes can be adjusted both in gradient and in configuration to accommodate any available materials not including salt. The berm can also be zoned to include materials with specific properties at the core and in the shell of the berm to perform the required structural functions if specific materials are required for these purposes. However, in general it would appear on first examination that any of the site soils should be usable in the construction of the berm.

5.4 Metals and Metallic Alloys

Suitable candidate metals and metallic alloys are available for use in the magnets and the radar reflectors. Both strontium ferrite and barium ferrite are suitable for making magnets, and the precedent for use of these materials is well established. However, the reference design size of the magnets cannot be achieved using any known metals; therefore, the configuration of the magnets will need to be changed in accordance with the sizes and shapes that material technology can support.

Both Inconel and several types of stainless steel appear to be suitable for use in the radar reflectors. Inconel and stainless steel also appear to be suitable for use in the small subsurface markers; however, it is likely that the cost of small subsurface markers with these or other metals would not be competitive compared to the cost of small subsurface markers made with nonmetallic materials. Both the reference design metals and the alternative metals described above have sufficient properties to meet the performance criteria of the magnets and radar reflectors, with the possible exception of longevity of magnetism. If the corrosion-resistant properties of the metal are unlikely to be adequate to protect the markers for the necessary service life, all of the candidate metals can be coated or otherwise protected against corrosion. The report of Collins and Hirschfeld (2000a) indicates that strontium ferrite is the preferred metal for construction of the magnets, and one of the stainless steels, stainless steel 304, is likely to be the material of choice for the radar reflectors because of cost considerations.

5.5 Ceramics

Ceramics technology has developed rapidly in recent years and provides a large variety of ceramic materials from which to choose for construction of one or more of the permanent markers. These materials are durable, readily inscribable in one or more ways, and sufficiently strong for use in the large surface markers, small subsurface markers, the message panels of the information center, and the buried storage room. Robocasting is an especially attractive means for creating the permanent marker messages, because the message can never be chipped, peeled, or otherwise

removed from the surface because the message is cast throughout the entire ceramic structure. The use of ceramics in large structural components of the marker systems will likely be too costly for consideration; therefore, ceramics are most likely to be considered as the media for the inscriptions which would then be encased or included in concrete or other structural materials making up the mass of the marker system.

Based on the evaluations done by Collins and Hirschfeld (2000a), the ceramic materials that look most attractive for further testing and evaluation are alumina, alumina-zirconia, and robocast silicon nitride and silicon carbide. These materials are currently being produced by one or more manufacturers in the United States, and it is likely that as technology expands the manufacturing capacity will also grow and these materials will become more readily available and less costly in the future.

5.6 Polymers

Use of polymers in the WIPP permanent marker system is likely to be limited to those applications in which ultraviolet exposure and abrasion will not be major considerations in durability. Unless protected by coatings or a UV-resistant material such as carbon black, polymers such as polyvinyl chloride (PVC) are not likely to be as durable as ceramics, concrete, and rock materials when exposed to sun and wind. Therefore, if considered for use in the permanent marker system, polymers will probably be limited to the small subsurface markers, coating on magnets or radar reflectors, or perhaps panels in the buried storage rooms.

5.7 Comparison of Materials for Specific Markers

Material comparisons for specific marker systems are provided in the following subsections.



5.7.1 Large Surface Markers

For the large surface markers the material selected must be very durable, with sufficiently high strength to withstand extreme natural loading conditions over long time periods. Inscribability is an important consideration but may be offset by using a combination of inscribable materials imbedded in otherwise very strong materials. Therefore, the large surface marker design might include two or more materials rather than a single material such as rock. The materials that may be considered for the large surface markers include rock (granite, basalt, well-indurated sandstone, andesite, and rhyolite), concrete, and ceramic. Of these materials, several rock types described above are known to be durable enough to last at least 10,000 years, based on geologic and archeological evidence. Durability of high volume fly ash concrete and ceramics must be demonstrated by tests. Strength of all the rock types mentioned, as well as concrete and the ceramics, is more than adequate to satisfy the performance criteria for the large surface markers. All materials are inscribable by one or another method, with ceramics offering the most advanced

and precise techniques for inscription. There is some question about whether the fine detail and small script of the reference design messages can be inscribed equally well in any of these material types.

5.7.2 Small Subsurface Markers

Any of the materials mentioned above for the large surface markers, as well as any of the metals and other ceramics and polymers discussed above, would provide adequate durability, strength, and inscribability for the small subsurface markers. However, due to the number of markers that will be fabricated, it is likely that rock and metal can be eliminated from the candidate list due to cost. Polymers are especially attractive for this application because of the ability to stamp or otherwise rapidly produce the markers at a low unit cost. However, mass production at relatively low cost might also be achieved for some ceramics.

5.7.3 Earth Berm

The berm will be constructed of earth materials. The only question is what specific soil types are present in the locations of the berm. The relative advantage of one soil type over the other is not a major issue, because with modern earthmoving, soil mixing, and compaction techniques, a large variety of soils can be used individually or in combination to create a stable earth berm; these materials should be found in the necessary quantities on or in the vicinity of the WIPP site.

5.7.4 Buried Storage Rooms

There is an obvious advantage for any material that can be prepared and cast in place to construct the base, walls, roof and panels of the buried storage rooms. Concrete is the only material that can fit this description. The difficulty and expense of quarrying, cutting to dimension, inscribing, loading, transporting, and setting in place rock slabs is so great that a variety of other design modifications can be made to allow concrete or other material to be used if it can be prepared and placed on site rather than imported. In this case, as for the large surface markers, it is possible that the ideal combination for the buried storage rooms will be either precast or cast-in-place concrete structural members with inscriptions cast into the concrete panels, or concrete panels in which ceramic message plates are imbedded. In the latter case, the most important consideration will be the chemical and thermodynamic compatibility between adjacent materials.

As the reference design for the buried storage rooms shows, there will be loads on the walls and roof that will include both compression and bending. Rock is not well suited to carrying bending loads. Therefore, if rock is used, the design of the buried storage rooms would have to be changed to include closely spaced vertical supports for the roof panel. On the other hand, concrete can be designed to include reinforcing in the form of synthetic fibers, prestressed, or otherwise formed in such a way that it can more readily accommodate bending stresses and moments.



5.7.5 Information Center

The same considerations discussed above for the buried storage rooms apply to the information center. While the information center will not have the earth loads to support that the buried structures would, there will be wind and possibly earthquake loads applied to the information center that must be resisted by the structural components (walls, roof, and base slab, if any). In addition, the exterior walls and the roof of the information center must withstand environmental stresses such as weathering and erosion; therefore, durability is a more important factor for the constitutive materials of the information center than for those of the buried storage rooms. The exterior walls of the information center would be most resistant to environmental stresses if they were constructed of a material with proven long-term durability such as basalt. Basalt blocks could be quarried and cut to fit into a masonry but mortarless wall in which the individual blocks were notched or otherwise fitted tightly against each other to form a structurally stable configuration. The interior walls could also be basalt blocks, but their dimensions would have to be appropriate for both structural support for the room and space for required inscriptions. The roof of the information center could be cut from long blocks of basalt or other rock but could also be readily fabricated of precast concrete panels formed to fit into the basalt walls.

As an alternative, the information center could be constructed of either precast concrete panels or cast-in-place concrete. In either case, the concrete would be of high volume fly ash content, cast in forms, and allowed to cure over long periods of time to obtain the highest possible strength and durability.

Ceramic materials may also be used for the message panels in the information center, either placed in the concrete panels or placed separately within the rock blocks. The selection of or between these materials should be based on further evaluation of rock sources as well as long-term tests on high volume fly ash concrete.

5.7.6 Magnets

Of the two metals evaluated for use in magnets, strontium ferrite and barium ferrite, strontium ferrite appears to be the better material based on the information provided by Collins and Hirschfeld (2000a). However, the utility of using magnets as a component of the permanent marker system should be reevaluated, because the longevity of magnetism in either of these metals cannot be assured for a sufficient period to be meaningful in the design service life of the entire marker system. Rather than trying to produce an active magnetic field as an anomaly, it may be more reasonable to provide another material in some other configuration that would be a passive magnetic anomaly with one or more other survey methods.



5.7.7 Radar Reflectors

The several types of stainless steel, as well as Inconel, that have been evaluated for this application do not appear to have clear advantages one over the other. Therefore, the selection of the material will probably come down to a matter of cost unless the ability to protect one or another of these materials against subsurface environmental conditions is in serious doubt. However, all of these metals can be coated with one or more materials that would be expected to provide sufficient long-term protection against corrosion. The current apparent choice among these materials is stainless steel 304 for cost reasons.



6.0 Results and Recommendations

This review has involved the collection of existing data from a variety of sources and experts. The results of this work and the recommendations made here are interim only, because no testing or exhaustive technical evaluation has been possible within the scope of this study. The recommendations included here are directed at increasing the level of knowledge for which this study provides a foundation.

6.1 Materials Recommended for Testing

Recommendations or further materials testing are provided below by material type.

6.1.1 Rock

The use of granite as a marker material is problematic for several reasons, including cost, high intrinsic value, quarrying and transportation complexities, and the potential for exfoliation over long periods of time. Accordingly, basalt is recommended as an alternative rock warranting further investigation for use in any one or more of the permanent marker systems. Although the recommendation is to emphasize the testing of the physical properties of basalt, other rock types including well-indurated sandstone, andesite, and rhyolite may be tested subsequently, if the results of the testing on basalt indicate that basalt would not satisfy performance criteria.

The selection of the material or materials to be used in the large surface markers, the small subsurface markers, the buried storage rooms, and the information center will be based on multiple considerations, not just material characteristics. One important factor that has not yet been evaluated is the availability and cost of rock materials other than granite. Because of the concern about the long-term durability of granite with respect to its susceptibility to exfoliation, an evaluation of candidate rock materials should include basalt, at a minimum, and perhaps other rock types if considerations of cost and availability of basalt cannot be satisfactorily addressed. However, given the widespread distribution of basalt in the Southwest in proximity to the WIPP site, it is apparent that some additional data about basalt and its potential sources, as well as other rock, should be collected. These data include the following:

- The locations of basalt, indurated sandstone, andesite and rhyolite sources within a distance of 200-300 miles of the WIPP site
- Physical properties of those specific rocks, including durability, strength, and inscribability



- Ownership and accessibility of the rock sources
- Probable cost to acquire and process the rock

6.1.2 Concrete

Although significant data are available on concretes in general and also on high volume fly ash concrete in particular, additional data are needed on the chemical and thermodynamic properties of specific mixes that could be considered for use in each possible marker application. Because a large number of possible concrete mixes for the various applications could be considered, an initial screening of candidate mixes should be made to minimize the number of mixes actually tested. Nevertheless, concrete testing should be exhaustive enough to evaluate all the variables important to concrete durability including fly ash and other pozzolanic material types and concentrations, aggregate types and concentrations, as well as mixing and curing protocols.

6.1.3 Local Earth Materials

Some data are available on soils in the immediate vicinity of the WIPP site, but additional data may be needed about the soils that exist in the proposed location of the berm. Data may be needed to characterize the soil from ground surface down through the caliche layer to document the soil types, thicknesses and lateral extent to evaluate the physical properties and the volumes of the soil that would be available for berm construction.

6.1.4 Metals and Metallic Alloys

For the magnets, strontium ferrite is the preferred metal and should be further evaluated through the tests necessary to determine its durability under anticipated conditions at the WIPP site over the long term. Tests on barium ferrite should be deferred until or unless strontium ferrite proves inadequate or too costly for use in the magnets.

The metals for the radar reflectors are adequately characterized to allow selection of a preferred material, which at this time is stainless steel 304. This material should be tested first for suitability, and then tests should be performed on Inconel 625 and Monel K-500, specifically to compare the durability of these three metals under conditions that simulate the most severe environmental stresses to which they may be subjected in the permanent markers applications. Other stainless steels should not be tested unless the results for these metals show that they are not acceptable.



6.1.5 Ceramics

Selection of ceramic materials is not as apparent at this stage as it is for some of the other material classifications. The primary candidate materials are aluminum oxide (alumina), aluminum zirconia, silicon nitride, and silicon carbide. All four of these materials should be tested through the range of tests needed to determine their inscribability and durability in the potential applications in the large surface markers, small subsurface markers, and the message panels of the buried storage rooms and the information center.

As with metals, considerable data exists on ceramics, and more is being generated at a very rapid pace as the technology expands. However, the application of one or more ceramic materials to the WIPP permanent markers depends on satisfying performance criteria that are in many ways different from performance criteria for other applications of ceramics. Therefore, some additional data are needed that would be specific to applications at WIPP. In particular, additional data are needed on the long-term performance characteristics of ceramics in an open environment that could include both environmental and man-made stresses. These additional data relate to weathering effects on:

- Absorption
- Hardness
- Fracture toughness
- Strength (tensile, flexural, and compression)

Weathering should be simulated by tests that measure:

- Erosion resistance
- Corrosion resistance
- Freeze-thaw response
- Thermal expansion and contraction characteristics
- UV resistance
- Effects of moisture



6.1.6 Polymers

Polymers are also, like ceramics, undergoing a rapid expansion in technology, and considerable data are available on their routine applications; therefore, no additional testing would be needed for such properties. However, in the applications anticipated at WIPP, some additional data needs would develop as a result of the need for the polymers to perform over a service life far beyond that anticipated in most polymer applications. Therefore, the same set of data needs described above for ceramics would apply to whatever polymers might be considered for use in the WIPP permanent markers.

6.2 Materials Testing Recommendations

Recommendations for materials testing are consistent with and expand upon the recommendations made previously in the testing program plan (John Hart and Associates, P.A., 1999).

6.2.1 Rock

Basalt and, if needed, other candidate rock types should be tested to determine mineralogical composition, specific gravity, absorption, sodium sulfate soundness, Schmidt hammer hardness, and Los Angeles abrasion. Standard ASTM procedures should be used. For any potential source of basalt or other rock, the source should be first delineated by a ground survey by qualified geologists and samples obtained to show a representative distribution of the rock from the source including different positions within the basalt flow or rock bed, depth within the source, and variation in visible features such as rock texture. The initial set of tests should be performed on at least 10 samples not less than 20 pounds each. These samples may be grab samples, that is, taken from surface outcrops and other exposures without the need for drilling and coring. However, if this rock is considered qualified after the first round of tests for further consideration, then drilling and coring to obtain additional rock samples and to characterize the rock source in three dimensions should be made, and the core samples should be subjected to an identical set of tests subsequently.

6.2.2 Concrete

The several high-volume fly ash concrete mixes prepared for testing should be tested for compressive strength at the end of three days, three weeks, and three months; and then, if satisfactory at three months, the samples of the mixes should be tested again at one year and three years. At the end of one year and three years, samples should be tested for compressive strength, specific gravity and absorption, sodium sulfate soundness, Schmidt hammer hardness, and Los Angeles abrasion. At the end of three years, samples successful thus far should be tested for all the properties tested at one year and for abrasion resistance by sand blasting and liquid impingement erosion. All mixes, regardless of their test success at 90 days, should be examined petrographically for texture and mineral composition, pore space, and other microscopic characteristics or impurities.

6.2.3 Local Earth Materials



Local earth materials should be tested for grain size distribution, Atterberg limits (plasticity indices), alkali and carbonate content by wet chemistry methods, Standard Proctor Density, and unconfined compressive strength. Materials that are considered for riprap use should be subject to all the same tests as described above for basalt.

6.2.4 Metals and Metal Alloys

If any metals are considered for use in exposed locations, they should be tested for absorption (ASTM 20) and hardness (ASTM E 3 and ASTM E 18, and ASTM E 140). Also, potential environmental and human damages should be evaluated using erosion simulation testing to evaluate solid particle or sandblasting effects (ASTM G 76), and liquid erosion (ASTM G 73). Impacts, or vandalism, should be tested by the Charpy impact test (ASTM E 23). Corrosion tests should be performed using ASTM G 50. The metals should also be tested for tensile strength (ASTM E 8) if they are considered for any use where the marker may be subjected to bending.

6.2.5 Ceramics

For ceramics, porosity, water absorption, specific gravity, and bulk density should be determined using ASTM 20. Hardness should be tested using ASTM E 92. Fracture toughness can be tested by method ASTM E 23. For strengths, a 4-point bend test should be used in accordance with ASTM C 1161. Impact susceptibility from vandalism can be evaluated through the Charpy test, which may also be used to determine fracture toughness in accordance with ASTM E 23. Erosion susceptibility should be tested using procedures ASTM G 76 and G 73. Corrosion susceptibility should be tested by ASTM G 50. ASTM C 1026 is the method to be used for measuring resistance to freeze-thaw cycling. Ceramic materials should also be tested for their resistance to extreme thermal cycling that may be associated with extreme weather conditions or brush fires followed suddenly by hailstorms and torrential rain. There is no established test procedure for this, and one will need to be developed. Resistance to natural weathering, including UV radiation, can be tested with several procedures including ASTM G 90 and G 7.

6.2.6 Polymers

PVC, HDPE and other potential candidate polymer materials, if any, should be tested for all of the environmental exposures that could occur, regardless of whether the materials will be intentionally exposed at ground surface. This is justified by the possibility that through erosion or casual excavation, buried markers may be exposed over a long period of time. Apparent porosity, water absorption, specific gravity and bulk density can be determined using ASTM 20. Indentation hardness should be determined using ASTM D 2583. Fracture toughness may be tested using ASTM E 23. Erosion susceptibility should be tested using ASTM G 76 and G73. UV radiation is a special concern for polymer materials and should be evaluated using ASTM G 90. General weathering susceptibility should be evaluated using ASTM G 7, as well as ASTM D 4364. Accelerated outdoor tests may also be performed where sunlight is amplified in conjunction with cooling devices to prevent overheating. Nonetheless, aging studies should be performed on all the proposed polymeric materials.

6.3 Implications for Marker Configurations and Locations

The reference design describes the materials, configurations and locations for the permanent marker system. All of these are subject to change or refinement. It is apparent as a result of this study that some modifications will be needed in the configurations and possibly the locations of markers.

The reference design configuration for the large surface markers is a two-part stone obelisk that would weigh a total of approximately 125 tons and would be made of granite. Granite and most other rocks are highly brittle materials and will not sustain high tensile stresses or bending moments; consequently, the quarrying, shaping, handling and transportation of very large rock shapes, including prisms and slabs, will be difficult. These rock shapes run a high risk of cracking during the process of removing them from the ground in the quarry and placing them in their locations as markers at the WIPP site. The likelihood of these large pieces surviving this process intact is very questionable and makes the selection of any rock material for these configurations problematic. If rock material is to be used, other configurations should be considered; specifically, multi-component configurations that can be made by assembling regularly-shaped blocks that weigh less than the safe lifting capacity of cranes that might reasonably be available to do the work on an undeveloped site with soft soil conditions. This problem is equally applicable to the slabs of rock called for in the reference design for the buried storage rooms and the information center. The alternative is either to change configurations, as stated above, or to change materials. Materials that can be either cast in place or pre-cast in convenient sizes and shapes are preferable, provided that the physical properties of these materials can satisfy performance criteria. The attractiveness of high-volume fly ash concrete is apparent as a likely solution to this problem.

There is a significant problem using salt as a component of the berm. Salt is not directly related to a problem of configuration or location, because salt itself is incompatible with any configuration of the berm. To use salt in this application, very flat side slopes of the berm would be required; and even with such flat slopes, the longevity of the berm would be in question because of the solubility of salt.



The magnet dimensions described in the reference design (3ft.x 1.5ft.x 1.5ft.) are too large; it is not possible currently or with foreseeable technology enhancements to make magnets of this size (Collins and Hirschfeld, 2000a). Therefore, either the concept of magnets per se or the dimensions of magnets must be revised to match the available technology. An additional problem is the longevity of the magnets; specifically, the decay of magnetism in a relatively short period of time, 100-to-200 years. Because of these factors, the usefulness of magnets comes into question. One alternative could be a marker capable of responding as a passive electromagnetic anomaly, using a mafic rock material such as basalt placed as backfill in a distinctively detectable pattern of trenches with a higher induced electromagnetic signature than the surrounding ground. This design involves materials that are readily available and relatively inexpensive, compared to many

individual magnets, and whose function will be indefinite rather than limited to a one-to-two hundred years.

If concrete or other manufactured material is used in place of rock for the construction of the buried storage rooms and the information center, the configuration of these structures may be changed to improve their constructability and structural stability. Specifically, a cylindrical shape may be more stable and less costly to construct than the rectangular prism configuration in the reference design. Because it is not likely that steel reinforcing bar will be used in the concrete design, it will be necessary to either add synthetic reinforcing fibers in the concrete or to design a configuration in which tensile stresses and bending moments will be minimized. A cylindrical configuration can accomplish this while maintaining all of the performance functions and satisfying the performance criteria of these two marker components.



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Contractor Report

Permanent Markers Monument Survey

Waste Isolation Pilot Plant
Carlsbad, New Mexico



August 31, 2000

Contractor Report

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1.0 Introduction

The Waste Isolation Pilot Plant (WIPP) has been constructed by the U.S. Department of Energy (DOE) in southeastern New Mexico as a disposal facility for transuranic (TRU) wastes. The WIPP is subject to the provisions of U.S. Environmental Protection Agency (EPA) environmental protection standards defined in 40 CFR Part 191 (EPA, 1993) and compliance certification criteria set forth in 40 CFR Part 194 (EPA, 1998).

These standards and compliance criteria include requirements pertaining to the implementation of a system of passive institutional controls (PICs) for the WIPP. PICs are required by 40 CFR 191.14(c) and 40 CFR 194.43. The primary purpose of the PICs program is to provide a permanent record that identifies 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 and long-term records.

The DOE Carlsbad Area Office (CAO) is currently implementing programs to ensure full compliance with the provisions of these standards and compliance criteria. As part of this implementation activity, alternative materials for the construction of permanent markers are being investigated. One of the considerations important to the selection of markers materials is the ability of the marker material to be inscribed with warning messages and the durability of these messages over very long time frames.

In its Compliance Certification Application (CCA) for the WIPP (DOE, 1996), the DOE provides details regarding the implementation of the permanent markers program. An important objective of the program is to develop information useful in optimizing the design of the marker systems by evaluating alternative configurations, alternative materials and aid in the development of final designs. One related activity identified in the CCA is the survey of monuments within 150 miles of the WIPP site, to obtain any information useful in the selection of markers materials and the development of markers designs.[1]

This report documents the results of a survey performed by John Hart and Associates, P.A. of Albuquerque, New Mexico, working under contract to the Westinghouse Government Environmental Services Company, LLC in the summer of 2000. The objective of this survey was to collect and compile information relevant to the assessment of the durability of ancient inscriptions made on various rock types.



[1]Several of the sites surveyed for this report are outside the 150-mile zone surrounding the WIPP. These sites were included in the survey as the number of available sites within the 150-mile zone is limited. These sites provide relevant information within similar climatological zones.

1.1 Related DOE Commitments

The WIPP Compliance Certification Application (CCA) includes a DOE commitment to perform a survey of monuments within a given area surrounding the WIPP site. The DOE commitment is in regard to testing to take place during the disposal phase; it is quoted below.

