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REMEDIAL DESIGN/ REMEDIAL ACTION

PROJECT WORK PLANS

Martin Marietta Reduction Facility
The Dalles, Oregon

GERAGHTY
& MILLER, INC.
Environmental Services

GERAGHTY & MILLER
ENGINEERS, INC.

SAP
June 30, 1989

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Department of Environmental Quality

SAMPLING AND ANALYSIS PLAN

Martin Marietta Reduction Facility
Remedial Design/Remedial Action Program

Prepared for:

MARTIN MARIETTA CORPORATION
The Dalles, Oregon

Prepared by:

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July, 1989

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1.0 INTRODUCTION

The purpose of the Sampling and Analysis Plan (SAP) is to provide input data to the Remedial Design (RD) process through the use of field investigations and sample collection and analyses, such that various parameters for the selected remedial action are designed to meet performance criteria. The remedial action consists primarily of site civil work and unit treatment process evaluation.

Site civil elements include the collection and geotechnical analysis of material in the Scrubber Sludge Ponds; the identification, classification, and geotechnical testing of local borrow areas for general fill and fine-grained cohesive soils; laboratory testing of bentonite amended soils; verification sampling trenches in the Salvage, Bath Recovery Pad, and the Unloading Areas for the purpose of verifying the lateral extent of areas to be excavated; and the general earthwork activities required to define the alignment and required construction effort for various design elements.

Unit process elements described within this SAP include a performance analysis of the cyanide destruction system and a bench study for the design of fluoride removal processes. The fluoride removal study will be conducted after the remedial action has been implemented, in the event that Northwest Aluminum ceases in-plant treatment.

2.0 SITE CIVIL EVALUATIONS

Site civil evaluations will provide geotechnical and other data necessary to layout, design and construct structures based on performance requirements. The site civil evaluations will consist of the following activities:

- Borrow source investigation;
- Borehole investigations; and
- Trench investigations.

As part of the borrow source investigations, bench scale laboratory evaluations of bentonite-amended soil will be performed. Borehole investigations address subsurface explorations and physical laboratory program to characterize the materials in the Scrubber Sludge Ponds. Trench excavations will be performed in the Landfill and Cathode Waste Management Areas to identify physical data needs for design as well as trench excavation for the purpose of verifying the required lateral extent of excavation in the Salvage, Bath Recovery Pad and Unloading Areas.

2.1 BORROW SOURCE INVESTIGATION

Several different construction materials will be required to meet design and performance standards for the various activities in the RD/RA. The basic construction materials available in The Dalles region consist of clayey silt soils, sands, gravels, and crushed rock. These materials will be used for structural and general fill, the soil barrier layer, drainage, and erosion protection and control. Additionally, the clayey silt soils will be used for construction of the low-permeable layer as part of the final cover over the Landfill. Three potential borrow areas containing clayey silt soil types have been identified and will be referred to as the Zutes, Brown's Creek and Clay Mountain areas. These three sources of clayey silt have been preliminarily evaluated by Wyo-Ben, Inc. (WyoBen) for soil amendment capabilities (Appendix A). Additionally, a number of local sand and gravel pits will be identified and evaluated. The specific sources will be selected by the field engineer.

The objective of the borrow source investigation is to evaluate the lateral and vertical extent of the borrow areas to estimate whether the material quantities available will meet or exceed the preliminary construction quantity estimate. Additional physical properties of the materials will be evaluated as described below.

2.1.1 Investigation Methodology

Test pits will be excavated at each of the selected clayey silt borrow areas by a backhoe, or available equipment, to obtain samples and to determine depths of adequate material. Approximately 4 test pits for every acre of ground surface will be conducted, with 10 test pits per source anticipated. Each test pit will be excavated to the depth practicable with available equipment (approximately 12 feet) by the backhoe. Test personnel are not permitted to enter the test pits nor can they stand any closer than two feet from the open excavation. All test pits will be backfilled at the completion of testing.

Sampling at each test pit will be based upon the soil stratum present. One sample will be taken from each stratum that is visually and physically distinct. Samples will also be taken from any cuts or open faces (greater than 5 feet vertical extent), at a frequency of one sample for every 200 linear feet of face. The field engineer observing the excavation of the test pits will determine the specific number of pits and record information pertinent to location and subsurface conditions (such as relative moisture content, the presence of organic materials, colors, textures, and gradations).

Local sources of pit run gravel, sand, and crusher run rock also will be investigated. Approximately three random samples from each source will be obtained for testing. Samples from sources of clayey silts and granular material will be placed in plastic-lined 5-gallon containers. Each sample will be sealed and labeled with borrow source, test-pit location, depth of sample and any other relevant information. The samples will be sealed and stored in a dry, cool place until testing is conducted.

2.1.2 <u>Laboratory Testing</u>

The laboratory testing will be accomplished on a phased approach. Phase 1 will consist of classifying borrow source materials using Atterberg Limits and particle-size analysis. Phase 2 will evaluate base line standard moisture-density relationships and permeability for each borrow area. Phase 3 will evaluate amended soil moisture-density relationships and permeability for each borrow area. Table 2-1 summarizes the borrow area investigation testing program and details are

TABLE 2-1

Laboratory Tests for Borrow Source Investigation
Sampling and Analysis Plan
Martin Marietta Reduction Facility
The Dalles, Oregon

Phase/ Test Method	Zutes	Browns Creek	Clay Mountain	Sand, Gravel and Rock Sources	Anticipated Maximum Number of Tests(1)
Phase 1					
Moisture (ASTM D-2216)	20	20	20	NA	60
Atterberg Limits (ASTM D-4318)	20	20	20	NA	60
Sieve(2) (ASTM D-422)	10	10	10	9	39
Phase 2					
Sieve(2) (ASTM D-422)	2	2	2	NA	6
Moisture(3) (ASTM D-2216)	2	2	2	NA	6
Moisture-Density(4) Relationship (ASTM D-698)	2	2	2	NA	6
Permeability(4) (ASTM D-2434