> *The major subjects which may be evaluated during this testing program are:*
>
> - *Survey representative monuments within a 150 mile radius of the WIPP to more extensively evaluate the climatic environmental affects on granite.*

In regard to the timing of this activity, the DOE states:

> *The following activities described in Appendix PIC will be addressed in the first five years of WIPP operation:*
>
> > *Survey stone monuments within a 150 mile radius of WIPP to evaluate the environmental affects on various types of granite (blue, gray, black etc.).*

1.2 Study Objectives

The objective of the survey was to determine how well various rock types, within similar climatological zones, have performed as media for inscriptions in terms of both legibility and durability. The assumption inherent in this objective is that old inscriptions in rock are analogs for the WIPP permanent markers; therefore, the older the inscription, the greater the relevance. The study objective includes increasing the understanding of the effects of several independent factors that affect rock inscriptions – rock texture and hardness, intrinsic rock durability, location and orientation (aspect) of inscriptions, and climate and weathering processes. Specific objectives that derive from these general objectives include documenting:

- rock properties
- inscription characteristics
- apparent age of inscriptions
- exposures to and processes of weathering and erosion



2.0 Survey Rationale and Methods

The rationale for the performance of the survey and the methods employed are described in this section. The rationale discussion addresses the selection of monument types, site selection criteria, and background studies. The methods discussion addresses site access factors and a description of measurements taken and observations made in the field.

2.1 Selection of Monument Types

The CCA commitment, discussed in Section 1.1 above, to perform a monument survey contains little guidance regarding the definition of "monument" and what types of monument should be surveyed. The term "monument" is commonly used to mean a grave marker or historical marker. Restricting the term to those meanings would limit the types of monuments to those erected during the historic period, say the last four hundred years. To determine whether any inscriptions are analogous in durability to that sought for the WIPP permanent markers, the definition of "monument" for this study was interpreted to include any material bearing an inscription, regardless of message or intent, that has remained in place and exposed to the elements for longer than the historic period. Using this definition, the monuments that were left were those most analogous to the WIPP permanent markers – petroglyphs of prehistoric age and fully exposed to environmental stresses.

2.2 Survey Site Selection Criteria

Sites included in the survey were selected on the basis of their individual relevance to the WIPP permanent marker performance requirements (set forth in the Draft *Permanent Markers Implementation Plan* (DOE, 1999)), similarities in material types to rock materials considered for use at the WIPP site, similar climatological setting, maximum age, and the least amount of preservation or restoration. Specifically:

1. Sites were limited to those that contain rock types that might be used in the permanent markers. Included were sites with durable sandstone, fine-grain igneous rocks (basalt, rhyolite, andesite) and coarse-grain igneous rock (e.g.; granite, diorite).

2. Sites were limited to those that are located in arid to semi-arid climates at elevations up to those that sustain pinon-juniper woodlands, but not higher elevations that receive more rainfall and support larger trees.

3. Sites were selected from those known or suspected to contain inscriptions that are at least 600 years old, with preference given to the oldest sites.

4. Sites were eliminated from consideration if they had received major restoration or artificial preservation (measures other than protection from vandalism or collection).

5. Sites were limited to those that contain rock inscriptions (petroglyphs); rock paintings (pictographs) were considered to be irrelevant to the WIPP permanent marker design because all messages on WIPP markers are planned to be inscribed.

2.3 Background Studies

Given the survey site selection criteria, background studies were focused on publicly available information sources, principally archeological reports and publications that deal with pre-Columbian cultures and rock art. Contacts were made with state and federal parks, the U.S. Bureau of Land Management, the U.S. Forest Service, the Western Archeological and Conservation Center in Tucson, Arizona, and the Rock Art Museum in Tempe, Arizona. The Museum of New Mexico Laboratory of Anthropology provided the majority of background information used in this survey; direct personal assistance was received from Curtis Schaafsma, Curator of Anthropology, and Polly Schaafsma, both of whom shared their own extensive experience with southwest rock art as well as the Laboratory's field records of their own surveys of many of these sites.

2.4 Site Access

The initial list of sites that met the selection criteria included 17 sites (including two sites at Rowe Mesa) in New Mexico and two in Texas (Figure 1). Of the 16 sites surveyed, five are on private or leased land, five are on public land, and six are on state or federal parks or monuments. Owners or lessees of lands with petroglyphs were contacted for permission to enter and conduct survey activities. Public agencies including the New Mexico State Land Office, the U.S. Bureau of Land Management, and the U.S. Forest Service were contacted for public land access and required fees were paid. Entry fees were paid where required for entry to parks and monuments.

Three sites were eliminated from the survey. One of these (Diablo Canyon) is on public land in Texas but could not be accessed because all roads to the site cross private land and all had gates that were locked due to recent vandalism. One New Mexico private landowner refused permission to the Olive Buttes site for access for reasons not given. The third site, Luna #5, could not be found in the field.



2.5 Measurements and Documentation

Measurements and observations were made at each site to satisfy the specific objectives of the study as outlined above. A more detailed description of those objectives is provided below:

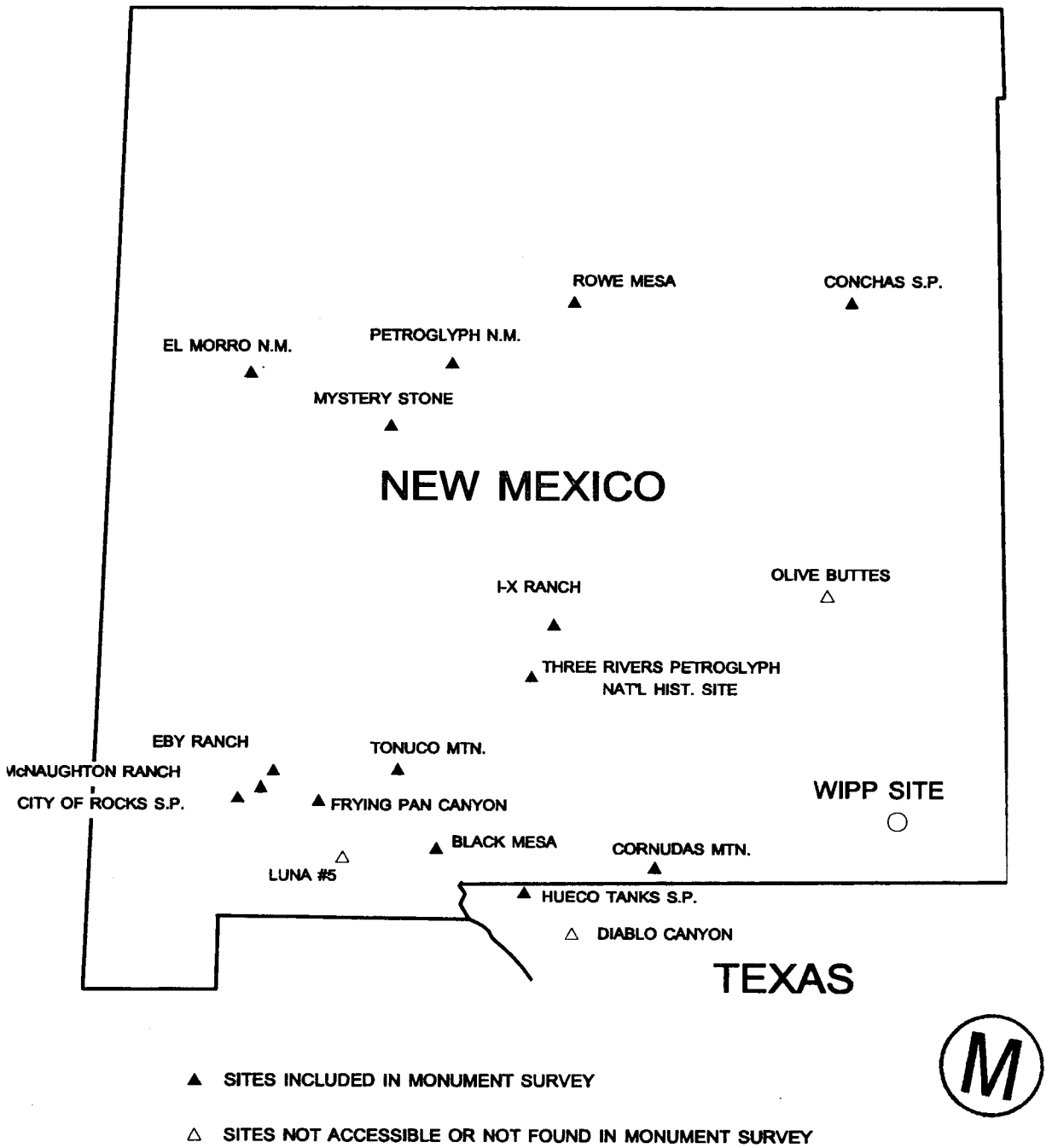

Figure 1. Monument survey sites

Rock properties important to the durability and inscribability of the rock included petrologic classification, texture, surface form and roughness, type and extent of weathering, and overall extent of patination (see Section 3.5 for a discussion of patination).

Inscription characteristics included apparent inscription type (i.e.; chiseled, scraped, pecked), form, range of widths and depths, and aspect (direction and inclination of inscribed surface).

Apparent ages of inscriptions were estimated based on the types of images, relative position of multiple layers of images, evidence of weathering within the inscription, amount of repatination and lichen growth on the inscriptions.

Exposures to and processes of weathering and erosion were evaluated from the position of the petroglyphs with respect to slopes, watercourses, surrounding terrain features and the climatic zone.

Observations and measurements were recorded on site data worksheets. Digital photographs were made to illustrate representative characteristics of rocks and their petroglyphs.



3.0 Survey Findings

Data collected during the survey are described in this section. The descriptions include rock types encountered, types of inscriptions, exposure of inscriptions, inscription condition, and inscription ages. Photographs of inscriptions (petroglyphs) referred to throughout this report are included as Attachment 1.

3.1 Site Reports

Site reports were prepared for each site visited during the survey and are included as Attachment 2 of this report. Some salient features of the sites are summarized in Table 1.

3.2 Rock Types

Petroglyphs surveyed in this study were inscribed into sandstones (six sites), fine-grained igneous and pyroclastic rocks (eight sites), and coarse-grained igneous rocks (two sites). The sandstones were all well indurated and resistant to erosion as evidenced by their positions as cliff formers or caprock on mountains. Petroglyphs were inscribed more deeply in sandstone than in the other rock types, but all rock types found in the survey preserved the inscriptions well. The only difference in durability was related to exfoliation, as discussed below.

3.3 Methods and Forms of Inscription

At all surveyed sites, pre-Columbian inscriptions had been made by pecking or scraping. Although both forms of inscription have survived for hundreds to thousands of years, the pecked images are deeper and, therefore, appear to be more durable.

Pecked inscriptions are characterized by contiguous crater-shaped pits in the rock surface, each about 1-3mm wide and deep, apparently made by a pointed stone or antler struck by another stone to break out small pieces from the rock surface (Photo #1). Pecked images usually have sharply defined lateral boundaries and are 2mm or more in depth.

Scraped inscriptions were apparently made by simply scratching the rock surface with a stone (Photo #2). Lateral boundaries of the scraped images were less well defined, especially on rough coarse-grained surfaces. Scraped inscriptions were less than 2mm deep, often too shallow to measure.

Widths of both pecked and scraped inscriptions vary widely, depending on the image. However, none of the surveyed images were less than 3mm wide, and most were at least 5mm wide.

Table 1. Features of Petroglyphs at Surveyed Sites

Site Name And Location	Rock Type	Inscription Age(s)	Method of Inscription	Level of Exposure	Condition of Inscription
Mystery Stone Valencia Co., NM	Andesite	Anasazi to recent	Pecked, Chiseled	High	Fair
I-X Ranch Lincoln Co., NM	Andesite Porphyritic	Archaic, Mogollon	Pecked, Scraped	High to Extreme	Fair to Good
Three Rivers National Rec. Site	Andesite Porphyritic	Mogollon	Pecked, Scraped	Extreme	Fair to Good
Black Mesa, Doña Ana Co., NM	Basalt	Archaic, Mogollon	Scraped, Pecked	Moderate	Fair
Petroglyph N.M., Albuquerque, NM	Basalt	Archaic, Anasazi	Scraped, Pecked	Moderate	Fair
Hueco Tanks S.P. Hudspeth Co., TX	Diorite	Mogollon	Pecked	Sheltered to Slight	Fair to Good
Cornudas Mtn., Otero Co., NM	Diorite Porphyritic	Archaic, Mogollon	Scraped	Moderate	Good
Eby Ranch, Faywood, NM	Rhyolitic Welded Tuff	Archaic, Mogollon, Apache, recent	Pecked	High	Good to Poor
McNaughton Ranch, Luna Co., NM	Rhyolitic Welded Tuff	Archaic, Mogollon	Scraped	High	Good to Poor
City of Rocks S.P. Faywood, NM	Rhyolitic Welded Tuff	Mogollon (Mimbres)	Scraped	Sheltered	Good
Frying Pan Canyon Luna Co., NM	Sandstone	Archaic, Mogollon	Pecked, some Scraped	High to Extreme	Good
Tonuco Mtn., Doña Ana Co., NM	Sandstone	Archaic, Mogollon	Pecked	Moderate to High	Fair to Good
El Morro N.M. Cibola Co., NM	Sandstone	Anasazi to recent	Pecked, Chiseled	Moderate	Fair to Poor
Conchas Lake S.P., San Miguel Co., NM	Sandstone	Archaic, Anasazi	Pecked	Moderate	Good
Rowe Mesa Site #1, San Miguel Co.,NM	Sandstone	Archaic	Pecked	Extreme	Fair
Rowe Mesa Site #2, San Miguel Co., NM	Sandstone	Archaic	Pecked	Extreme	Fair

At one site, the "Mystery Stone" in Valencia County, New Mexico, the rock is inscribed with V-shaped grooves about 2mm deep and 3-5 mm wide (Photo #3). The grooves are very uniform, straight, and consistent throughout the very large inscription. Fresh rock powder is still stuck to the bottoms of some of the grooves. It is evident that this inscription was made with a hard metallic tool.

3.4 Aspect and Level of Exposure

As used in this survey, aspect means the direction and inclination of the petroglyph surface. Directions and inclinations were measured by field compass and recorded according to approximate direction (e.g.; NE, W, SW) and to the nearest 10 degrees inclination from horizontal. Petroglyph aspects covered the whole range of possible direction as well as inclinations from horizontal to 20 degrees past vertical. No discernible difference in petroglyph condition was observed, based on aspect.

Level of exposure is a qualitative description of the location of the petroglyphs with respect to sun, rain, wind and runoff. Extreme exposure is a condition without shelter, totally exposed to sun during all seasons and daylight hours, to wind and rain from all directions, and to local runoff. High exposure indicates shelter from wind and runoff from one half of the compass rose, but otherwise fully exposed. Moderate exposure means exposure to half the compass rose and some shelter from adjacent terrain. Slight exposures have limited direct sun and protection from all but one quadrant of wind and rain. Sheltered locations are surrounded by obstacles to wind and sun or located on the underside of inclined rocks. The differences in exposure of petroglyphs at any site did not result in measurable differences in the condition of those petroglyphs, nor were discernible differences observed between sites based on exposure.

3.5 Inscription Condition and Visibility

Several factors that affect inscription condition and visibility were observed and evaluated: inscription size, contrasts in texture and color, boundary sharpness, and mechanical weathering.

The importance of *inscription size* is obvious; larger petroglyphs were easier to see. Inscription depths and widths affect visibility and, as stated above, were measured. Deeper inscriptions were more visible than shallow inscriptions on repatinated surfaces at close range, but wider inscriptions, regardless of depth or repatination, were more visible at a distance.

Visibility of petroglyphs was strongly affected by *contrasts in texture and color* between the host rock and the inscription grooves, and this contrast was more important than size, width, or depth in being able to locate petroglyphs. The color and texture of rock surfaces in the Southwest that have been exposed for long periods of time are commonly darkened and muted by a patina that results from a combination of chemical and microbial processes not yet well understood. In nearly all the sites surveyed, the petroglyphs were created by breaking the patinated layer, usually the outermost 1-2 mm of darkest color, leaving a groove that is a lighter color or different texture than the undisturbed surface (Photos #4 and 5). Over time, from several hundreds to thousands of years, the inscription is repatinated; i.e., the patina reforms on the disturbed rock surface. Even if a petroglyph is relatively large, it might be easily missed if it is totally repatinated, while a very small petroglyph with sharply contrasting color or texture (no repatination) would be very visible (Photo # 6).

Boundary sharpness is the visible distinction between the inscription groove and the adjacent rock surface. Observations of the oldest petroglyphs, those of Archaic age, reveal that boundary sharpness deteriorates over time. Edges of grooves gradually round to a flattening transition to the uninscribed rock; in effect, the inscription broadens and its slopes flatten (Photo #7). If this loss of groove boundary sharpness is accompanied by repatination, the visibility of the inscription is greatly reduced (Photo #8).

Mechanical weathering contributes gradually and on a small scale to loss of boundary sharpness, but it also acts on a larger scale in the form of scaling or exfoliation. The exfoliation process was most obvious in the intrusive igneous rocks of the Cornudas Mountain site (porphyritic diorite) and Hueco Tanks site (diorite), as shown in photos #9, 10, and 11. In exfoliation, the rock surface gradually peels away like an onionskin in thin (5-20mm) layers. Similar scaling of rock surface, although less regular, was observed in sandstone (Photo #12) and andesite (Photo #13).

Inscription condition was assessed primarily on the basis of visibility but also included consideration of the groove depth and boundary sharpness. Excellent condition was reserved for petroglyphs that looked fresh and sharp, a description applicable only to historic inscriptions at El Morro, that are discounted for this study. Good condition indicates clear visibility, measurable depth, and no apparent erosion of the inscribed surface (Photo #14). Fair condition means some degradation in visibility or depth, in some cases with erosion (exfoliation or spalling) in some locations (Photo # 15, 16). Poor condition describes inscriptions that are difficult to see due to erosion, weathering, or perhaps less than typical original craftsmanship. Two sites with exposed petroglyphs on rhyolitic welded tuff had a number that were in poor condition (Photos # 17 and 18). At all other sites, petroglyphs were mostly in fair to good condition.

3.6 Petroglyph Ages



In general, absolute ages of petroglyphs are impossible to determine directly. For this survey, previous studies by Polly Schaafsma and others were used to identify the cultural periods and approximate ages of petroglyphs in the area of interest and to select the sites with the oldest (Archaic) petroglyphs (Schaafsma, 1972; Schaafsma, 1979). Curtis Schaafsma and Polly Schaafsma indicated that petroglyph ages are estimated based on correlation of images depicted in petroglyphs with identical or similar images in pottery and other artifacts on which dating techniques, such as carbon-14 isotope concentrations, have produced absolute ages (personal communication, May 18, 2000).

The age of petroglyphs examined in this survey range from less than 100 years to as much as 6000 years. Emphasis was placed on Archaic age petroglyphs, ranging in age from about 1800 years to 6000 years, which were examined at 10 of the 16 sites surveyed. Petroglyphs of Mogollon and Anasazi age, about 600 to 1800 years old, were examined at 13 sites, including seven that also contain Archaic petroglyphs. The Archaic petroglyphs are called Desert Abstractions and are characterized by geometric patterns that do not represent any life form or cultural object

(Schaffsma, 1979). These patterns include parallel straight or wavy lines, circles in concentric or chain patterns, cross-hatched or intersecting diagonal lines, circles with radial lines, and irregular lines (Photos #19 and 20). Mogollon and Anasazi petroglyphs also include circles but are more representational, depicting human forms (anthropomorphs), animals, spirits, and weapons (Photos #21 and 22). Apache and other more recent cultures have left inscriptions at some of the sites, but they can usually be distinguished by the absence of repatination or lichens. At several sites, a type of lichen with bright chartreuse color has formed in the inscription grooves (Photos #23, 24, and 25), fixing the minimum age of the petroglyph at about 600 years, the time this lichen takes to get established on a rock surface (C. Schaafsma, personal communication, May 18, 2000).

The actual ages of petroglyphs at two sites, Rowe Mesa Site #1 and #2, have been established by two independent scientific methods, carbon-14 dating and soil morphology. At these sites, the petroglyphs are on a flat sandstone surface. Over at least part of those surfaces a soil profile was developed, then partially eroded. A charcoal layer at the rock-soil contact and the soil profile morphology have independently provided ages for the underlying petroglyphs of about 5900 years (Brent Abel, USFS, personal communication, June 16, 2000)(Photos # 26 and 27).



4.0 Conclusions

Reasonable conclusions based on the results of the monument survey are identified in this section. Issues such as the durability of various rock types, the effects of aspect, the rates of erosion of inscriptions, the effects of inscription form, and the importance of contrast in color and texture are addressed.

4.1 Durability of Rock Types

The petroglyphs examined in this survey involved the most common types of hard rock occurring in the Southwest with the exception of granite, on which no petroglyphs of prehistoric age have been identified within a few hundred miles of the WIPP site. All the petroglyph rocks are very durable and resistant to erosion, but not all are apparently capable of preserving inscriptions for thousands of years. The intrusive igneous rocks most like granite, the porphyritic diorite of Cornudas Mountain and the diorite of Hueco Tanks, exhibited exfoliation that caused gradual loss of petroglyph inscriptions. Because exfoliation is a common weathering mechanism of intrusive igneous rocks, this class of rocks would probably not be able to keep an inscribed surface intact for more than a few thousand years. If not jointed or otherwise fractured, the other rock types (sandstone, basalt, andesite, and rhyolite/welded rhyolitic tuff) appears to weather more evenly and to be able to retain inscriptions for thousands of years. Chemical weathering rates are relatively slow in the arid Southwest climate, so all of these rock types should be able to remain chemically intact for at least 10,000 years and possibly much longer. Therefore, any of these rocks could be considered for use in the WIPP permanent markers.



4.2 Effects of Aspect

The direction and inclination of the petroglyph surface has no observed effect on the longevity of the petroglyph. This conclusion seems to be contrary to logic; surfaces exposed to the prevailing wind direction should show more erosion. Nevertheless, survey observations revealed no aspect that was better for petroglyph survival than any other.

4.3 Rates of Erosion of Inscriptions

None of the survey observations were able to support a determination, or even a reasonable estimation, of erosion rates of inscriptions. Although measurements of inscription depth might have revealed differences in erosion rates according to aspect or rock type, in fact differences in inscription depth could not be attributed directly to erosion because 1) the inscription depths at each site do not vary measurably from one petroglyph to the other, and 2) the original depths of inscriptions cannot be ascertained. It is worth noting, however, that where the soil covered only

about half of a petroglyph at the Rowe Mesa #1 site, the inscription depths of the covered side are not measurably different from the uncovered side.

Lacking any data to indicate to the contrary, it is reasonable to conclude that petroglyphs will erode at the same rate as the rest of the rock surface. Considering the fact that the petroglyph rock surfaces are generally patinated and the older petroglyph grooves are repatinated, it is apparent that the rate of inscription erosion must be less than the rate of patination, which takes hundreds to thousands of years to develop to a depth of 1-2mm. This conclusion is consistent with the fact that even scraped Archaic inscriptions less than 1mm deep have survived at least 1800 years.

The apparent substantial durability of the several rock types bearing petroglyphs indicates that erosion rates of rock surfaces are slow enough to lend confidence that rock inscriptions can last at least 10,000 years. It also supports the conclusion that chemical weathering and mechanical weathering rates are very slow in the Southwest.

4.4 Effects of Inscription Form

The form of the inscriptions (shape, depth, and width) is remarkably consistent between generations of petroglyphs at each site and between sites for each archeological period. Petroglyphs that have familiar shapes, like circles and human bodies, are more readily recognized than irregular shapes, regardless of age. Circles exist at all the petroglyph sites, and during the field surveys a circle was frequently the first image noticed and the visual trigger to look more closely for other petroglyphs. Shapes that are similar to natural rock contours, like curves and wavy lines, are more difficult to see, especially in mid-day light.

Depth of inscription, while possibly having an impact on inscription durability, has little effect on image visibility, but groove width is very important, especially on rock surfaces with more coarse textures due to either mineral particle size or surface roughness. On coarse-texture surfaces, grooves narrower than the amplitude of roughness or the largest mineral size are difficult to see, especially under low sun angles.

4.5 Importance of Contrast in Color and Texture

The contrast between color and texture of the inscription groove and the color and texture of the host rock surface is the most important factor in the visibility and legibility of petroglyphs that are inscribed into patinated rock surfaces. As important as this color contrast is in recognizing petroglyphs, its importance will be much less for any WIPP permanent marker inscriptions, which would be placed on fresh, unpatinated rock surfaces. Patination of the marker surfaces would probably develop as the same rate across the whole marker surface, including the inscription grooves, so it is unlikely that color contrast would ever contribute to the visibility of the WIPP

inscriptions.

The primitive tools of the Archaic and Mogollon/Anasazi people were not capable of producing smooth grooves. The grooves of the recent "Mystery Stone" inscriptions are not deeper or wider than the older petroglyphs, but both the Mystery Stone grooves and historic age grooves of El Morro's Inscription Rock are more visible because the metal tools used to create them were capable of making sharp boundaries and smooth surfaces in the grooves. The sharp edges and smooth surfaces of the grooves provide a distinct textural contrast that makes the inscription stand out visually.

5.0 Recommendations

Recommendations based on the monument survey are provided in this section. Recommendations are provided on rock type, form of inscriptions, and additional studies.

5.1 Rock Type

Rocks of hardness and durability suitable for use as WIPP permanent markers are available within a few hundred miles of the WIPP site. Basalt and sandstone are the most abundant, so one or both of these should be selected for further evaluation, including durability and inscribability testing. Granite and other intrusive igneous rocks that are susceptible to exfoliation should not be used.

5.2 Form of Inscriptions

To the extent consistent with the necessary written and symbolic warnings and messages, inscriptions should be as large as possible, with groove widths several times the largest mineral particle size. Unless the rock is very fine grained like basalt, it probably will not be practical to inscribe letters smaller than about 25mm minimum plan dimension or less than 5mm deep.

5.3 Additional Studies

Given the consistent findings over the 16 sites included in this survey, it is anticipated that additional monument (petroglyph) surveys would not be useful. However, studies on material properties of rock and man-made materials would be useful, with emphasis on surface hardness, methods to create and preserve color contrast, and the effects of rock texture on inscribability and inscription durability.



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U.S. Environmental Protection Agency (EPA),1998, *40 CFR Part 194 Criteria for the Certification and Recertification of the Waste Isolation Pilot Plant's Compliance with the Disposal Regulations: Certification Decision; Final Rule*, Federal Register, Vol. 63, No. 95, pp. 27354-27406, May 18, 1998, Washington, D.C.



Attachment 1

Report Photographs



Photo #1. Close-up view of petroglyph pecked through patina on basalt. Petroglyph National Monument.

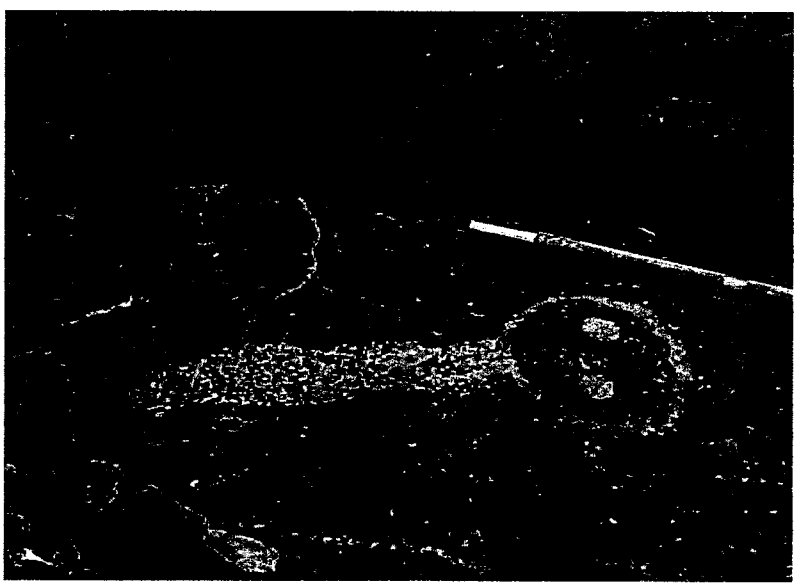


Photo #2. Petroglyph scraped into patina at Frying Pan Canyon.

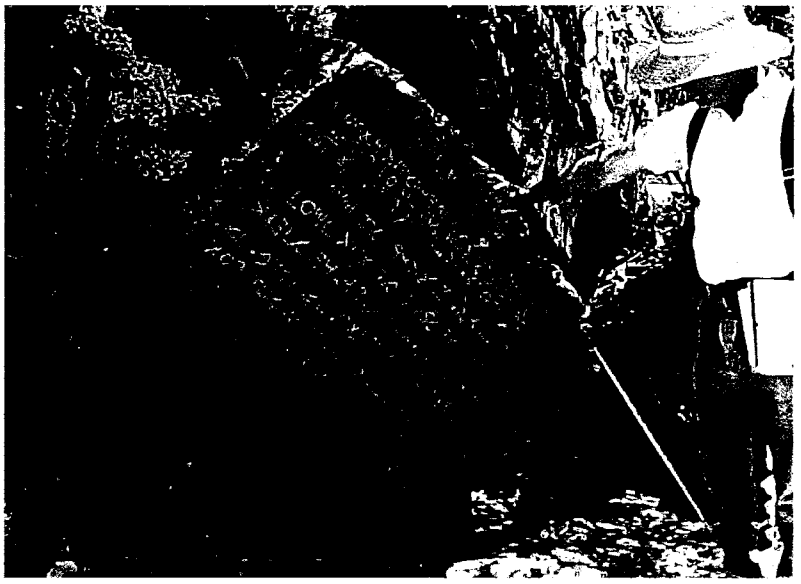


Photo #3. Sharp V-shaped grooves of this inscription at Mystery Stone indicate that this petroglyph was made by metallic tools and is recent.

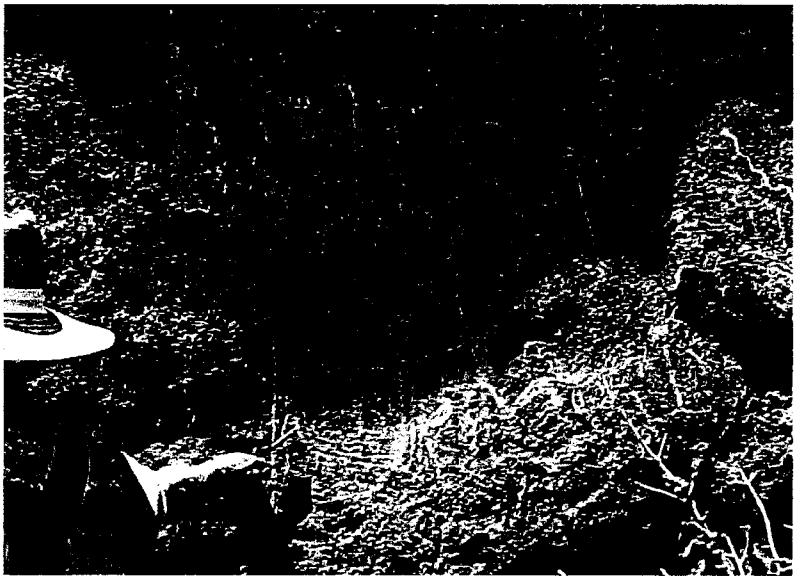


Photo #4. Petroglyphs at Cornudas Mountain, showing effects of color and texture contrasts on visibility if images.



Photo #5 – Circle image at end of pointer is repatinated to background color and texture, while images to left are unpatinated, aiding visibility. McNaughton Ranch.

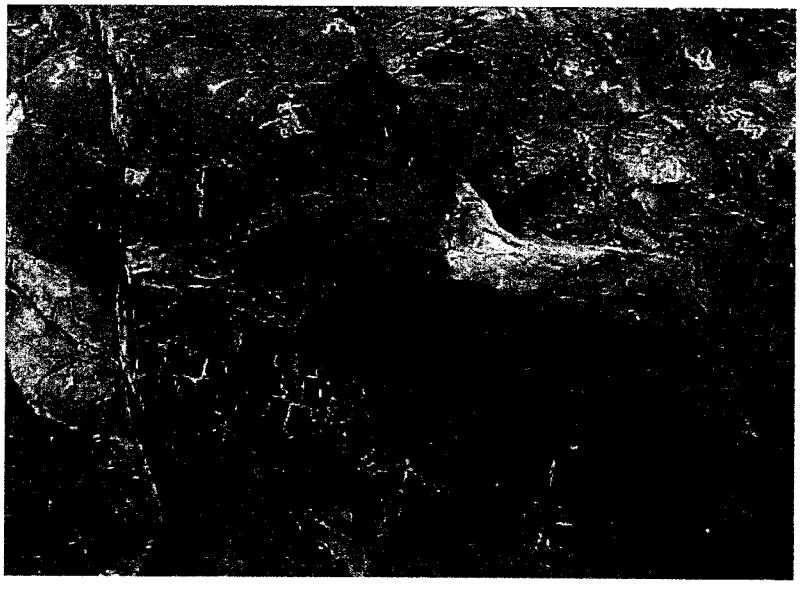


Photo #6. Very small petroglyphs that visually stand out because of contracts in color and texture with surrounding rock. Frying Pan Canyon.

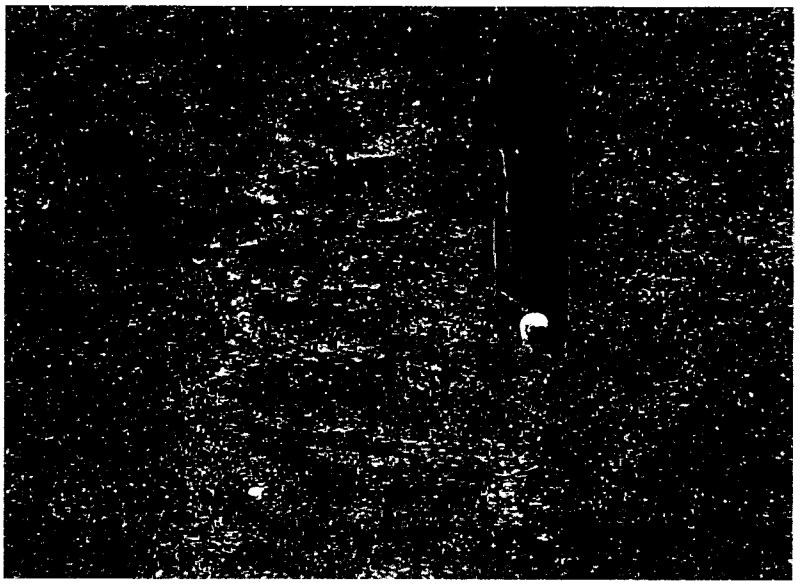
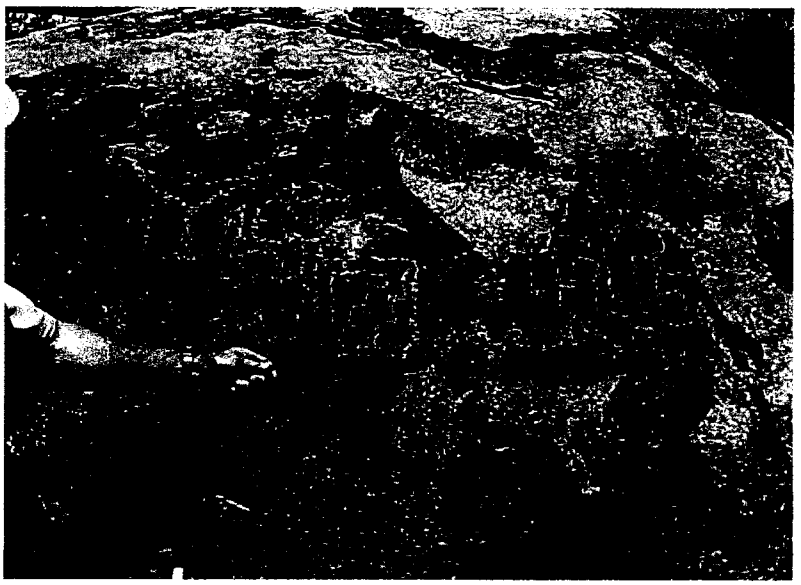


Photo #7. Petroglyph on horizontal surface at Rowe Site #2 with edges rounded and flattened by weathering and erosion.



Photo #8. Circle with cross, barely visible due to repatination and loss of boundary sharpness. Eby Ranch site.



Photo#9. Petroglyphs gradually being lost to exfoliation (lighter area). Cornudas Mountain Site



Photo #10. Archaic petroglyph above exfoliating surface. Cornudas Mountain.

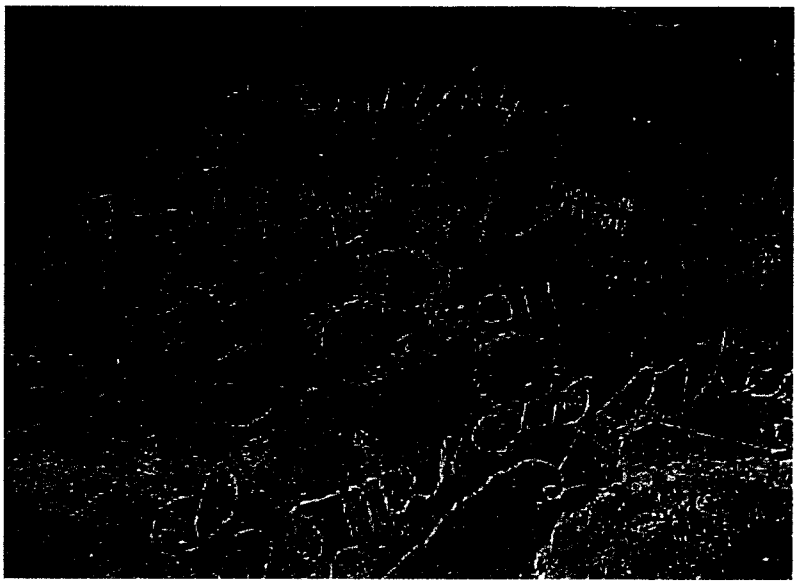


Photo #11. Exfoliation in diorite, lower right corner, encroaching on Archaic "chain" and recent script images. Hueco State Park.

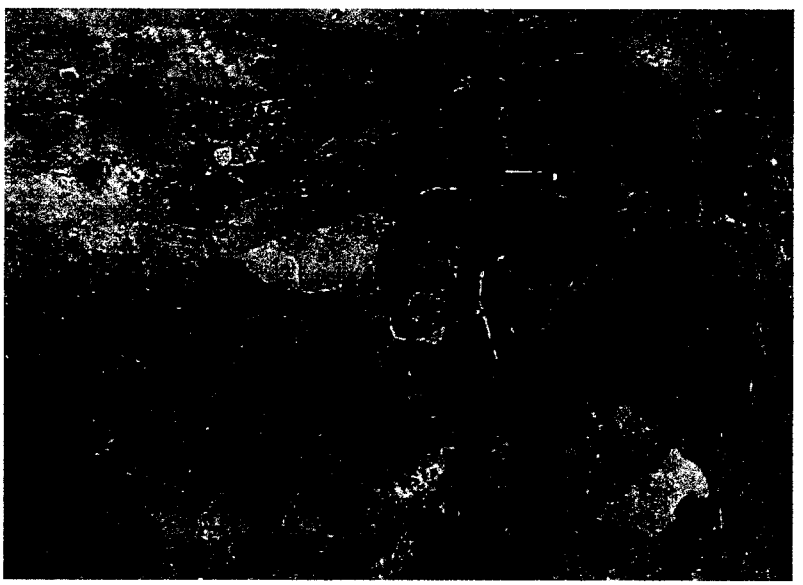


Photo #12. Remnant of inscribed surface in water course gradually being lost spalling and erosion. Frying Pan Canyon.

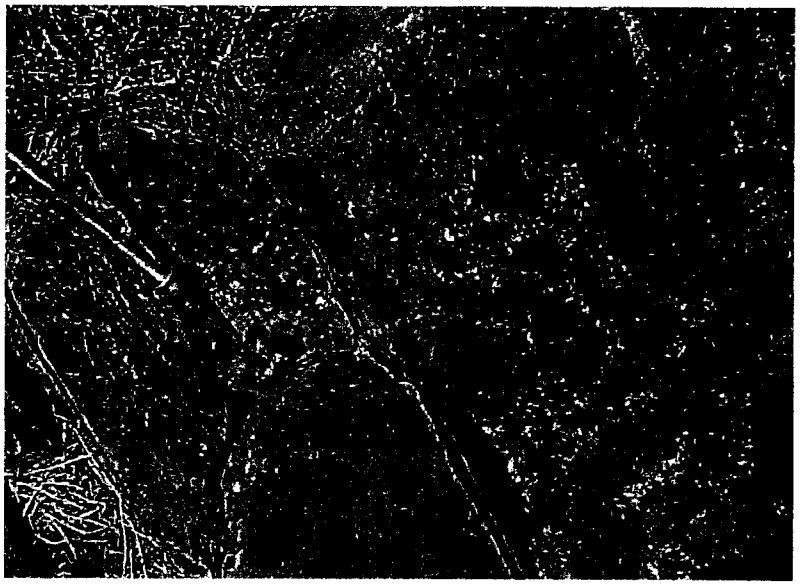


Photo #13. Petroglyph with left half lost to spalling. I-X Ranch.



Photo #14. Petroglyph in good condition in sandstone at Frying Pan Canyon.

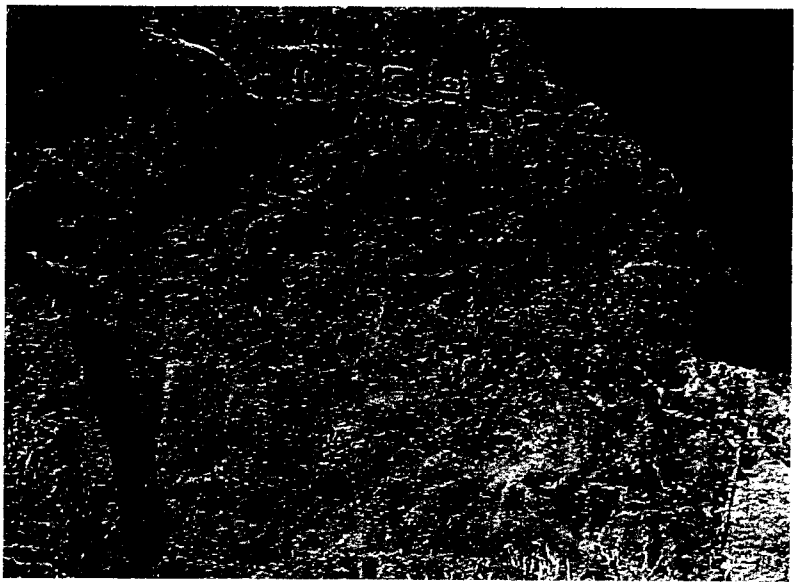


Photo #15. Petroglyphs in lower part of panel are in fair condition. Cornudas Mountain.



Photo # 16. Petroglyph in fair condition, with some spalling and erosion. Tonuco Mountain.

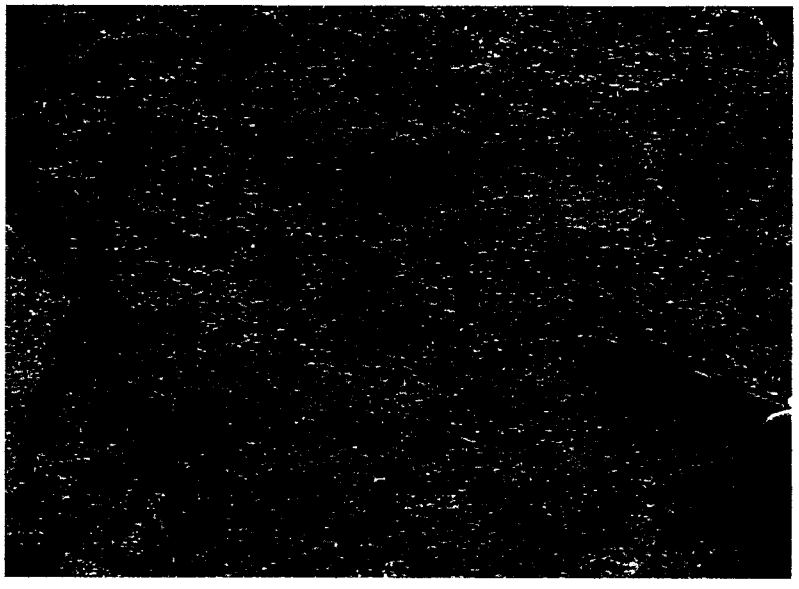


Photo # 17. Petroglyph of concentric circles, in poor condition. Eby Ranch.

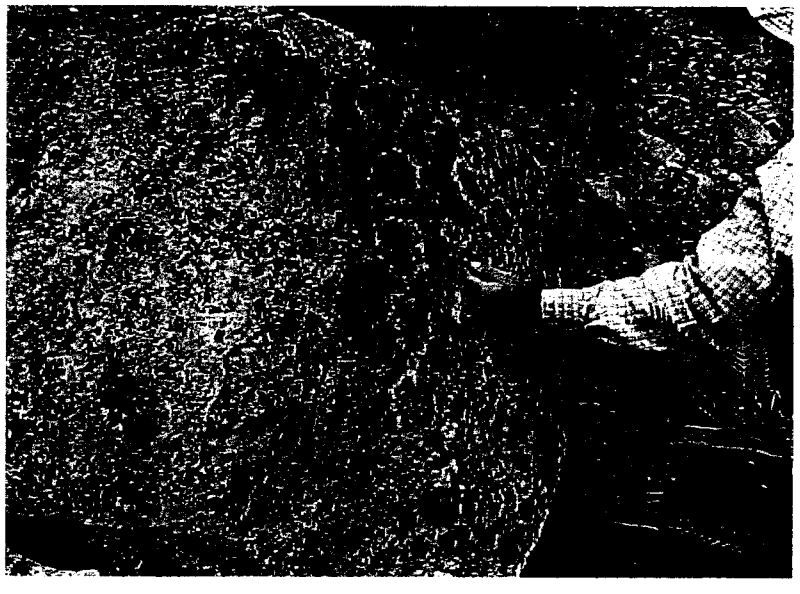


Photo # 18. Chain of circles (Archaic), with lowest two circles deteriorated to poor condition. McNaughton Ranch.

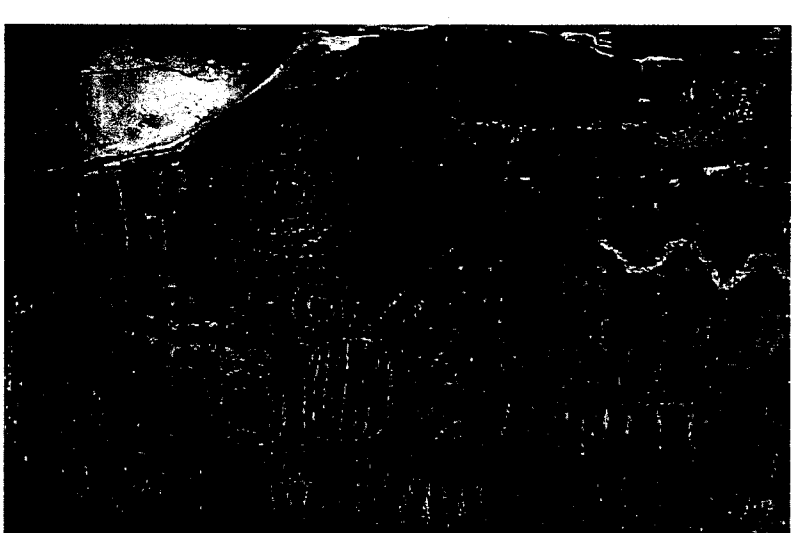


Photo #19. Archaic Desert Abstractions at Conchas Lake State Park.



Photo #20. Typical Archaic line patterns. McNaughton Ranch.



Photo #21. Mogollon images including animal, anthropomorphic, and other representational forms. Three Rivers Petroglyph National Historic Site.



Photo #22. Mogollon (Jornada) spirit mask. Black Mesa.

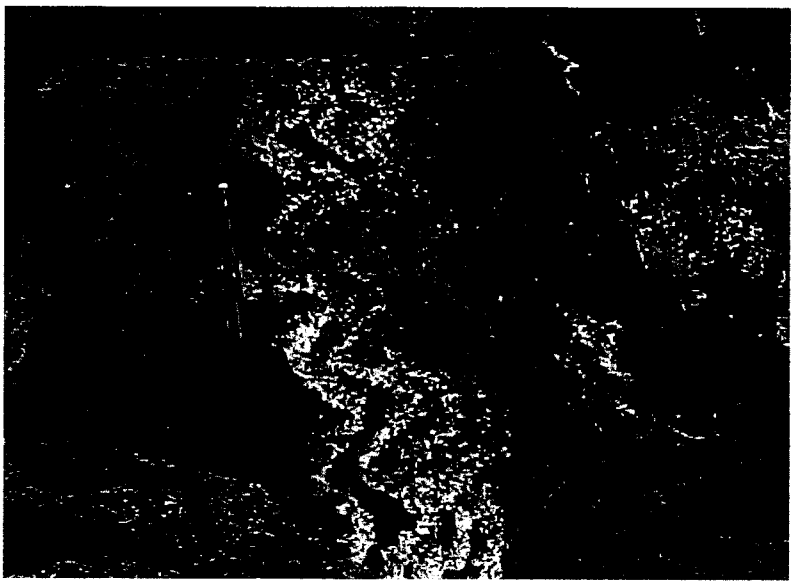


Photo #23. Chartreuse-colored lichens on Archaic petroglyph. Tonuco Mountain.



Photo #24. Chartreuse lichens highlighting Mogollon mask. Tonuco Mountain.



Photo # 25. Lichens growing in Archaic comb form. I-X Ranch.

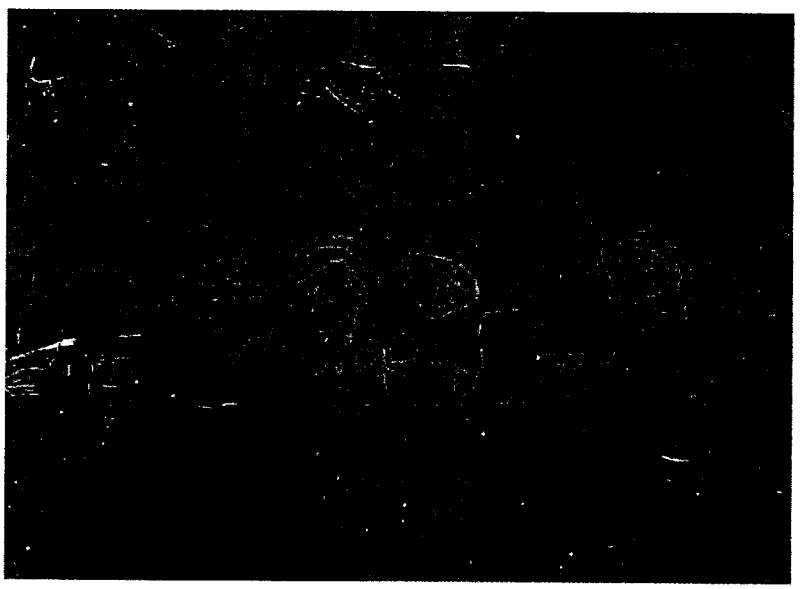


Photo #26. Soil cover partially removed from petroglyphs on horizontal surface. Rowe Mesa Site #1.

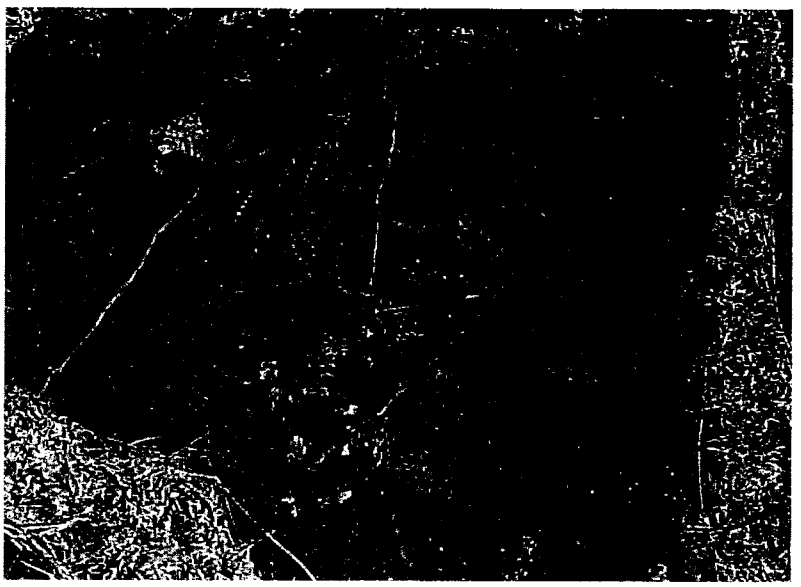


Photo #27. Petroglyphs extending into the open from underneath soil cover. Rowe Mesa Site #2.

Attachment 2

Site Reports



SITE REPORT
WIPP PERMANENT MARKERS MONUMENT SURVEY

SITE NAME: Three Rivers Petroglyph National Historic Site
LOCATION: Otero Co., NM
SITE OWNED BY: Bureau of Land Management
ACCESS AUTHORIZED BY: Public access, fee paid
SITE VISIT DATE: 6/14/00
BY: A. Kuhn, K. Lickliter, S. Casey

MONUMENT DESCRIPTION: Petroglyph

ROCK DESCRIPTION: Porphyritic Andesite

AGE(S) OF PETROGLYPHS: Mogollon

INSCRIPTION TYPE OR METHOD: Pecked, some scraped

INSCRIBED SURFACE ASPECT
DIRECTIONS: All directions, mostly south and southwest
INCLINATIONS: 70 degrees to vertical

ROCK SURFACE FORM: Varies widely from flat to curved, moderately smooth-to-rough

INSCRIPTION GROOVE FORM
WIDTHS: 3-20mm
DEPTHS: <2mm, most <1mm

WEATHERING: Rock surfaces patinated, petroglyphs not repatinated.



PHOTOS:

#	Description
ThreeR~1	Assortment of superimposed figures including Aztec-like geometrics and a rabbit.
ThreeR~2	Images on adjacent boulders including representational fish, footprint, and circle with cross.
ThreeR~3	Concentric circles surrounded by dots; this figure appears many places.
ThreeR~4	Geometric patterns of multiple ages; pole pointing to oldest partly repatinated figure.

NOTES: This andesite has large (5-15mm) mafic phenocrysts that cause some of the narrower inscriptions grooves to be partially obscured. The petroglyphs were made by pecking or scraping only deep enough to break through the patina. There are at least two generations of petroglyphs here, as shown by the superposition of petroglyphs. This site has suffered some vandalism in the form of recent scratching of petroglyph images.



SITE REPORT
WIPP PERMANENT MARKERS MONUMENT SURVEY

SITE NAME: Black Mesa
LOCATION: Doña Ana Co., NM
SITE OWNED BY: Stahmann Farms
ACCESS AUTHORIZED BY: Dave Lowry, Stahmann Farms
SITE VISIT DATE: 5/30/00, 6/2/00
BY: A. Kuhn, K. Lickliter

MONUMENT DESCRIPTION: Petroglyph

ROCK DESCRIPTION: Basalt

AGE(S) OF PETROGLYPHS: Archaic, Mogollon

INSCRIPTION TYPE OR METHOD: Scraped, some pecked

INSCRIBED SURFACE ASPECT
DIRECTIONS: Mostly north, east, and southeast
INCLINATIONS: 80 degrees to vertical

ROCK SURFACE FORM: Mostly wavy and smooth, some rough



INSCRIPTION GROOVE FORM
WIDTHS: 5-30mm
DEPTHS: <1mm

WEATHERING: All old rock surfaces heavily repatinated, no apparent chemical weathering of the basalt minerals.

PHOTOS:

#	Description
BlackM1	Mogollon spirit figure on wavy surface.
BlackM2	Archaic geometric barely visible on boulder face.
BlackM3	Zigzag line partly repatinated.
BlackM4	Barely visible images on boulders.
BlackM5	Archaic image obscured by patina and shadow.
BlackM6	Sunburst pattern on surface partly broken by spalling.
BlackM7	Same as BlackM6.
BlackM8	Totally repatinated image left of pencil point.

BlackM9	Zigzag pattern in shadow on boulder.
BlackM10	Very faint group of images to left of pointer.
BlackM11	Same as BlackM10.
BlackM12	Centipede image.
BlackM13	Same as BlackM12.
BlackM14	Orthogonal line pattern on curved rock face below shadow, heavily repatinated.
BlackM15	Orthogonal line pattern, repatinated, below and to right of pencil.
BlackM16	Rock face with partially repatinated zigzag lines and unpatinated scratches made by earthmoving equipment.

NOTES: This site is on Stahlmann Farms property at the foot of the east slope of Black Mesa. The petroglyphs are scattered among boulders at the foot of the slope, with heavy vegetation in many places obscuring the petroglyphs. The heavy patination makes most images difficult to see and even more difficult to photograph. All images are very shallow, made by scraping the surface which is patinated to a dark gray-black color. Some of the petroglyphs are pecked but have not broken through the patina completely. The unpatinated color of the rock is a medium-to-dark gray, so the patination does not produce a strong color contrast, which also makes many petroglyphs difficult to see.



SITE REPORT
WIPP PERMANENT MARKERS MONUMENT SURVEY

SITE NAME: City of Rocks State Park
LOCATION: Luna Co., NM
SITE OWNED BY: State of New Mexico
ACCESS AUTHORIZED BY: Brian Pender
SITE VISIT DATE: 6/2/00
BY: A. Kuhn, K. Lickliter

MONUMENT DESCRIPTION: Petroglyph

ROCK DESCRIPTION: Rhyolitic Welded Tuff

AGE(S) OF PETROGLYPHS: Mogollon

INSCRIPTION TYPE OR METHOD: Scraped

INSCRIBED SURFACE ASPECT
DIRECTIONS: (see note)
INCLINATIONS: Overhang surface

ROCK SURFACE FORM: Smooth, planar

INSCRIPTION GROOVE FORM
WIDTHS: 10mm
DEPTHS: <2mm

WEATHERING: Rock surface mostly patinated, petroglyph not repatinated



PHOTOS:

#	Description
Cityroc1	Unidentifiable image looking like an abstract hand or tree form.
Cityroc2	Same as Cityroc1.
Cityroc3	Same as Cityroc1&2 using flash.
Cityrock4	Picture of rock surface showing three different levels of patination; pencil in right hand points to most recent, ruler points to intermediate age, darks areas have oldest patina.

NOTES: This site contains several pictographs but only one petroglyph, which is inscribed on an overhanging surface in a relatively sheltered location. Patterns of patination are informative; at least three ages or levels are present.



SITE REPORT
WIPP PERMANENT MARKERS MONUMENT SURVEY

SITE NAME: Conchas Lake State Park
LOCATION: San Miguel CO., NM
SITE OWNED BY: State of New Mexico
ACCESS AUTHORIZED BY: Park Superintendent
SITE VISIT DATE: 6/15/00
BY: A. Kuhn, K. Lickliter

MONUMENT DESCRIPTION: Petroglyph

ROCK DESCRIPTION: Sandstone

AGE(S) OF PETROGLYPHS: Archaic, some Anasazi

INSCRIPTION TYPE OR METHOD: Pecked

INSCRIBED SURFACE ASPECT
DIRECTIONS: West to south, one horizontal surface
INCLINATIONS: Vertical

ROCK SURFACE FORM: Curved, moderately rough; also one planar surface; horizontal surface is wavy

INSCRIPTION GROOVE FORM
WIDTHS: Up to 30mm
DEPTHS: 1-5mm

WEATHERING: Some surfaces are patinated; others appear to be unweathered. Some petroglyphs are repatinated.

PHOTOS:

#	Description
Conchas1	Vertical face with concentric circles, comb patterns partly repatinated.
Conchas2	Partly repatinated dots, more recent curved line not repatinated.
Conchas3	Repatinated geometric figure, with fresh rock break to right.
Conchas4	Same as Conchas1.

Conchas5	Panel of geometric images partially repatinated except for more recent wavy line at right; high water indicated by top of grayish zone at bottom of photo.
Conchas6	Same view as Conchas5 shifted to the right.
Conchas7	Distant view of images in Conchas5&6.
Conchas8	Distant view of images just above high water mark.

NOTES: The south-facing petroglyph panel is fully repatinated. Patterns are all abstract geometrics except for one quadraped. Dominant patterns are concentric circles, diamonds cross patterns, wavy lines, dots, and parallel lines. Also, one animal form with pincers and one antlered head are probably Anasazi age. Some of the petroglyphs are below the high water line of the lake and are partially obscured with deposits from the lake water.



SITE REPORT
WIPP PERMANENT MARKERS MONUMENT SURVEY

SITE NAME: Cornudas Mountain
LOCATION: Doña Ana Co., NM
SITE OWNED BY: Stahmann Farms
ACCESS AUTHORIZED BY: Dave Lowry, Stahmann Farms
SITE VISIT DATE: 5/30/00, 6/2/00
BY: A. Kuhn, K. Lickliter

MONUMENT DESCRIPTION: Petroglyph

ROCK DESCRIPTION: Basalt

AGE(S) OF PETROGLYPHS: Archaic, Mogollon

INSCRIPTION TYPE OR METHOD: Scraped, Pecked

INSCRIBED SURFACE ASPECT
DIRECTIONS: East, South and Southwest
INCLINATIONS: 60 degrees to vertical

ROCK SURFACE FORM: Smooth

INSCRIPTION GROOVE FORM
WIDTHS: 5-80mm
DEPTHS: <2mm



WEATHERING: Older rock surfaces patinated to about 2mm. Extensive exfoliation in layers 2-10mm.

PHOTOS:

#	Description
Cornud1	East-facing panel with Archaic and Mogollon images scraped and pecked through patina.
Cornud2	Closeup of Cornud1 location, showing Archaic geometrics surrounded by Mogollon anthropomorphs.
Cornud3	Southwest-facing surface with images partly lost to exfoliation.
Cornud4	East-facing panel with several generations of images.
Cornud5	Chain pattern on surface substantially exfoliated.
Cornud6	Archaic pattern of parallel zigzag lines on partly exfoliated surface.

Cornud7	Panel of mixed images, mostly Archaic geometrics.
Cornud8	Same as Cornud7.
Cornud9&10	Pictographs.

NOTES: This site has extensive petroglyphs of both Archaic and Jornada (Mogollon) age, mostly scraped, some pecked, through a 2mm patina layer. Extensive exfoliation affects rock surface to depths of 5-10mm. All Jornada and older petroglyphs are at least partially repatinated. This site is exposed to the south quadrants, sheltered from the north quadrants. Phenocrysts of nepheline (?) appear to control the depth of exfoliation.



SITE REPORT
WIPP PERMANENT MARKERS MONUMENT SURVEY

SITE NAME: Eby Ranch
LOCATION: Faywood, NM
SITE OWNED BY: Larry Eby
ACCESS AUTHORIZED BY: Larry Eby
SITE VISIT DATE: 6/1/00
BY: A. Kuhn, K. Lickliter

MONUMENT DESCRIPTION: Petroglyph

ROCK DESCRIPTION: Rhyolitic Welded Tuff

AGE(S) OF PETROGLYPHS: Archaic, Mogollon, maybe some Apache, recent

INSCRIPTION TYPE OR METHOD: Pecked

INSCRIBED SURFACE ASPECT
- DIRECTIONS: Northwest to southwest
- INCLINATIONS: 45 degrees to vertical

ROCK SURFACE FORM: Wavy, smooth to rough

INSCRIPTION GROOVE FORM
- WIDTHS: 2-80mm
- DEPTHS: Most <2mm, some up to 5mm

WEATHERING: Old rock surfaces heavily patinated, some petroglyphs completely repatinated.

PHOTOS:

#	Description
EBY1	Concentric circles completely repatinated on wavy rough surface.
EBY2	Hand patterns, one partly repatinated, on wavy surface.
EBY3	Spirit form on rough, partially fractured surface.
EBY4	Recent image of house on wavy rough surface.
EBY5	Recent house image in lower right, recent donkey in center, and repatinated circle pattern in upper left, showing contrast in appearance of very old vs. recent inscriptions.
EBY6	Partially repatinated geometric image.

EBY7	Pencil and pole point to limits of large circle with horizontal line, partially repatinated, with lichen growth.
EBY8	Intricate diamond pattern, repatinated, with some lichen growth.
EBY9	Wider view of EBY8 image, with recent inscription to left.
EBY10	Rough patinated surface with extensive scaling of patinated surface; pinwheel and other geometric patterns.
EBY11	Anthropomorph to right of pencil, mostly repatinated.
EBY12	Repatinated circle with cross right of pencil.
EBY13	Repatinated concentric circles right of pencil and above pencil.

NOTES: This site is on private property at the crest of a low hill capped by the welded tuff. Petroglyphs face primarily toward the western quadrants and are fully exposed to sun, wind and rain from that direction. The Archaic images and some of the Mogollon images are completely repatinated; some Mogollon images are partly repatinated. Patina development is apparently more uniform here than at other sites with the same kind of rock. Recent images were apparently made by local school children within the last 50 years.

SITE REPORT
WIPP PERMANENT MARKERS MONUMENT SURVEY

SITE NAME: El Morro National Monument
LOCATION: Cibola Co., NM
SITE OWNED BY: National Park Service
ACCESS AUTHORIZED BY: Public access, fee paid
SITE VISIT DATE: 6/13/00
BY: A. Kuhn, K. Lickliter, S. Casey

MONUMENT DESCRIPTION: Petroglyph

ROCK DESCRIPTION: Sandstone

AGE(S) OF PETROGLYPHS: Anasazi to recent

INSCRIPTION TYPE OR METHOD: Chiseled, pecked

INSCRIBED SURFACE ASPECT
DIRECTIONS: East, south, west, most north
INCLINATIONS: Vertical

ROCK SURFACE FORM: Planar, smooth-to-rough

INSCRIPTION GROOVE FORM
WIDTHS: Various, up to 50mm
DEPTHS: Generally 3-10mm, some larger

WEATHERING: Repatinated completely on oldest petroglyphs. No repatination on historic age inscriptions. Some spalling. Lichens only on oldest petroglyph surfaces.

PHOTOS:

#	Description
ElMorro1	Patinated surface with fully-repatinated images of hands, quadrapeds, anthropomorphs.
ElMorro2	Line of mountain goats on unpatinated surface.
ElMorro3	Panel of unweathered surface with many quadraped forms.
ElMorro4	Zigzag pattern in unweathered surface.
ElMorro5	Same as ElMorro4.
ElMorro6	Concentric circles left of stick, scraped letters to right.

NOTES: This site has many generations of inscriptions from Anasazi to recent. Anasazi images include pecked handprints, anthropomorphic zigzag patterns, and concentric circles. Some historic age letters have dark gray-to-black lichens in them. The sandstone is very fine-grained and massive, making inscribing relatively easy compared to the other sites surveyed.

SITE REPORT
WIPP PERMANENT MARKERS MONUMENT SURVEY

SITE NAME: Hueco Tanks State Park
LOCATION: Hudspeth Co., TX
SITE OWNED BY: State of Texas
ACCESS AUTHORIZED BY: Public access – fee paid
SITE VISIT DATE: 5/31/00
BY: A. Kuhn, K. Lickliter

MONUMENT DESCRIPTION: Petroglyph

ROCK DESCRIPTION: Diorite

AGE(S) OF PETROGLYPHS: Mogollon

INSCRIPTION TYPE OR METHOD: Pecked

INSCRIBED SURFACE ASPECT
DIRECTIONS: East, horizontal
INCLINATIONS: 60 degrees to horizontal

ROCK SURFACE FORM: Wavy and smooth

INSCRIPTION GROOVE FORM
WIDTHS: 5-20mm
DEPTHS: <1mm

WEATHERING: Relatively uniform patination of exposed rock surfaces, exfoliation to depths of several mm.

PHOTOS:

#	Description
Hueco1	Two x-shaped "bird tracks" pecked into patina.
Hueco2	Images of tracks pecked into patina, with exfoliation at upper right corner.
Hueco3	Very faint bird tracks pecked into patina, exfoliation visible at top of photo.
Hueco4	Circle with inscribed cross, exfoliation to upper right.
Hueco5	Daisy chain of circles and other geometrics superimposed by recent writing; images disrupted by exfoliation at lower right.

Hueco6 Same image as Hueco5.

NOTES: At this state park there are a few petroglyphs, shown above, and many pictographs not surveyed. The petroglyphs have been pecked into but not through the patina. Exfoliation is gradually removing the inscribed surfaces. Exfoliation layers are 2-5mm thick in most places, locally deeper.

SITE REPORT
WIPP PERMANENT MARKERS MONUMENT SURVEY

SITE NAME: I-X Ranch
LOCATION: Lincoln Co., NM
SITE OWNED BY: State of New Mexico, Bill Stephenson
ACCESS AUTHORIZED BY: State Land Office, Bill Stephenson
SITE VISIT DATE: 6/14/00
BY: A. Kuhn, K. Lickliter, S. Casey

MONUMENT DESCRIPTION: Petroglyph

ROCK DESCRIPTION: Porphyritic Andesite

AGE(S) OF PETROGLYPHS: Archaic, Mogollon

INSCRIPTION TYPE OR METHOD: Pecked, Scraped

INSCRIBED SURFACE ASPECT
DIRECTIONS: Mostly south to southwest
INCLINATIONS: 80 degrees

ROCK SURFACE FORM: Planar, rough

INSCRIPTION GROOVE FORM
WIDTHS: 5-50mm
DEPTHS: 1-2mm

WEATHERING: Oldest petroglyphs are fully repatinated. Successive generations partially repatinated. Some lichen growth in inscription grooves.

PHOTOS:

#	Description
Lincoln1	Multiple images of different ages.
Lincoln2	Multiple images in rough, broken surface; surface spalling older than images.
Lincoln3	Older repatinated images with superimposed unrepatinated images.
Lincoln4	Broken concentric circle pattern, partly repatinated.
Lincoln5	Multiple images on fractured, partially-spalled surface, older repatinated images predominate.

Lincoln6	Pencil pointing to Archaic repatinated circle; pole pointing to Archaic cone pattern; more recent spiral pattern at far right shows difference in patination.
Lincoln7	Totally repatinated concentric circles at left; more recent unrepatinated circles at right.
Lincoln8	Archaic comb pattern with some lichen growth.
Lincoln9	Wide angle of Lincoln8, including other comb patterns.
Lincoln10	Large south-facing panel with multiple images of at least two generations.

NOTES: This site is primarily the dip slope of an andesite dike, with the dip slope containing large panels of multigenerations of petroglyphs. The oldest are fully repatinated Archaic abstract geometrics. Typical Archaic images such as concentric circles, parallel lines, and connected circles are present in at least two generations and may also have been repeated by Mogollon Indians. The large panel faces are fully exposed to the sun and to wind and rain coming from the southern quadrants.



SITE REPORT
WIPP PERMANENT MARKERS MONUMENT SURVEY

SITE NAME: McNaughton (formerly Simmons) Ranch
LOCATION: Luna Co., NM
SITE OWNED BY: McNaughton
ACCESS AUTHORIZED BY: Russell Baker
SITE VISIT DATE: 6/1/00
BY: A. Kuhn, K. Lickliter

MONUMENT DESCRIPTION: Petroglyph

ROCK DESCRIPTION: Rhyolite (welded tuff)

AGE(S) OF PETROGLYPHS: Archaic, Mogollon, Apache, recent

INSCRIPTION TYPE OR METHOD: Pecked

INSCRIBED SURFACE ASPECT
- DIRECTIONS: Primarily east to southeast, some southwest and northeast
- INCLINATIONS: 60 degrees to vertical

ROCK SURFACE FORM: Rough wavy-to-curving surfaces

INSCRIPTION GROOVE FORM
- WIDTHS: 5-40mm
- DEPTHS: Most <1mm, some up to 3mm

WEATHERING: Rock surfaces moderately patinated, some spalling.

PHOTOS:

#	Description
Luna1-1	Horned lizard on patinated surface, fragment of rock in hand shows color of fresh unpatinated rock.
Luna1-2	Multiple images, including concentric circles, on southwest-facing surface.
Luna1-3	Southeast-facing weathered surface with mostly Archaic images including concentric circles, sunbursts, and fishnet patterns.
Luna1-4	East-facing surface, partially repatinated wavy lines.
Luna1-5	Panel of mostly Archaic images with recent spray-painted graffiti, facing northeast.

Luna1-6	Set of wavy parallel lines (Archaic) on curved rough surface, with other abstract and animal images nearby.
Luna1-7	Chain pattern of circles on patinated but partly eroded surface.
Luna1-8	Abstract image on east-facing rough surface.
Luna1-9	Panel with geometric abstractions, concentric circles at end of pointer, largely obscured by surface roughness.
Luna1-10	Archaic concentric circles and diamond patterns.
Luna1-11	Archaic wavy parallel lines on rough surface.

NOTES: This site contains both Archaic and Mogollon petroglyphs. The texture of the rhyolitic welded tuff makes some of the images difficult to see because the depth of inscription is less than the amplitude of surface roughness. Some vandalism has occurred recently. Pictures show that the rock is somewhat vuggy in places, making the rock more porous than it is in neighboring locations. The surfaces with petroglyphs are oriented in many different directions and seem to have no clear differences in degree of patination or amount of weathering; also no distinction in preservation of the petroglyphs based on aspect.



SITE REPORT
WIPP PERMANENT MARKERS MONUMENT SURVEY

SITE NAME: Frying Pan Canyon
LOCATION: Luna Co., NM
SITE OWNED BY: Bureau of Land Management
ACCESS AUTHORIZED BY: Sara Schlanger
SITE VISIT DATE: 6/1/00
BY: A. Kuhn, K. Lickliter

MONUMENT DESCRIPTION: Petroglyph

ROCK DESCRIPTION: Sandstone

AGE(S) OF PETROGLYPHS: Archaic, Mogollon

INSCRIPTION TYPE OR METHOD: Pecked

INSCRIBED SURFACE ASPECT
DIRECTIONS: Northeast, southeast, south-to-west
INCLINATIONS: 30 degrees to vertical, horizontal, some overhangs

ROCK SURFACE FORM: Mostly planar and rough, some curved

INSCRIPTION GROOVE FORM
WIDTHS: 10-15mm
DEPTHS: 2mm

WEATHERING: Rock surfaces heavily patinated, some spalling.

PHOTOS:

#	Description
Luna2-1	Has relief cross forms through patina, not repatinated.
Luna2-2	Wolf tracks pecked through patina, on heavily fractured surface.
Luna2-3	Concentric circles in pinwheel form on rough surface.
Luna2-4	Archaic diagonal network, linked circles and comb forms overlain by Mogollon human footprints and other life forms on rough curved surface (note spall of rock left of pointer).
Luna2-5	Starburst and other geometrics on rough fractured surface.
Luna2-6	Concentric circles on horizontal surface, slightly repatinated.
Luna2-7	Southeast-facing rough fractured surface with animal forms.

Luna2-8	Flat surface, rough and fractured, with Archaic and Mogollon images.
Luna2-9	Archaic cross form, Mogollon footprints and bird tracks, on rough surface.
Luna2-10	Ghost image on rough horizontal surface.
Luna2-11	Mogollon images on remnant patinated surface surrounded by spalled and scoured surfaces.

NOTES: Site is located on the west slope of Frying Pan Canyon just north of an old stock tank dam. Petroglyphs are on intact rock outcrops and boulders of a hard ferruginous sandstone. All surfaces are relatively rough and fractured. Many petroglyphs on horizontal surfaces on the tops of boulders and outcrops. A combination of Archaic abstract geometrics, with Mogollon images of footprints, animals, anthropomorphs. Very few images are completely repatinated, but many are partially repatinated, especially Archaic images.



SITE REPORT
WIPP PERMANENT MARKERS MONUMENT SURVEY

SITE NAME: Mystery Stone
LOCATION: Valencia CO., NM
SITE OWNED BY: State of New Mexico
ACCESS AUTHORIZED BY: State Land Office
SITE VISIT DATE: 6/13/00
BY: A. Kuhn, K. Lickliter, S. Casey

MONUMENT DESCRIPTION: Petroglyph

ROCK DESCRIPTION: Andesite

AGE(S) OF PETROGLYPHS: Anasazi, recent

INSCRIPTION TYPE OR METHOD: Pecked, chiseled

INSCRIBED SURFACE ASPECT
- DIRECTIONS: Northwest to northeast
- INCLINATIONS: 10 degrees past vertical for Mystery Stone, 60-80 degrees elsewhere

ROCK SURFACE FORM: Wavy to planar, and smooth

INSCRIPTION GROOVE FORM
- WIDTHS: Mystery Stone: V-shaped grooves 3-5mm at top
  Others: 10-40mm
- DEPTHS: Mystery Stone: 1-2mm
  Others: <1mm

WEATHERING: Mystery Stone face slightly patinated, inscriptions unpatenated. Anasazi petroglyphs slightly repatinated.

PHOTOS:

#	Description
Mystery1	The "Mystery Stone" inscription.
Mystery2	Quadraped with long tail on patinated surface with fragments of other images next to recent breaks in the rock surface.
Mystery3	Crude face on patinated surface.

NOTES: The Mystery Stone has V-shaped grooves with sharply-defined sides and edges, and some rock dust can still be seen in the bottoms of the grooves. This inscription was obviously made with a metallic tool and, therefore, can't be older than historic age or not more than 400 years. The other petroglyphs in the vicinity are crudely done and penetrate only into the patina. These are consistent with Anasazi and older petroglyphs surveyed elsewhere.



SITE REPORT
WIPP PERMANENT MARKERS MONUMENT SURVEY

SITE NAME: Petroglyph National Monument
LOCATION Albuquerque, NM
SITE OWNED BY: National Park Service
ACCESS AUTHORIZED BY: Public access
SITE VISIT DATE: 6/12/00
BY: A. Kuhn, K. Lickliter, S. Casey

MONUMENT DESCRIPTION: Petroglyph

ROCK DESCRIPTION: Basalt

AGE(S) OF PETROGLYPHS: Archaic, Anasazi

INSCRIPTION TYPE OR METHOD: Pecked, scraped

INSCRIBED SURFACE ASPECT
DIRECTIONS: Mostly south and southeast, some northwest
INCLINATIONS: 45 degrees to vertical

ROCK SURFACE FORM: Planar to curved, mostly rough, some smooth

INSCRIPTION GROOVE FORM
WIDTHS: Mostly 3-30mm, one image 40-110mm
DEPTHS: Most <1mm, none >2mm

WEATHERING: Natural rock surfaces extensively patinated. Petroglyphs unpatinated to partially repatinated.

PHOTOS:

#	Description
PETRNM1	Various geometric images on a curved, rough surface.
PETRNM2	Partially repatinated images on a rough surface.
PETRNM3	Circles scraped partly through the patina on a curved surface.
PETRNM4	Same as #3.
PETRNM5	Abstract images on a rough, curved surface, partially repatinated.
PETRNM6	Same as #5.
PETRNM7	Large geometric pattern between walking stick and scale obscured by repatination and light reflection.



PETRNM8	Rough surface obscuring repatinated image.
PETRNM9	Surface with variable texture and random line images with wedge-shaped piece spalled from surface.
PETRNM10	Image partially broken through patina surface.
PETRNM11	Circle with tree partially obscured by reflected sunlight.
PETRNM12	Various images pecked through patina on uneven surface.
PETRNM13	Closeup of cross form in previous photo.
PETRNM14	Geometric image partially repatinated.

NOTES: Petroglyphs at this site, a side canyon of the Monument, are described by park personnel as being "a couple thousand years old." The petroglyphs occur among scattered boulders in a narrow canyon. The level of exposure of the petroglyphs varies widely, depending on position in the canyon and orientation. Some of the photographs did not capture the image clearly, due to intense mid-day sunlight. Surfaces here are among the roughest seen at any of the surveyed sites. Several generations of petroglyphs are represented, some clearly Anasazi and others apparently older.



SITE REPORT
WIPP PERMANENT MARKERS MONUMENT SURVEY

SITE NAME: Rowe Mesa Site #1
LOCATION: San Miguel Co., NM
SITE OWNED BY: U.S. Forest Service
ACCESS AUTHORIZED BY: Brent Abel, USFS
SITE VISIT DATE: 6/16/00
BY: A. Kuhn, K. Lickliter

MONUMENT DESCRIPTION: Petroglyph

ROCK DESCRIPTION: Sandstone

AGE(S) OF PETROGLYPHS: Archaic

INSCRIPTION TYPE OR METHOD: Pecked

INSCRIBED SURFACE ASPECT
DIRECTIONS: Horizontal
INCLINATIONS: Horizontal

ROCK SURFACE FORM: Irregular, wavy

INSCRIPTION GROOVE FORM
WIDTHS: 2-80mm
DEPTHS: 1-4mm

WEATHERING: All petroglyphs are repatinated. Iron oxide concentrated in fossil crab burrows now form resistant knobs at the surface.

PHOTOS:

#	Description
Rowe A1	Figure that was half cover by soil (right half, below pencil) and half exposed. Except for soil in grooves of previously covered half, halves are identically preserved.
Rowe A2	Cluster of petroglyphs previously covered with soil, prior to archeological excavation.
Rowe A3	Cluster of petroglyphs not previously covered with soil.
Rowe A4	Cluster of petroglyphs on surface that is part of water course.
Rowe A5	Concentric circles, right of pencil, heavily repatinated.

NOTES: According to Brent Abel, soil over the petroglyphs is at least 3000 years old. Charcoal at the site has been dated at 5300 years, patina at 5970 years. In the area not previously covered by soil, some petroglyphs are repatinated, some not. Some repatinated petroglyphs have lichen growth. This site has a starburst pattern unlike patterns seen elsewhere. Solstice and equinox marks have been identified here. Site is in an area of P-J woodland with very little surface slope, but a shallow drainage course runs across this site. Most of the ground in the vicinity is soil-covered. Soil cover over the petroglyphs has been partially removed by archeologists to expose some of the buried petroglyphs, one of which was only half-buried by soil prior to excavation. The petroglyph shown in Photo #Rowe 1-1 was covered in the area next to the pencil in the photo, exposed in the other half. Petroglyphs are generally in fair condition.



SITE REPORT
WIPP PERMANENT MARKERS MONUMENT SURVEY

SITE NAME: Rowe Mesa Site #2
LOCATION: San Miguel Co., NM
SITE OWNED BY: U.S. Forest Service
ACCESS AUTHORIZED BY: Brent Abel, USFS
SITE VISIT DATE: 6/16/00
BY: A. Kuhn, K. Lickliter

MONUMENT DESCRIPTION: Petroglyph

ROCK DESCRIPTION: Sandstone

AGE(S) OF PETROGLYPHS: Archaic

INSCRIPTION TYPE OR METHOD: Pecked

INSCRIBED SURFACE ASPECT
DIRECTIONS: Horizontal
INCLINATIONS: Horizontal

ROCK SURFACE FORM: Knobby, wavy

INSCRIPTION GROOVE FORM
WIDTHS: 10-30mm
DEPTHS: 3-5mm



WEATHERING: All petroglyphs are repatinated. Rock surface is differentially weathered, leaving iron oxide concentrations around fossil crab burrows sticking up. This weathering predates the petroglyphs, as evidenced by the petroglyphs that include the fossil burrows as part of the petroglyph image.

PHOTOS:

#	Description
Rowe B1	Cluster with "bird tracks", sun burst, wavy lines, circle.
Rowe B2	Cluster with spiral, orthogonal lines,dendritic patterns extending under soil cover to lower left.
Rowe B3	Partially eroded petroglyphs with adjacent soil cover.
Rowe B4	Petroglyph with pencil in one groove, to illustrate depth.
Rowe B5	Petroglyph grooves across natural knob in rock.

NOTES: This site is similar in most respects to Rowe Mesa #1, except that there is no drainage course. Generally, the condition of the petroglyphs here is slightly poorer than at Rowe Mesa #1. The sandstone was identified by Brent Abel as the Santa Rosa Sandstone of Triassic age. It is well indurated and forms the cap rock of the mesa. The petroglyphs here, as at the nearby Rowe Mesa #1 site, may have been broadened and deepened by erosion or weathering, but the repatinated grooves of the inscriptions show that the weathering/erosion processes have been very slow.



SITE REPORT
WIPP PERMANENT MARKERS MONUMENT SURVEY

SITE NAME: Tonuco Mountain
LOCATION: Doña Ana Co., NM
SITE OWNED BY: Bureau of Land Management
ACCESS AUTHORIZED BY: Sara Schlanger
SITE VISIT DATE: 5/30/00
BY: A. Kuhn, K. Lickliter

MONUMENT DESCRIPTION: Petroglyph

ROCK DESCRIPTION: Sandstone

AGE(S) OF PETROGLYPHS: Archaic, Mogollon

INSCRIPTION TYPE OR METHOD: Pecked

INSCRIBED SURFACE ASPECT
DIRECTIONS: All compass points
INCLINATIONS: 20 degrees to vertical

ROCK SURFACE FORM: Flat to wavy, smooth, some fractures

INSCRIPTION GROOVE FORM
WIDTHS: 7-20mm
DEPTHS: 1-5mm

WEATHERING: Old rock surfaces patinated to reddish-brown to steel gray color, mottled together in some places. Extensive growth of chartreuse colored lichens.

PHOTOS:

#	Description
Tonuco1	Concentric circles partly lost to spalling/erosion, repatinated.
Tonuco2	Diamond and orthogonal line patterns, partly repatinated.
Tonuco3	At least two generations of images, Archaic and Mogollon, latter less repatinated than former.
Tonuco4	Archaic patterns, including one dendritic pattern with lichens.
Tonuco5	Parallel wavy lines partly repatinated and lichens in grooves.
Tonuco6	Sunburst and other Archaic patterns, repatinated.
Tonuco7	Archaic geometrics, partly repatinated.

Tonuco8	Large boulder with mottled patination, Archaic and Mogollon images.
Tonuco9	Mogollon head with chartreuse lichens in inscription grooves.

NOTES: This site is in a steep-walled canyon that runs southeast to northwest. The sandstone cap rock has broken into boulders that line the north slope of the canyon, and the petroglyphs are concentrated on a group of these boulders. The patina varies randomly from reddish-brown to steel gray, with the latter being thicker. Petroglyphs are pecked through the patina to a depth of up to 5mm. The Archaic petroglyphs are mostly completely repatinated, and the Mogollon petroglyphs are at least partly repatinated. Chartreuse lichens are common.



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

Permanent Markers Testing Program Plan

Waste Isolation Pilot Plant
Carlsbad, New Mexico

DOE/WIPP 00-3175



September 28, 2000

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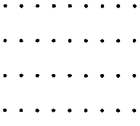

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List of Abbreviations and Acronyms

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.



[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.

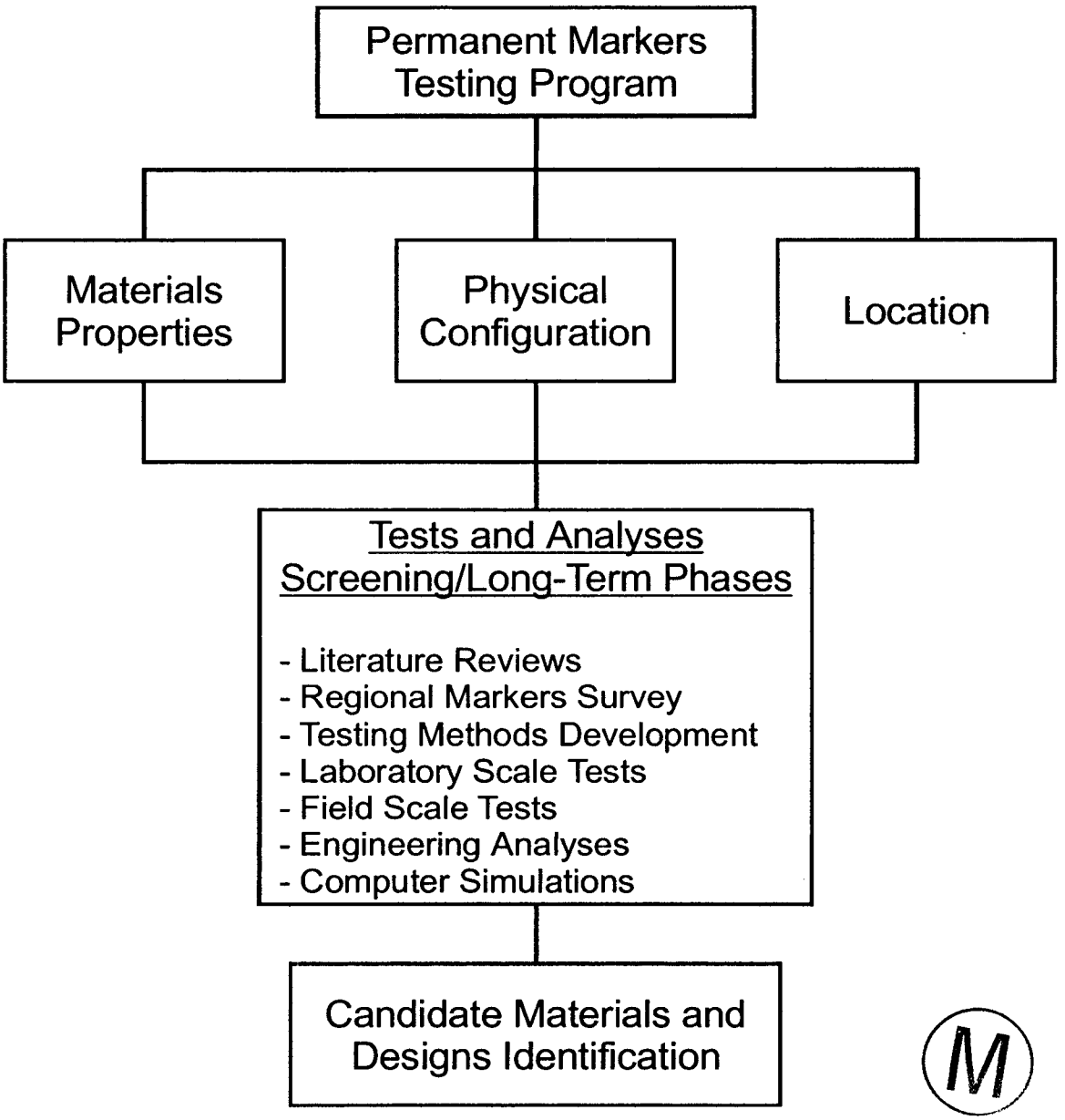

Figure 1. Testing Program Organization

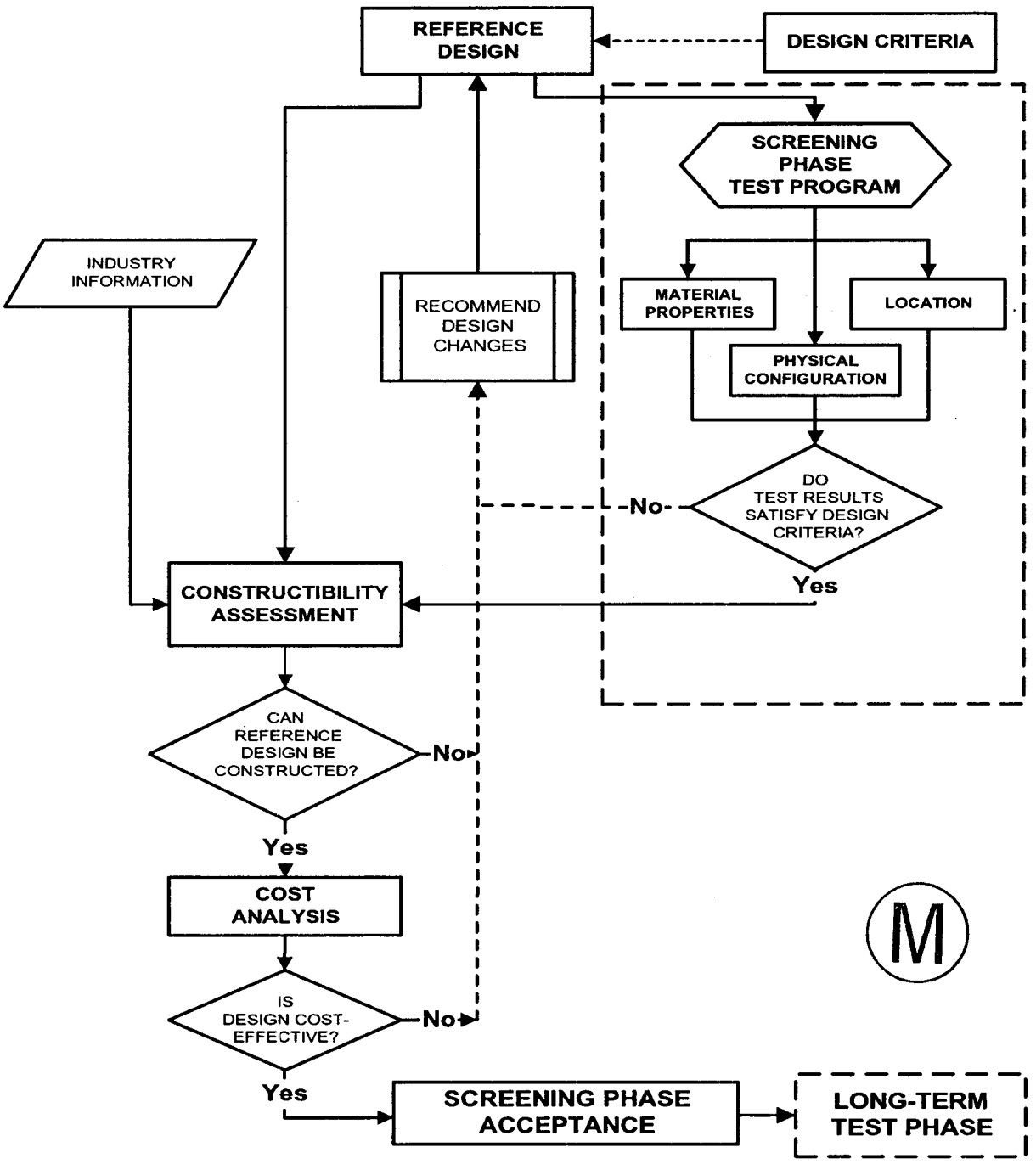

Figure 2. Screening Phase Testing Process

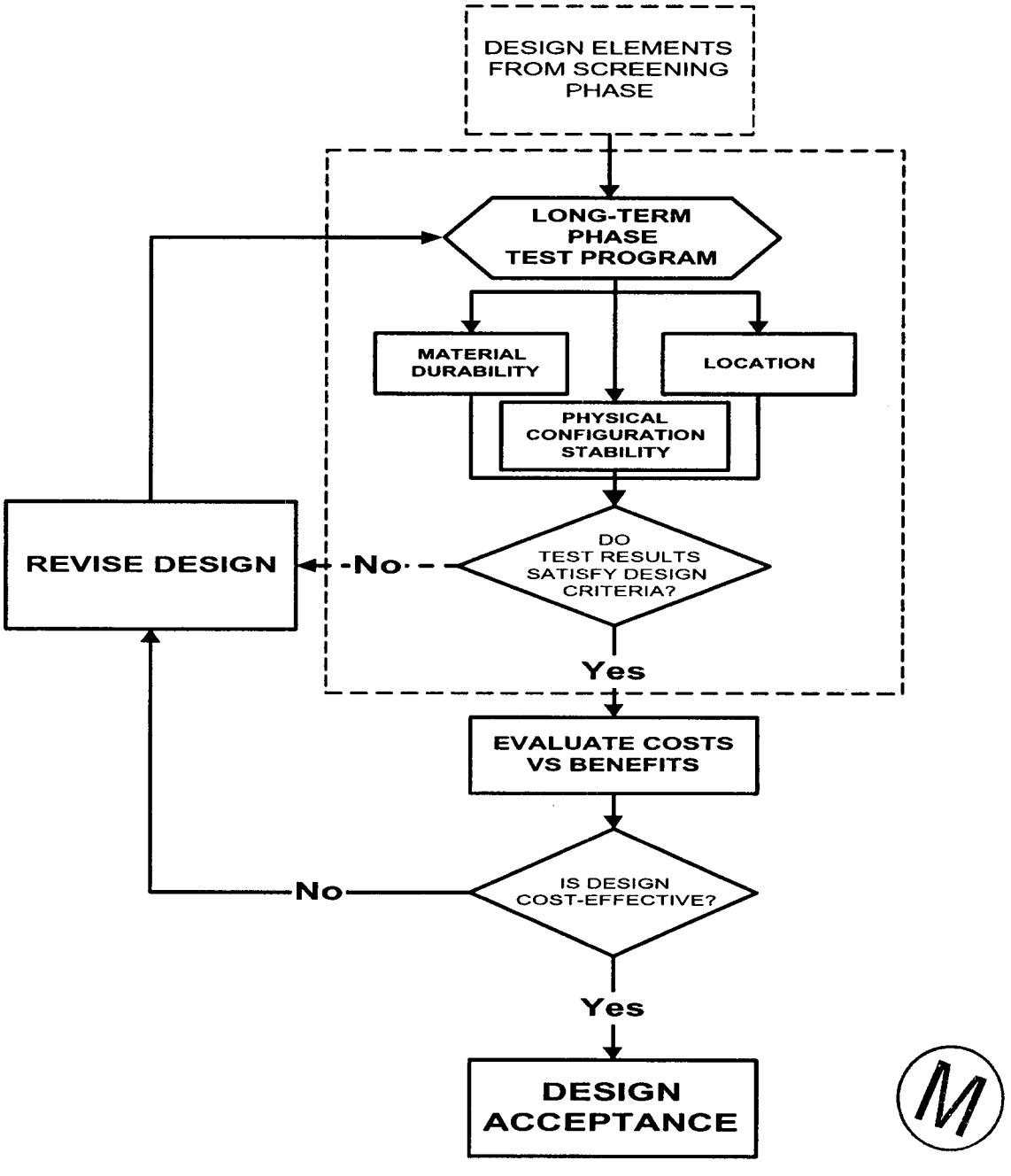

Figure 3. Long-Term Phase Testing Process

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.



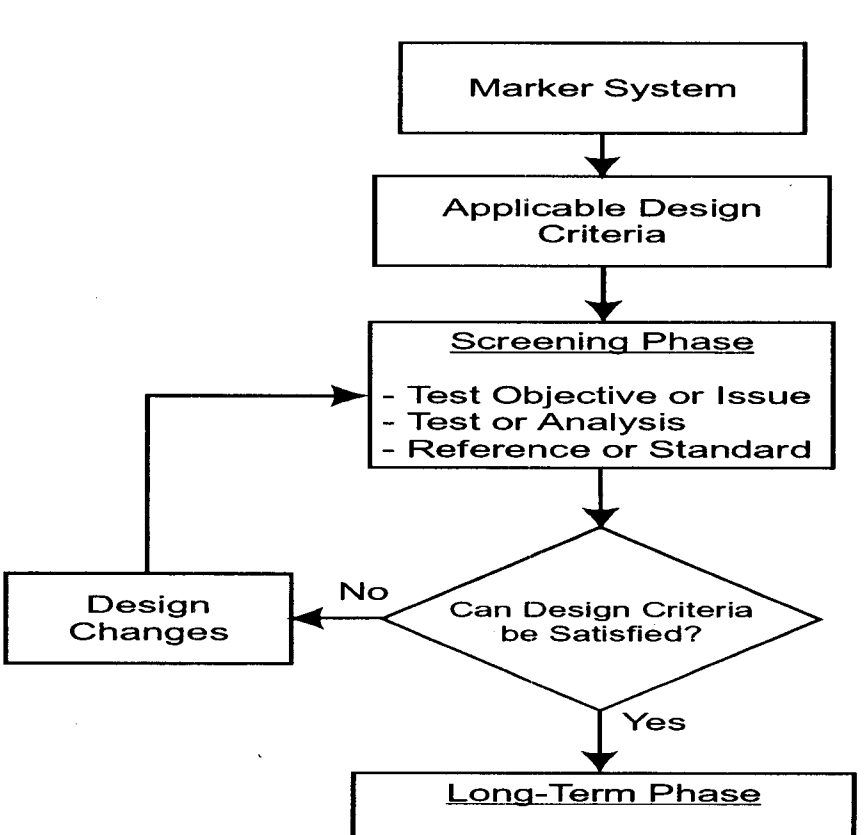

Figure 4. Tests Selection Rationale

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	*Evaluate **visibility** of single marker*	Full-scale mock-up	TO BE DEVELOPED	none		
	2a, 2b	*and of inscriptions on marker* height and shape	with inscriptions 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			Material Properties		
		*Evaluate rock properties that affect **durability**, including:*					
	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***	Measure losses in rock	prototype field demonstration
			solid particle impingement	ASTM G76	***erosion***	surface on all sides	
	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			
M		*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	TO BE DEVELOPED			
			blind excavation test	TO BE DEVELOPED	none		
		Location			Location		
	1a, 1b, 1c, 4g	*Evaluate **number and positions** of markers*	ground-penetrating radar	TO BE DEVELOPED			
			blind excavation test	TO BE DEVELOPED	none		
		Material Properties			Material Properties		
		*Evaluate rock properties that affect **durability**, including:*					
	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			
		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			
		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		
		Evaluate rock properties that affect durability, including:	granite dimension stone standards	ASTM C615	*Durability*	use results of marker and buried room prototype tests	
	4a	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			
		Evaluate rock properties that affect inscription, including:			*Inscription*	use results of marker and buried room prototype tests	
	3a	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		Material Properties			*Evaluate* ***durability***		
		Evaluate properties that affect durability, including:				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			
	4a, 4c	material stability	petrographic analysis of concrete	ASTM C856	rate of erosion	Measure losses from exposed surfaces	TO BE DEVELOPED
	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		Material Properties			*Evaluate* ***durability***		
		Evaluate properties that affect durability, including:				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		Material Properties			*Evaluate* ***durability***		
		Evaluate properties that affect ***durability****, including:*				Construct full-scale prototypes	TO BE DEVELOPED
	4a	erosion resistance	sandblast abrasion	ASTM C418		of metallic structures	
			mechanical abrasion	ASTM C779, C944		to be evaluated, then:	
			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	TO BE DEVELOPED
	4a, 4c	material stability	hardness	ASTM E3, ASTM E92, ASTM E18,		exposed surfaces	
				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		Material Properties			Material Properties		
		Evaluate properties that affect			*Continue to monitor*		
	4a, 4b, 4c	***foundation performance*** *including:*			***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	TO BE DEVELOPED	settlement and bearing failure	settlement plates at foundation	TO BE DEVELOPED
			plates at test berm foundation surface			surface and inclinometers	



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		Material Properties			Material Properties		
		Evaluate properties that affect			*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			
		Evaluate properties that affect					
	4a, 4b, 4c	***durability**:*					
		porosity	specific gravity, compacted density	ASTM D5550, D698, D1557	long-term dissolution of salt	periodic surveys of salt core using:	
		hydraulic conductivity	permeability	ASTM D2434		ground penetrating radar surveys	TO BE DEVELOPED
		solubility at field density	soluble salt content, leachability	ASTM D4542, D5744		cone penetrometer	ASTM D3441, D5778
						in-place density measurements	ASTM D5195, D6031
Caliche		Material Properties			Material Properties		
		Evaluate properties that affect			*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			
			test berm in-place density	ASTM D1556, D2922, D3017, D4564	structural failure	inclinometer deformations	TO BE DEVELOPED
		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		Material Properties			Material Properties		
		Evaluate rock properties that			*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		
		Evaluate properties that affect			*Continue to monitor test berm for:*		
	4a, 4b, 4c	***structural performance** including:*	drilling, logging, and sample collection	ASTM D1452, D1586, D1587, D2488, D6151, D6169, D4220, D420, D3550			
		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
		Evaluate properties that affect					
	4a, 4b, 4c	***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			
		Evaluate properties that affect					
	4a, 4b, 4c	***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	ASTM D5852	soil loss and rill formation	visual observations and manual measurements	NRCS and IECA procedures
			soil loss and allowable shear calc.	RUSLE, USCOE (1970)			
		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		
		Evaluate factors that affect			*Continue to monitor test berm for:*		
	4b, 4c	***structural stability:***					
		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 analysis	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			
		Evaluate factors that affect					
	4a, 4b, 4c	***erosional stability:***					
		erosional resistance	erosion resistance	ASTM D5852	erosion	visual observations and manual measurements	NRCS and IECA procedures
			soil loss and allowable shear calc.	RUSLE, USCOE (1970)			
		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			

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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

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[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.

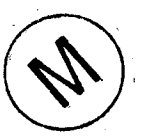
These analyses of structural and erosional stability will be used to confirm or revise the reference design of the Berm. However, they are predictive methods only. A test berm will be constructed in the field stage of the screening phase of the markers test program, after the laboratory tests of Berm 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.

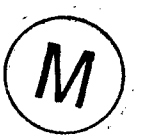
3.1.5.3.3 Material Properties

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.

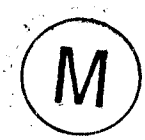
- QAPD Section 5.3.2, Data Validation. Relevant data validation requirements include:

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.



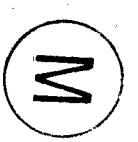
5.0 Evaluation of Testing and Analysis Results

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.



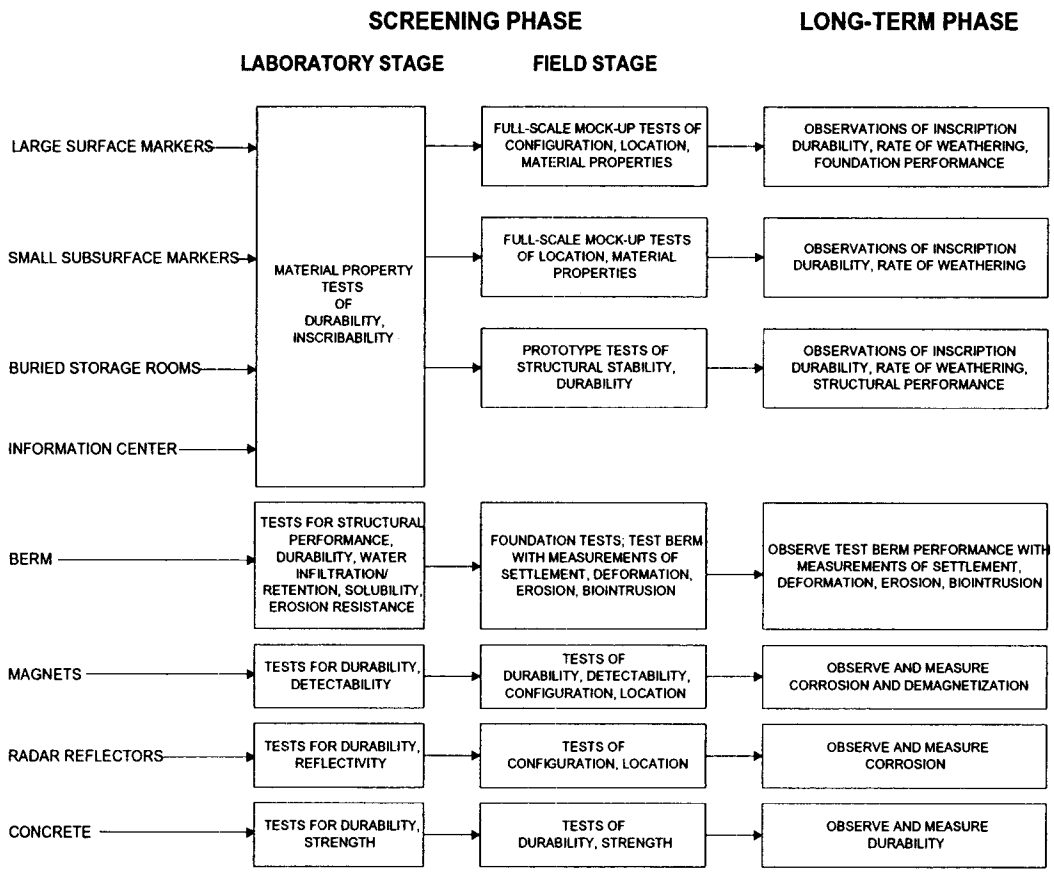


Figure 5. Permanent Markers Test Program Sequence

- 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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Appendix A

Summary Descriptions of Test Methods



Summary Descriptions of Test Methods

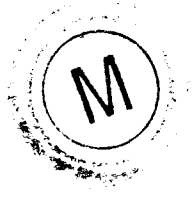
Standard No.	Name	Description
C 20	Standard Test Methods for Apparent Porosity, Water Absorption, Apparent Specific Gravity, and Bulk Density of Burned Refractory Brick and Shapes by Boiling Water	This standard describes methods to determine properties of burned refractory brick and shapes. Data generated through the use of this method may be used in quality control, research and development, and to provide data for design purposes.
C 88 - 90	Standard Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate	This test method covers the testing of aggregates to estimate their soundness when subjected to weathering action in concrete or other applications. The values obtained may be compared with specifications, for example Specification C 33, that are designed to indicate the suitability of aggregate proposed for use.
C 97 - 96	Standard Test Methods for Absorption and Bulk Specific Gravity of Dimension Stone	These test methods cover the tests for determining the absorption and bulk specific gravity of all types of dimension stone, except slate. These test methods are useful in indicating the differences in absorption between the various dimension stones. These test methods provide one element in comparing stones of the same type.
C 99 - 87	Standard Test method for Modulus of Rupture of Dimension Stone	This test method covers the determination of the modulus of rupture of all types of dimension stone except slate. This test method is useful in indicating the differences in modulus of rupture between the various dimension stones. This test method also provides one element in comparing stones of the same type.
C 119 - 93b	Standard Terminology Relating to Dimension Stone	A glossary of standard terminology.
C 127 - 88	Standard Test Method for Specific Gravity and Absorption of Coarse Aggregate	This test method covers the determination of specific gravity and absorption of coarse aggregate. Bulk specific gravity is the characteristic generally used for calculation of the volume occupied by the aggregate in various mixtures containing aggregate. Bulk specific gravity (SSD) is used if the aggregate is wet. Absorption values are used to calculate the change in the weight of an aggregate due to water absorbed in the pore spaces within the constituent particles.



Standard No.	Name	Description
C 170 - 90	Standard Test Method for Compressive Strength of Dimension Stone	This test method covers the sampling, preparation of specimens, and determination of the compressive strength of dimension stone. This test method is useful in indicating the differences in compressive strength between the various dimension stones. This test method also provides one element in comparing stones of the same type.
C 217 - 94	Standard Test Method for Weather Resistance of Slate	This test method covers two procedures for weather resistance of slate in all outdoor installations by determining the depth of softening by an abraser or by hand scraping. This test method is useful in indicating the differences in weather resistance between various slates. This test method also provides one element in the comparison of slates.
C 295 - 90	Standard Guide for Petrographic Examination of Aggregates for Concrete	This guide outlines procedures for the petrographic examination of samples representative of materials proposed for use as aggregates in concrete.
C 535 - 96	Standard Test method for Resistance to Degradation of Large-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine	This test method covers testing sizes of coarse aggregate larger than 19 mm (3/4 in.) For resistance to degradation using the Los Angeles testing machine. The test has been widely used as an indicator of the relative quality or competence of various sources of aggregate having similar mineral compositions.
C 615 - 96	Standard Specification for Granite Dimension Stone	This specification covers the material characteristics, physical requirements, and sampling appropriate to the selection of granite for general building and structural purposes.
C 805 - 97	Standard Test Method for Rebound Number of Hardened Concrete	This test method covers the determination of a rebound number of hardened concrete using a spring-driven steel hammer. This test method may be used to assess the in-place uniformity of concrete, to delineate regions in a structure of poor quality or deteriorated concrete, and to estimate in-place strength development.



Standard No.	Name	Description
C 880 - 96	Standard Test Method for Flexural Strength of Dimension Stone	This test method covers the procedure for determining the flexural strength of stone by use of a simple beam using quarter-point loading. This test method is useful in indicating the differences in flexural strength between the various dimension stones. This test method also provides one element in comparing stones of the same type.
C 1026	Standard Test Method for Measuring the Resistance of Ceramic Tile to Freeze-Thaw Cycling	This test method describes the procedures and equipment required to test either glazed or unglazed ceramic tile for resistance to repeated cycles of freezing and thawing. Ceramic tile of any size or shape may be tested by this method.
C 1161	Standard Test Method for Flexural Strength of Advanced Ceramics at Ambient Temperature	This text method covers the manner in which flexural strength of advanced ceramics at ambient temperatures is determined. Details of the testing process, including multiple point test loadings and test spans are specified.
C 1201 - 91	Standard Test Method for Structural Performance of Exterior dimension Stone Cladding Systems by Uniform Static Air Pressure Difference	This test method covers the determination of the structural performance of dimension stone cladding systems under positive and negative uniform static air pressure differences, using a test chamber. This typically is intended to represent the effects of wind loads on exterior building surface elements.
C 1353 - 96	Standard Test Method for Abrasion Resistance of Dimension Stone by the Taber Abraser	This test method covers the establishment of an index of abrasion resistance by determination of loss of weight resulting from abrasion of dimension stone. This test method is useful in indicating the differences in abrasion resistance between the various dimension stones. This test method provides one element in comparing stones of the same type.
D 420 - 93	Standard Guide to Site Characterization for Engineering, Design, and Construction Purposes	This guide refers to ASTM methods by which soil, rock, and ground water conditions may be determined.
D 421 - 85	Standard Practice for Dry Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants	This practice covers the dry preparation of soil samples as received from the field for particle-size analysis and the determination of soil constants. This practice can be used to prepare samples for particle-size and plasticity tests where it is desired to determine test values on air-dried samples, or where it is known that air drying does not have an effect on test results.



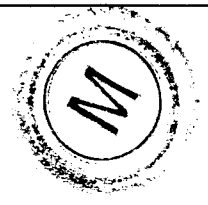
Standard No.	Name	Description
D 422 - 63	Standard Test Method for Particle-Size Analysis of Soils	This test method covers the quantitative determination of the distribution of particle sizes in soils.
D 653 - 97	Standard Terminology Relating to Soil, Rock, and Contained Fluids	A glossary of standard terminology.
D 698 - 91	Standard Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort [12,400 ft-lbf/ft^3 (600 kN-m/m^3)]	This test method covers laboratory compaction procedures used to determine the relationship between water content and dry weight of soils (compaction curve). Laboratory compaction tests provide the basis for determining the percent compaction and water content needed to achieve the required engineering properties, and for controlling construction to assure that the required compaction and water contents are achieved.
D 756	Standard Practice for Determination of Weight and Shape Changes of Plastics Under Accelerated Service Conditions	This standard defines seven different test procedures for determining weight and shape changes of plastics. The various tests prescribe a range of conditions for different types of exposure, including extremes of temperature and humidity.
D 854 - 92	Standard Test Method for Specific Gravity of Soils	This test method covers the determination of the specific gravity of soils that pass the 4.75-mm (No. 4) sieve, by means of a pycnometer. The specific gravity of a soil is used in calculating the phase relationships of soils (that is, the relative volumes of solids to water and air in a given volume of soil).
D 1140 - 97	Standard Test Method for Amount of Material in Soils Finer than the No. 200 (75-µm) Sieve	This test method covers determination of the amount of material finer than a 75-µm (No. 200) sieve by washing. Material finer than the 75µm (No. 200) sieve can be separated from larger particles much more efficiently and completely by wet sieving than through the use of dry sieving. Therefore, when accurate determinations of material finer than 75-µm in soil are desired, this test method is used on the sample prior to dry sieving.
D 1194 - 94	Standard Test Method for Bearing Capacity of Soil for Static Load and Spread Footings	This test method covers estimation of the bearing capacity of soil in place by means of field loading tests. This test method is used to estimate the bearing capacity of a soil under field loading conditions for a specific loading plate and depth of embedment.



Standard No.	Name	Description
D 1452 - 80	Standard Practice for Soil Investigation and Sampling by Auger Borings	This practice covers equipment and procedures for the use of earth augers in shallow geotechnical exploration. Auger borings often provide the simplest method of soil investigation and sampling. They may be used for any purpose where disturbed samples can be used and are valuable in connection with ground water lever determination and indication of changes in strata and advancement of hole for spoon and tube sampling.
D 1556 - 90	Standard Test method for Density and Unit Weight of Soil in Place by the Sand-Cone Method	This test method may be used to determine the in-place density and unit weight of soils using a sand cone apparatus. This test method is used to determine the density of compacted soils placed during the construction of earth embankments, road fill, and structural backfill.
D 1557 - 91	Standard Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2,700 kN-m/m^3))	This test method covers laboratory compaction procedures used to determine the relationship between water content and dry unit weight of soils (compaction curve) compacted in a 4- or 6-in. (101.6 or 152.4 mm) diameter mold with a 10-lbf. (44.5-N) rammer dropped from a height of 18 in.(457 mm) producing a compactive effort of 56,000 ft-lbf/ft^3 (2,700 kN-m/m^3). Laboratory compaction tests provide the basis for determining the percent compaction and water content needed to achieve the required engineering properties, and for controlling construction to assure that the required compaction and water contents are achieved.
D 1586 - 84	Standard Test Method for Penetration Test and Split-Barrel Sampling of Soils	This test method describes the procedure, generally known as the Standard Penetration Test (SPT), for driving a split-barrel sampler to obtain a representative soil sample and a measure of the resistance of the soil to penetration of the sampler. This test method is used extensively in a great variety of geotechnical exploration projects. Many local correlations and widely published correlations which relate SPT blowcount, or N-Value, and the engineering behavior of earthworks and foundations are available.
D 1587 - 94	Standard Practice for Thin-Walled Tube Geotechnical Sampling of Soils	This practice covers a procedure for using a thin-walled metal tube to recover relatively undisturbed soil samples suitable for laboratory tests of structural properties.



Standard No.	Name	Description
D 1883 - 94	Standard Test Method for CBR (California Bearing Ratio) of Laboratory-Compacted Soils	This test method covers the determination of the CBR (California Bearing Ratio) of pavement subgrade, subbase, and base/course materials from laboratory compacted specimens. This test method is used to evaluate the potential strength of subgrade, subbase, and base course material, including recycled materials for use in road and airfield pavements.
D 2166 - 91	Standard Test Method for Unconfined Compressive Strength of Cohesive Soil	This test method covers the determination of the unconfined compressive strength of cohesive soil in the undisturbed, remolded, or compacted condition, using strain-controlled application of the axial load. The primary purpose of the unconfined compression test is to quickly obtain the approximate compressive strength of soils that possess sufficient cohesion to permit testing in the unconfined state.
D 2168 - 90	Standard Test Methods for Calibration of Laboratory Mechanical-Rammer Soil Compactors	These test methods for the calibration of mechanical soil compactors are for use in checking and adjusting mechanical devices used in laboratory compacting of soil and soil-aggregate.
D 2216 - 92	Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock	This test method covers the laboratory determination of the water (moisture) content of soil, rock, and similar materials by mass. For many materials, the water content is one of the most significant index properties used in establishing a correlation between soil behavior and its properties.
D 2217 - 85	Standard Practice for Wet Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants	This practice covers the wet preparation of soil samples as received from the field for particle-size analysis and determination of soil constants.
D 2325 - 68	Standard Test Method for Capillary-Moisture Relationships for Coarse- and Medium- Textured Soils by Porous-Plate Apparatus	This test method covers the determination of capillary-moisture relationships for coarse- and medium-textured soils as indicated by the soil-moisture tension relations.
D 2434 - 93	Standard Test Method for Permeability of Granular Soils (Constant Head)	This test method covers the determination of the coefficient of permeability by a constant-head method for the laminar flow of water through granular soils. The procedure is to establish representative values of the coefficient of permeability of granular soils that may occur in natural deposits as placed in embankments, or when used as base courses under pavements.



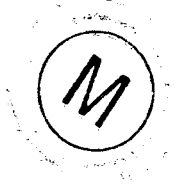
Standard No.	Name	Description
D 2435 - 96	Standard Test Method for One-Dimensional Consolidation Properties of Soils	This test method covers procedures for determining the magnitude and rate of consolidation of soil when it is restrained laterally and drained axially while subjected to incrementally applied controlled-stress loading. The data from the consolidation test are used to estimate the magnitude and rate of both differential and total settlement of a structure or earthfill. Estimates of this type are of key importance in the design of engineered structures and the evaluation of their performance.
D 2487 - 93	Standard Classification of Soils for Engineering Purposes	This standard describes a system for classifying mineral and organo-mineral soils for engineering purposes based on laboratory determination of particle-size characteristics, liquid limit, and plasticity index and shall be used when precise classification is required. This standard classifies soils from any geographic location into categories representing the results of prescribed laboratory tests to determine the particle-size characteristics, the liquid limit, and the plasticity index.
D 2488 - 93	Standard Practice for Description and Identification of Soils (Visual-Manual Procedure)	This practice covers procedures for the description of soils for engineering purposes.
D 2573 - 94	Standard Test Method for Field Vane Shear Test in Cohesive Soil	This test method covers the field vane test in soft, saturated, cohesive soils. This test method provides an indication of in-situ shear strength. This test method is used extensively in a variety of geotechnical explorations, such as in cases where a sample for laboratory testing cannot be obtained.
D 2583	Standard Test Method for Indentation hardness of Rigid Plastics by Means of a Barcol Impressor	This test method covers the determination of indentation hardness of both reinforced and nonreinforced rigid plastics using a Barcol Impressor, Model No. 934-1 and Model No. 935.
D 2922 - 96	Standard Test Methods for Density of Soil and Soil-Aggregate in Place by Nuclear Methods (Shallow Depth)	These test methods cover the determination of the total or wet density of soil and soil-rock mixtures by the attenuation of gamma radiation where the source and detector(s) remain on the surface (Backscatter Method) or the source or detector is placed at a known depth up to 300 mm (12 in.) While the detector(s) or source remains on the surface (Direct Transmission Method). The test methods described are useful as rapid nondestructive techniques for the in-place determination of density of soil and rock.



Standard No.	Name	Description
D 2937 - 94	Standard Test Method for Density of Soil in Place by the Drive-Cylinder Method	This test method covers the determination of in-place density of soil by the drive-cylinder method. This test method can be used to determine the in-place density of natural, inorganic soils which do not contain significant amounts of particles coarser than 4.75 mm, and which can be readily retained in the drive cylinder.
D 2938 - 95	Standard Test Method for Unconfined Compressive Strength of Intact Rock Core Specimens	This test method specifies the apparatus, instrumentation, and procedures for determining unconfined compressive strength of intact rock core specimens. Unconfined compressive strength of rock is used in many design formulas and is sometimes used as an index property to select the appropriate excavation technique.
D 3017 - 96	Standard Test Method for Water Content of Soil and Rock in Place by Nuclear Methods (Shallow Depth)	This test method covers the determination of water content of soil and rock by the thermalization or slowing of fast neutrons where the neutron source and the thermal neutron detector both remain a the surface. The test method described is useful as a rapid, nondestructive technique for the in-place determination of water content of soil and rock.
D 3152 - 72	Standard Test Method for Capillary-Moisture Relationships for Fine-Textured Soils by Pressure-Membrane Apparatus	This test method covers the determination of capillary-moisture properties of fine-textured soils as indicated by the moisture content -moisture tension relationships determined by pressure-membrane apparatus using tensions between 1 and 15 atm (101 and 1520 kPa). The test result is a moisture content which is a measure of the water retained in the soil subjected to a given soil - water tension (or at an approximately equivalent height above the water table).
D 3385 - 94	Standard test Method for Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer	This test method describes a procedure for field measurement of the rate of infiltration of liquid (typically water) into soils using double-ring infiltrometer. This test method is useful for field measurement of the infiltration rate of soils.
D 3402 - 93	Standard Test Method for Tumbler Test for Coke	This test method describes a procedure for obtaining a relative measure of the resistance to degradation of coke by impact and abrasion.



Standard No.	Name	Description
D 3441 - 94	Standard Test Method for Deep, Quasi-Static, Cone and Friction-Cone Penetration Tests of Soils	This test method covers the determination of end bearing and side friction, the components of penetration resistance which are developed during the steady slow penetration of a pointed rod into soil. This test method supplies data on the engineering properties of soil intended to help with the design and construction of earthworks and the foundations for structures.
D 3550 - 84	Standard Practice for Ring-Lined Barrel Sampling of Soils	This practice covers a procedure for using a ring-lined barrel sampler to obtain representative samples of soil for identification purposes and other laboratory tests. This practice is used where soil condition and resistance to advance of the sampler do not permit the use of a thin-wall tube.
D 3740 - 96	Standard Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction	This practice establishes minimum qualifications for agencies engaged in the testing and inspection of soil and rock. The intent of this practice is to provide a consensus basis for evaluating a testing or inspection agency, or both, with respect to that agency's capability to objectively and competently provide the specific services needed by the user.
D 3967 - 95	Standard Test Method for Splitting Tensile Strength of Intact Rock core Specimens	This test method covers testing apparatus, specimen preparation, and testing procedures for determining the splitting tensile strength of rock by diametral line compression of a disk. By definition the tensile strength is obtained by the direct uniaxial tensile test. But the tensile test is difficult and expensive for routine application. The splitting tensile test appears to offer a desirable alternative, because it is much simpler and inexpensive.
D 4219 - 93	Standard Test Method for Unconfined Compressive Strength Index of Chemical Grouted Soils	This test method covers the determination of the short-term unconfined compressive strength index of chemically grouted soils, using strain-controlled application of test load. The purpose of this test method is to obtain values for comparison with other test values to verify uniformity of materials or the effects of controllable variables, in grout-soil compositions.



Standard No.	Name	Description
D 4141	Standard Practice for Conducting Accelerated Outdoor Exposure Tests of Coatings	This practice covers three accelerated outdoor exposure procedures for evaluating the exterior durability of coatings applied to metal substrates. The three procedures are: (1) Procedure A -Black Box Exposure; (2) Procedure B -Heated Black Box Exposure; and (3) Procedure C -Fresnel Reflector Rack Exposure. The acceleration of degradation rates of coatings produced by the three procedures of exposure are discussed.
D 4220 - 95	Standard Practices for Preserving and Transporting Soil Samples	These practices cover procedures for preserving soil samples immediately after they are obtained in the field and accompanying procedures for transporting and handling the samples.
D 4221 - 90	Standard Test Method for Dispersive Characteristics of Clay Soil by Double Hydrometer.	This test method, when used in conjunction with a test performed by method D 422 on a duplicate soil sample, provides an indication of the natural dispersive characteristics of clay soils. Dispersive clays are those which normally deflocculate when exposed to water of low-salt content, the opposite of aggregated clays that would remain flocculated in the same soil-water system. Generally, dispersive clays are highly erosive, possible subject to high shrink-swell potential, may have lower shear strength, and have lower permeability rates than aggregated clays.
D 4253 - 93	Standard Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table	These test methods cover the determination of the maximum index density/unit weight of cohesionless, free-draining soils using a vertically vibrating table. For many cohesionless, free-draining soils, the maximum index density/unit weight is one of the key components in evaluating the state of compactness of a given soil mass that is either naturally occurring or placed by man (fill).
D 4254 - 91	Standard Test method for Minimum Index Density and Unit Weight of Soils and Calculations of Relative Density	These test methods cover the determination of the minimum index density/unit weight of cohesionless, free-draining soils. The density/unit weight of a cohesionless soil may be determined by various in-place methods in the field or by the measurement of physical dimensions and masses by laboratory soil specimens.



Standard No.	Name	Description
D 4318 - 95	Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils	This test method covers the determination of the liquid, plastic limit, and the plasticity index of soils. This test method is used as ain integral part of several engineering classification systems to characterize the fine-grained fractions of soils and to specify the fine-grained fraction of construction materials.
D 4364	Standard Practice for Performing Accelerated Outdoor Weathering of Plastics Using Concentrated Natural Sunlight	This standard method describes the use of reflecting concentrators that use the sun as a source of ultraviolet and longer wavelength radiation to accelerate the effects of outdoor weathering of plastics.
D 4429 - 93	Standard Test Method for CBR (California Bearing Ratio) of Soils in Place	This test method covers the determination of the California Bearing Ratio (CBR) of soil tested in place by comparing the penetration load of the soil to that of a standard material. Field in-place CBR tests are used for evaluation and design of flexible pavement components such as base and subbase course and subgrades and for other applications (such as unsurfaced roads) for which CBR is the desired strength parameter.
D 4542 - 95	Standard Test Method for Pore Water Extraction and Determination of the Soluble Salt Content of Soils by Refractometer	This test method covers a rapid procedure for squeezing pore water from fine-grained soils for the purpose of determining the amount of soluble salts present in the extracted pore water. The soluble salt content may be used to correct the index properties of soils (water content, void ration, specific gravity, degree of saturation and dry density).
D 4546 - 96	Standard Test Methods for One-Dimensional Swell or Settlement Potential of Cohesive Soils	These test methods cover three alternative laboratory methods for determining the magnitude of swell or settlement of relatively undisturbed or compacted cohesive soil. The relative swell/settlement potential of soil determined from these test methods can be used to develop estimates of heave or settlement for given final moisture and loading conditions.
D 4647 - 93	Standard Test Method for Identification and Classification of Dispersive Clay Soils by the Pinhole Test	This test method presents a direct, qualitative measurement of the dispersibililty and consequent colloidal erodibility of clay soils by causing water to flow through a small hole punched in a specimen. The pinhole test provides one method of identifying the dispersive characteristics of clay soils that are to be or have been used in earth construction.



Standard No.	Name	Description
D 4829 - 95	Standard Test Method for Expansion Index of Soils	This test method provides an index to the expansion potential of compacted soils when inundated with distilled water. The expansion index, EI, is used to measure a basic index property of soil and therefore the EI is comparable to other indices such as the liquid limit, plastic limit, and plasticity index of soils, as in Test Method D 4813.
D 4992 - 94	Standard Practice for Evaluation of Rock to be Used for Erosion Control	This practice covers the evaluation of rock to be used for erosion control. The field examination and petrographic examination in this practice along with appropriate laboratory testing may be used to determine the suitability of rock for erosion control.
D 5030 - 89	Standard Test Method for Density of Soil and Rock in Place by the Water Replacement Method in a Test Pit	This test method covers the determination of the in-place density and unit weight of soil and rock using water to fill a lined test pit to determine the volume of the test pit. This test method is used to determine the in-place unit weight of compacted materials in construction of earth embankments, road fills, and structure backfill.
D 5121 - 90	Standard Practice for Preparation of Rock Slabs for Durability Testing	This practice covers the preparation of rock slabs for various tests used to evaluate any visual internal defects, or the durability of rock by means of laboratory tests.
D 5195 - 91	Standard Test Method for Density of Soil and Rock In-Place at Depths Below the Surface by Nuclear Methods	This test method is useful as a rapid, nondestructive technique for the calculation of the in-place density of soil and rock at desired depths below the surface as opposed to surface measurements. With proper calibration in accordance with Annex A1 this test method can be used for quality control and acceptance testing for construction and for research and development applications.
D 5220 - 92	Standard Test Method for Water Content of Soil and Rock In-Place by the Neutron Depth Probe Method	This test method covers the calculation of the water content of soil and rock by thermalization or slowing of fast neutrons where the neutron source and the thermal neutron detector are places at the desired depth in the bored hole lined by an access tube. This test method is useful as a rapid, nondestructive technique for the calculation of the in-place water content of soil and rock at desired depths below the surface.



Standard No.	Name	Description
D 5240 - 92	Standard Test method for Testing Rock Slabs to Evaluate Soundness of Riprap by Use of Sodium or Magnesium Sulfate	This test method covers test procedures for evaluating the soundness of riprap by the effects of a sodium or magnesium sulfate solution on slabs of rock. The sodium sulfate or magnesium sulfate soundness test is one method by which to estimate qualitatively the durability of rock under weathering conditions.
D 5255 - 97	Standard Practice for Certification of Personnel Engaged in the Testing of Soil and Rock	This practice provides a guide for evaluation and certification procedures for personnel engaged in testing soil and rock in accordance with ASTM test methods and is intended for use by independent organizations providing certification services.
D 5312 - 92	Standard Test Method for Evaluation of Durability of Rock for Erosion Control Under Freezing and Thawing Conditions	This test method covers the procedures for evaluating the durability of rock for erosion control when exposed to freezing and thawing conditions. This test method is designed to determine the effects of freezing and thawing action on the individual pieces of rock for erosion control and the resistance of the rock to deterioration.
D 5313 - 92	Standard Test Method for Evaluation of Durability of Rock for Erosion Control Under Wetting and Drying Conditions.	This test method covers procedures for evaluating the durability of rock for erosion control when exposed to wetting and drying conditions. This test method is designed to determine the effects on the individual pieces of rock for erosion control of wetting and drying action and the resistance of the rock to deterioration.
D 5333 - 92	Standard Test Method for Measurement of Collapse Potential of Soils	This test method covers the determination of the magnitude of one-dimensional collapse that occurs when unsaturated soils are inundated with fluid. This test method may be used to determine the magnitude of potential collapse that may occur for a given vertical (axial) stress and an index for rating the potential for collapse. Predicting collapse potential is important to the design of many engineering structures.
D 5434 - 93	Standard Guide for Field Logging of Subsurface Explorations of Soil and Rock	This guide describes the type of information that should be recorded during filed subsurface explorations in soil and rock.



Standard No.	Name	Description
D 5522 - 94	Standard Specification for Minimum Requirements for Laboratories Engaged in Chemical Analysis of Soil, Rock, and Contained Fluid	This specification covers specific criteria for evaluating the technical capabilities of laboratories involved in testing, measuring, inspecting, and calibrating activities related to chemical analysis of earth materials.
D 5550 - 94	Standard Test Method for Specific Gravity of Soil Solids by Gas Pycnometer	This test method covers the determination of the specific gravity of soil solids by means of a gas pycnometer. The specific gravity value is used in many phase relation equations to determine relative volumes of particle, water, and gas mixtures.
D 5730 - 96	Standard Guide for Site Characterization for Environmental Purposes With Emphasis on Soil, Rock, the Vadose Zone and Ground Water	This guide covers a general approach to planning field investigations that is useful for any type of environmental investigation with a primary focus on the subsurface and major factors affecting the surface and subsurface environment.
D 5731 - 95	Standard Test Method for Determination of the Point Load Strength Index of Rock	This test method covers the guidelines, requirements, and procedures for determining the point load strength index of rock. The point load strength test is used as an index test for strength classification of rock materials.
D 5744 - 96	Standard Test Method for Accelerated Weathering of Solid Materials Using a Modified Humidity Cell	This test method covers a procedure that accelerates the natural weathering rate of a solid material sample so the diagnostic weathering products can be produced, collected, and quantified. The purpose of this accelerated weathering procedure is to determine the following: (1) whether a solid material will produce and acidic, alkaline, or neutral effluent, (2) whether that effluent will contain diagnostic cations (including trace metals) and anions that represent solublized weathering products formed during a specified period of time, and (3) the rate at which these diagnostic cations and anions will be released (from the solids in the effluent).
D 5778 - 95	Standard Test Method for Performing Electronic Friction Cone and Piezocone Penetration Testing of Soils	This test method covers the procedure for determining the resistance to penetration of a conical pointed penetrometer as it is advanced into subsurface soils at a slow, steady rate. Tests performed using this test method provide a detailed record of cone resistance which is useful for evaluation of site stratigraphy, homogeneity and depth to firm layers, voids or cavities, and other discontinuities.



Standard No.	Name	Description
D 5779 95	Standard Test Method for Field Determination of Apparent Specific Gravity of Rock and Manmade Materials for Erosion Control	This test method covers the determination of the specific gravity of rock for erosion control. This test method can be used for all types of materials, both naturally occurring or manmade. Specific gravity is one factor used to determine the required mass of individual particles used as gabion-fill, riprap, armor stone, breakwater stone, or other types of rock products used for erosion control applications, and acceptability of these materials for their intended use.
D 5852 - 95	Standard Test Method for Erodibility Determination of Soil in the Field or in the Laboratory by the Jet Index Method	This test method covers the estimation of erodibility of a soil by a jet index method. Erosion potential of a soil is of concern in vegetated channels, road embankments, dams, levees, spillways, construction sites, etc.. The jet index method is intended to provide a standard method of expressing erosion resistance; to assist those who work with different soils and soil conditions to measure erosion resistance for design purposes; and to provide a common system of characterizing soil properties to develop performance and prediction relationships.
D 6031 - 96	Standard Test Method for Logging In Situ Moisture Content and Density of Soil and Rock By the Nuclear Method in Horizontal, Slanted, and Vertical Access Tubes	This test method covers collection and comparison of logs of thermalized-neutron counts and back-scattered gamma counts along horizontal or vertical air-filled access tubes. This test method is useful as a repeatable, nondestructive technique to monitor in-place density and moisture of soil and rock along lengthy sections of horizontal, slanted, and vertical access holes or tubes.
D 6151 - 97	Standard Practice for Using Hollow-Stem Augers for Geotechnical Exploration and Soil Sampling	This practice covers how to obtain soil samples using hollow-stem sampling systems and use of hollow-stem auger drilling methods for geotechnical exploration.
D 6169 - 97	Standard Guide for Selection of Soil and Rock Sampling Devices Used With Drill Rigs for Environmental Investigations	This guide covers guidance for the selection of soil and rock sampling devices used with drill rigs for the purpose of characterizing in situ physical and hydraulic properties, chemical characteristics, subsurface lithology, stratigraphy and structure, and hydrogeologic units in environmental investigations.



Standard No.	Name	Description
E 3	Standard Methods of Preparation of Metallographic Specimens	This standard provides guidance in the preparation of metal and metal alloy samples for examination, primarily by use of the light microscope.
E 8	Standard Methods of Tension Testing of Metallic Materials	This standard specifies methods for tension testing of metallic materials in any form at room temperature to determine yield strength, yield point elongation, tensile strength, elongation, and reduction of area.
E 9	Standard Methods of Compression Testing of Metallic Materials at Room Temperature	These test methods cover the apparatus, specimens, and procedure for axial-load compression testing of metallic materials at room temperature.
E 18	Standard Test Method for Rockwell Hardness Measurement of Metallic Materials	This standard describes methods for the determination of Rockwell hardness and the Rockwell superficial hardness of metallic materials, including test methods for the verification of machines for Rockwell hardness testing and the calibration of standardized hardness test blocks.
E 23	Standard Methods for Notched Bar Impact (Charpy Impact) Testing of Materials	This standard method is for notched-bar impact testing of metallic materials by the Charpy (simple-beam) test and the Izod (cantilever-beam) test. Test requirements are specified for test specimens, procedures, reports, machines, and other aspects of the procedure.
E 92	Standard Test Method for Vickers Measurement of Metallic Materials	This method covers the determination of Vickers hardness of metallic materials, using applied forces of 1 kgf to 120 kgf, the verification of Vickers hardness testing machines, and the calibration of test blocks.
E 140	Standard Hardness Conversion Tables	Conversion tables are provided defining the relationship among various measures of hardness including Rockwell C, Brinell, Vickers, Knoop, and Scleroscope.
G 7	Standard Practice for Atmospheric Environmental Exposure Testing of Nonmetallic Materials	This practice covers procedures to be followed for direct exposure of nonmetallic materials to the environment.
G 50	Standard Practice for Conducting Atmospheric Corrosion Tests on Metals	This standard defines conditions and general procedures for exposure of metals and alloys to the weather for testing.
G 73	Standard Practice for Liquid Impingement Erosion Testing	This standard specified testing methods in which solid specimens are eroded or otherwise damaged by repeated discrete impacts of liquid drops or jets.



Standard No.	Name	Description
G 76	Standard Practice for Conducting Erosion Tests by Solid Particle Impingement Using Gas Jets	This standard specifies methods for the determination of material loss by gas-entrained solid particle impingement erosion with jet nozzle type erosion equipment.
G 90	Standard Practice for Performing Accelerated Outdoor Weathering of Nonmetallic Materials Using Concentrated Natural Sunlight	This practice covers a procedure for performing accelerated outdoor exposure testing of nonmetallic materials using a Fresnel-reflector accelerated outdoor weathering test machine. The apparatus and guidelines are described to minimize the variables encountered during outdoor accelerated exposure testing.



DOE F 1325.8

United States Government **Department of Energy**

memorandum

Carlsbad Field Office
Carlsbad, New Mexico 88221

DATE: 16 MAY 2002

REPLY TO ATTN OF: CBFO:NTP:KWW:VW:02-2535:UFC:5400

SUBJECT: Approval of RFETS Procedure PRO-945-WIPP-009

TO: Lam Xuan, DOE-RFFO

The Carlsbad Field Office (CBFO) has reviewed the following procedures for changes that affect data quality PRO-945-WIPP-009, Rev. 5 *RCRA Characterization of TRU Waste to be Disposed of at WIPP*. The CBFO has determined that the revision is acceptable and meets the requirements of the Hazardous Waste Facility Permit "Waste Analysis Plan" issued on November 27, 2001.

If you have any questions, please call me at (505) 234-7374.

Reinhard M. Knerr
National TRU Waste Certification Team Leader

Attachment

cc: w/attachment
G. O'Leary, RFETS
C. Ferrera, RFETS
J. Cotton, WTS
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S. Calvert, CTAC
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CBFO Mailroom

0203002

MAY 17 2002

CARLSBAD FIELD OFFICE

DOCUMENT REVIEW RECORD

SITE: RFETS

DOCUMENT TITLE: RCRA Characterization of TRU Waste TO BE Disposed Of At WIPP

DOCUMENT NUMBER/REVISION PRO-945-WIPP-009, Rev. 5, DCF-CHG-04 (3/19/02)

DOCUMENT DATE: For Approval

TYPE OF REVIEW: Technical and QA

ASSIGNED REVIEWER: Kerry Watson and Ava Holland DELEGATED REVIEWER: RSI and CTAC

ADDITIONAL INSTRUCTIONS:

FORWARD RESPONSE TO: Site.Documents@wipp.ws

#	PAGE	SECTION/ PARA	COMMENT	RESPONSE	ACC	REJ
1.	1		Add DCF-CHG-04 to "IMPORTANT NOTES" (CR)	No. In the IMPORTANT NOTES section, the DCFs being referred to are the DCFs that were associated with the previous revision of the procedure (i.e., revision 4). Refer to the bottom of page 2 for the DCFs that are effective for the current revision (i.e., revision 5) of the procedure and you will see DCF-CHG-04 listed there.	✓	
2.	10	6.1.1 [2]	Delete the reference to Appendix 3 since there is no text or example on this page. (MD)	Appendix 3 was inadvertently omitted from the electronic document sent to you. Appendix 3 is attached to these responses for your review.	✓	
3.	11		Fig. 6.1. It appears the arrow is pointing the wrong way at the "Proceed to next analyte" box. (MD)	Correct. The arrow has been reversed.	✓	
4.	12	6.1.1. [3]	There is no worksheet at Appendix 3, identify where to get the worksheet. Cannot review this section without the worksheet to know what is being done. (MD)	Appendix 3 was inadvertently omitted from the electronic document sent to you. Appendix 3 is attached to these responses for your review.	✓	
5.		6.1.1	Waste stream hazardous determinations cannot be made on a container basis. AK is confirmed using the UCL_{90} of a set of samples. It is not correct to revise waste stream designations based on a single headspace gas sample. (See B4-3d) Based on what is written in this section, this section needs to be deleted. (MD)	Section revised to address comment. Title of Figure 6-1 and Appendix 3 changed to reflect distinction of identification rather than confirmation of EPA HWNs. ~~B4-3d states: "If the confirmatory process determines that the~~	✓	

DOCUMENT REVIEW RECORD (continuation)

Title:	Doc No: PRO-945-WIPP-009	Rev: R5	Reviewer:

#	PAGE	SECTION/ PARA	COMMENT	RESPONSE	ACC	REJ
				~~source of the F-listed constituent is a spent solvent used in the process or is determined to be the result of mixing a listed waste with a solid waste during waste packaging, or applicable toxicity characteristic or non-toxic F003 wastes are present in excess of regulatory levels, then the site will either: 1) assign the applicable listed hazardous waste code to the entire waste stream, or 2) segregate the drums containing detectable concentrations of the solvent into a separate waste stream and assign applicable hazardous waste codes." Section 6.1.1 is the procedure we use to segregate individual drums with detectable concentrations of spent solvent constituents into a separate waste stream.~~		
6.	13	6.1.2	This section needs to include calculations for reduced sampling also. (MD)	Reduced headspace gas sampling is covered in section 6.1.3. Without additional information, it is unclear as to why this section needs to include calculations for reduced sampling..	✓	
7.	13	6.1.2 [1]	Once the gases have been composited, there is no way to separate the gases, the only option is to analyze the original samples if they are still available. Revise the note. (MD)	Reworded to say: "In these cases, the original samples used to prepare the composite sample may be recomposited into smaller composite samples for analysis, or the original samples may be analyzed individually in order to isolate and segregate the specific sample(s) that contain the elevated analyte(s)."	✓	
8.	13	6.1.2	Delete this step, this segregation must occur as part	Certainly waste	✓	

DOCUMENT REVIEW RECORD (continuation)

Title:	Doc No: PRO-94S-WIPP-009	Rev: Rev.5	Reviewer:

#	PAGE	SECTION/ PARA	COMMENT	RESPONSE	ACC	REJ
		[2]	of the AK process long before headspace gas samples are even collected. (MD)	containers are assigned to individual waste streams by AK well before this step. However, you need to read this step in relation to step [1]. In step [1] we have performed headspace gas sampling and analysis on a certain number of containers. Step [2] is merely stating that we will then segregate those containers headspace gas sampled into waste stream lots for further statistical evaluation by this procedure.		
9.	13	6.1.2 [2]	Include "A composited sample is treated as one sample for the purposes of completeness, because only one sample is run through the analytical instrument." Revise the reference to B3-5. (MD)	Added.	✓	
10.	15	6.1.2	NOTE 1, revise "guidance" to "requirements". (MD)	Revised.	✓	
11.	15	6.1.2	Note 3 is not clear. As written, this is not specified in the WAP. If MDL>PRQL means the sample was diluted, this step is correct. If it means the system cannot resolve concentrations below the PRQL, you have a different problem and the analysis cannot be used to certify waste. (MD)	Rewrite Note 3 to read: "Analysis results flagged as "U" but showing an elevated MDL (reported as MDL greater than the PRQL) due to sample dilution should not be used in calculating the mean concentration."	✓	
12.	15	6.1.2 [4]	Specify that U-flagged data must be used as ½ the MDL. (MD)	Append the following note to section 6.1.2 [4]: "NOTE Per Section B4-3d of the WIPP-WAP, 'U'-flagged data shall be replaced with a value equal to one-half the reported MDL in calculating the mean concentration. Other substitutions, if statistically justified, may also be used and reported in addition to the treatment directed by the WIPP-WAP."	✓	
13.	15	6.1.2 [6]	Revise to read "...greater than the PRQL." (MD)	Changed.	✓	
14.	15	6.1.2 [8]	Revise to read "...in accordance with the equations in Attachment B2 of the WIPP-WAP." (Otherwise this one line would be all a procedure would need to	Make the recommended wording change and append the following	✓	

DOCUMENT REVIEW RECORD (continuation)

Title:	Doc No: PRO-GS-WIPP-009	Rev: R5	Reviewer:

#	PAGE	SECTION/ PARA	COMMENT	RESPONSE	ACC	REJ
			say.) (MD)	note to Section 6.1.2 [8]: "NOTE Alternative calculation approaches, if statistically justified, may also be used and reported in addition to the treatment directed by the WIPP-WAP."		
15.	16	6.1.2 [13]	Revise the THEN actions, no HWNs will be modified at this point, you need to perform the AK reevaluation first to determine what the correct action will be. (MD)	Revised to read "THEN document any potential modifications of EPA HWNs.."	✓	
16.	16 the 2nd		There are two page 16s. (MD)	Fixed	✓	
17.	16	6.1.3 [2]	In the NOTE, revise "guidance" to "requirements". (MD)	Revised.	✓	
18.	16	6.1.3 [3]	Specify how to make the random selection. (MD)	Append the following note to Section 6.1.3 [3]: NOTE "Per Section B2-2a of the WIPP-WAP, random selection shall be performed in such a manner as to provide an unbiased estimate of true mean contaminant concentrations in the waste stream. This requires that all potential sample units in the waste stream have equal or approximately equal probability of selection. To ensure this is so, an objective random selection method, such as available in commercial statistical software packages, shall be employed and documented as directed in Section 6.1.3 [4] below."	✓	
19.	16	6.1.3 [7]	Specify to make the calculations in accordance with the equations in Attachment B2-2b of the WIPP-WAP. (MD)	Add the words "... in accordance with the equations cited in Attachment B2 of the WIPP-WAP." and append the following note to Section 6.1.3 [7]: "NOTE Alternative calculation approaches, if statistically justified, may also be used and	✓	

DOCUMENT REVIEW RECORD (continuation)

Title:	Doc No: PRO-94-WIPP-004	Rev: R5	Reviewer:

#	PAGE	SECTION/ PARA	COMMENT	RESPONSE	ACC	REJ
				reported in addition to the treatment directed by the WIPP-WAP."		
20.	16	6.1.3 [8]	Require the statistician to perform the verification calculation from B2-3b and then proceed with the "IF the highest..." (MD)	Insert new Section 6.1.3 [8] preceding the Section addressed by this comment and renumber following sections accordingly: New section 6.1.3 [8] to read: " [8] Compare the required number of samples calculated in accordance with Section B2-3b of the WIPP-WAP with the actual number of samples taken."	✓	
21.	19	6.1.3	In the NOTE, revise "guidance" to "requirements". (MD)	Revised.	✓	
22.	19	6.1.3	Note 3 is not clear. As written, this is not specified in the WAP. If MDL>PRQL means the sample was diluted, this step is correct. If it means the system cannot resolve concentrations below the PRQL, you have a different problem and the analysis cannot be used to certify waste. (MD)	Rewrite Note 3 to read: "Analysis results flagged as "U" but showing an elevated MDL (reported as MDL greater than the PRQL) due to sample dilution should not be used in calculating the mean concentration."	✓	
23.	19	6.1.3 [9]	Specify that U-flagged data must be used as ½ the MDL. (MD)	Add note to section 6.1.3 [9] as follows: "NOTE: Per Section B4-3d of the WIPP-WAP, 'U'-flagged data shall be replaced with a value equal to one-half the reported MDL in calculating the mean concentration. Other substitutions, if statistically justified, may also be used and reported in addition to the treatment directed by the WIPP-WAP."	✓	
24.	19	6.1.3 [11]	Revise to read "...greater than the PRQL." (MD)	Revised.	✓	
25.	19	6.1.3 [13]	Revise to read "...in accordance with the equations in Attachment B2 of the WIPP-WAP." (MD)	Add the words "... in accordance with the equations cited in Attachment B2 of the WIPP-WAP." and append the following note to Section 6.1.3 [13]: "NOTE Alternative	✓	

DOCUMENT REVIEW RECORD (continuation)

Title:	Doc No: PPO-94S-WIPP-001	Rev: P5	Reviewer:

#	PAGE	SECTION/ PARA	COMMENT	RESPONSE	ACC	REJ
				calculation approaches, if statistically justified, may also be used and reported in addition to the treatment directed by the WIPP-WAP."		
26.	20	6.1.3 [14], [16], [17] & [18]	Headspace gas is compared to the PRQL, revise accordingly. (MD)	Revised.	✓	
27.	23	6.2[3]	Revise "guidance" to "requirements". (MD)	Revised.	✓	
28.	23	6.2[4]	This direction needs to reflect that once step 8 provides a random number of samples, these are the preliminary samples and you return to step 2. (MD)	You cannot proceed from step [2] with just the sample selection from step [8]. Step [8] provides no data in and of itself. Steps [5] though [7] are only required when there is preliminary data. If there is not, then the initial sample size is determined in step [3] based on the minimum size defined procedurally by the WIPP-WAP and the adequacy of this number is verified in step [21] based upon the data obtained from the samples identified in steps [8] through [10].	✓	
~~1.~~29.	24	6.2[8]	Specify the methodology that is to be used to do the random selection. State how it is done to assign containers and to select sampling locations inside the container. (MD)	Append the following note to Section 6.2 [8]: NOTE: "Per Section B2-2a of the WIPP-WAP, random selection shall be performed in such a manner as to provide an unbiased estimate of true mean contaminant concentrations in the waste stream. This requires that all potential sample units in of the waste stream, including specific sampling locations (e.g., within-core and/or inner container sampling locations), have approximately equal probability of selection. To ensure this is so, an	✓	

DOCUMENT REVIEW RECORD (continuation)

Title:	Doc No: PRO-905-WIM-009	Rev: B5	Reviewer:

#	PAGE	SECTION/ PARA	COMMENT	RESPONSE	ACC	REJ
				objective random selection method, such as available in commercial statistical software packages, shall be employed and documented as directed in Section 6.2 [10] below." To be more specific than this would require specification of all possible methods of selection in detail or designation of a single method which could prove to be potentially inappropriate under the actual circumstances involved. As long as the statistician selects a method that meets the above requirements and is properly documented for review, there should be no need to limit the process to a single narrowly defined approach.		
~~2.~~30.	25	6.2	In NOTE 1, revise "guidance" to "requirements". (MD)	Revised.	✓	
~~3.~~31.	25	6.2	Note 2 is not clear. As written, this is not specified in the WAP. If MDL>PRQL means the sample was diluted, this step is correct. If it means the system cannot resolve concentrations below the PRQL, you have a different problem and the analysis cannot be used to certify waste. (MD)	Rewrite Note 2 to read: "Analysis results flagged as "U" but showing an elevated MDL (reported as MDL greater than the PRQL) due to sample dilution should not be used in calculating the mean concentration."	✓	
~~4.~~32.	25	6.2 [13]	Specify that U-flagged data must be used as ½ the MDL. (MD)	This requirement is stated in the WIPP-WAP only for VOC data. However, such blanket substitution is statistically contra-indicated in many if not most cases. It may be justified under some limited circumstances and could still be accommodated as follows: Add note to section 6.2 [13]: "NOTE As a minimum, 'U'-	✓	

DOCUMENT REVIEW RECORD (continuation)

Title:	Doc No: PRO-945-WIPP-009 R5	Rev:	Reviewer: M

#	PAGE	SECTION/ PARA	COMMENT	RESPONSE	ACC	REJ
				flagged data shall be replaced with a value equal to one-half the reported MDL in calculating the mean concentration. Other substitutions, if statistically justified, may also be used and reported in addition to the treatment directed by the WIPP-WAP."		
~~5.~~33.	26	6.2[29]	Revise this step, no HWNs will be modified at this point, you need to perform the AK reevaluation first to determine what the correct action will be. (MD)	Revised to read "document any potential changes to the EPA HWNs.."	✓	
~~6.~~34.	27	6.3[1] [B]	The initial site rate will always be 11%. Clarify that once you have done the 50, you will calculate the site-miscertification rate. (MD)	The site miscertification rate is calculated in procedure WIPP-010. Step [B] here just tells the person performing the procedure to obtain this initial miscertification rate from procedure WIPP-010.	✓	
~~7.~~35.	27	6.3[2]	Clarify if WIPP-010 performs the drum-weighted average calculation or just identifies the number of miscertifications. Delete this step or reconcile it with step 5. It is either redundant to [B] or out of place according to 5. Specify what to do with that number (go do VE) before you recalculate the SCG-specific rate 6 months later. (MD)	~~Step [2] states to obtain the reassessed annual site-specific miscertification rate that was prepared in accordance with WIPP-010.~~Section 6.3 has been rewritten to clarify the sequence of operations.	✓	
~~8.~~36.	27	6.3[4]	You can't annually use something initially. Revise this step to state what to do initially, and then what to do annually. (MD) W	~~Step 6.3[1] describes how to proceed initially. The word "initially" has been replaced with the word" assigned" in the step.~~Section 6.3 has been rewritten to clarify the sequence of operations.	✓	
~~9.~~37.	28	6.3[9] & [10]	The number of containers was already identified by the SPM. The WAP gives no guidance on how to select the containers, it only says to randomly select that number from the population. This procedure needs to specify how that random selection is to be performed. (MD)	Section 6.3 has been rewritten to clarify the sequence of operations. ~~Change the first word in Section 6.3 [9] to read "Confirm..." vice "Determine" and append~~ the following note added to clarify random	✓	

DOCUMENT REVIEW RECORD (continuation)

Title:	Doc No: PRO-945-WIPP-009	Rev: R5	Reviewer:

#	PAGE	SECTION/ PARA	COMMENT	RESPONSE	ACC	REJ
				selection. ~~to Section 6.3 [10].~~ "NOTE: Random selection shall be performed in such a manner as to provide an unbiased estimate of the true miscertification rate for the Summary Category Group. This requires that all containers in of the Summary Category Group inventory have approximately equal probability of selection. To ensure this is so, an objective random selection method, such as available in commercial statistical software packages, shall be employed and documented as directed in Section 6.~~2~~3 [~~10~~GO] below."		
~~10.~~38	29	6.3[15]	This is a nonconforming condition since the WAP does not allow for replacements. State so. (MD) M	It certainly may be a nonconforming condition, but we have had several instances where a container selected for visual examination was later assayed or reassayed and determined to be low level waste. This is not considered a nonconforming condition, the container is simply reclassified as low level waste and dropped from the VE selection population.	✓	
~~11.~~39	30	6.4	In the NOTE, revise "guidance" to requirements. (MD)	Revised	✓	
~~12.~~40	33	8	Change the HWFP reference from "Carlsbad Area Office" to "Carlsbad Field Office". (CR)	Changed	✓	

COMMENT RESOLUTION APPROVED:

Signature

5/16/02
Date

DOE F 1325.8

United States Government **Department of Energy**

memorandum

Carlsbad Field Office
Carlsbad, New Mexico 88221

DATE:

REPLY TO ATTN OF: CBFO:NTP:KWW:VW:02-2535:UFC:5400

SUBJECT: Approval of RFETS Procedure PRO-945-WIPP-009

TO: Lam Xuan, DOE-RFFO

The Carlsbad Field Office (CBFO) has reviewed the following procedures for changes that affect data quality PRO-945-WIPP-009, Rev. 5 *RCRA Characterization of TRU Waste to be Disposed of at WIPP*. The CBFO has determined that the revision is acceptable and meets the requirements of the Hazardous Waste Facility Permit "Waste Analysis Plan" issued on November 27, 2001.

If you have any questions, please call me at (505) 234-7374.

Reinhard M. Knerr
National TRU Waste Certification Team Leader

Attachment

cc: w/attachment
G. O'Leary, RFETS
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CORSPDNCE ID
CBFO:NTP:RMK
CORSPDNCE/UFC #
02-2535:UFC:5400
CONCURRENCE
RTG. SYMBOL
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Department of Energy
Carlsbad Field Office
P. O. Box 3090
Carlsbad, New Mexico 88221

May 20, 2002

MAIL ROOM COPY

Mr. Frank Marcinowski
Office of Radiation and Indoor Air
U.S. Environmental Protection Agency
401 M. Street, S.W.
Washington, DC 20460

Dear Mr. Marcinowski:

This purpose of this letter is to inform the Environmental Protection Agency (EPA) of our plan to mine a ventilation overcast in the Waste Isolation Pilot Plant underground. The overcast will be constructed at the intersection of S-3080 (Panel 3 access drift) and E-300 (the exhaust drift). This mining is planned during construction of the Panel 3 access drifts, currently scheduled in the February 2003 timeframe.

These overcasts are routinely used where the access (intake) drift of a panel crosses E-300 (exhaust) in order to prevent mixing of disposal circuit intake air with the exhaust air-stream. Each overcast involves a small excavation above the access drift to contain exhaust ductwork. In the case of Panels 1 and 2, the ventilation overcast excavation extended up to or near Clay Seam G. For Panels 3 and 4, which have the roof at Clay Seam G, it is planned to excavate up to or near Clay Seam H for the overcast. These overcasts are quite short, with a typical excavated length of approximately 60 feet to accommodate the overcast and allow for a smooth airflow transition (see enclosed).

As part of our routine ground control program, we have found it desirable to excavate the roof up to and including Clay Seam G. This provides the most stable conditions. We provided a discussion and photographs of such ground control mining up to Clay Seam G in E-140 between S-1950 and S-2580 at our June 28-29, 2000 meeting.

This configuration provides good ground conditions and adequate ventilation for the protection of workers. We believe this change is insignificant in terms of long-term performance. Moreover, it involves a level of detail of repository geometry that is too fine to be effectively incorporated in the models used in Performance Assessment (PA) or to influence the results from PA.

We will incorporate the mining of the ventilation overcasts in the upcoming Annual Change Report. If you have any questions about this matter, please contact Mr. Daryl Mercer at (505) 234-7452.

Sincerely,

Lawrence D. Dailey for

Dr. Inés R. Triay
Manager

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MAY 2 0 2002

CBFO:ORC:DDM:VW:02-1119:UFC:5400

Enclosure

cc: w/enclosure
L. Smith, HQ
B. Lilly, CBFO
C. Zvonar, CBFO
E. Rose, CBFO
J. Plum, CBFO
D. Mercer, CBFO
B. Forinash, EPA-ORIA
C. Byrum, EPA, Region VI
N. Stone, EPA, Region VI
J. Bearzi, NMED
S. Zappe, NMED
M. Silva, EEG
J. Lee, WTS
S. Kouba, WTS
P. Shoemaker, SNL

CBFO:ORC:DDM:VW:02-1119:UFC:5400

bcc: w/o enclosure
W. Root, WTS
S. Casey, WTS



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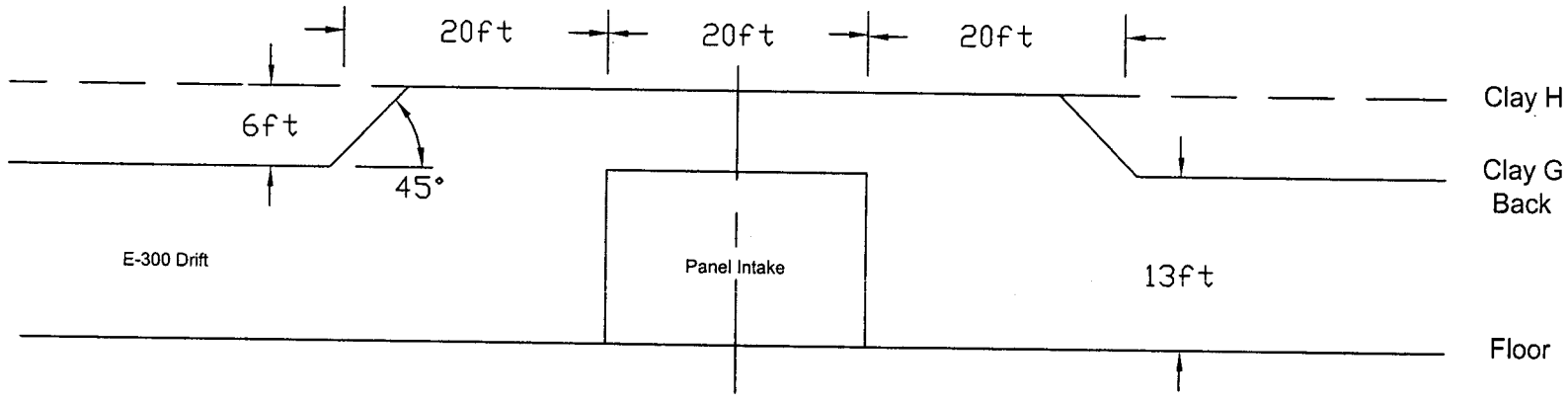

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Typical Overcast Profile

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Department of Energy
Carlsbad Field Office
P. O. Box 3090
Carlsbad, New Mexico 88221

Mr. Frank Marcinowski
Office of Radiation and Indoor Air
U.S. Environmental Protection Agency
401 M. Street, S.W.
Washington, DC 20460

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~~As you know, we sometimes find it desirable~~, ~~as~~ A part of our routine ground control program, we have found it desirable to excavate the roof up to and including Clay Seam G, ~~in order to~~ this provide the most stable conditions. We provided a discussion and photographs of such ground control mining up to Clay Seam G in E-140 between S-1950 and S-2580 ~~in a presentation at an EPA working meeting on June 28-29, 2000 here in Carlsbad.~~ at our June 28-29, 2000 meeting.

This configuration provides good ground conditions and adequate ventilation for the protection of workers. We believe the change is insignificant in terms of long-term performance, ~~and~~ Moreover, it involves a level of detail of repository geometry that is too fine to be effectively incorporated in the models used in Performance Assessment (PA) or to influence the results from PA.

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Sincerely,

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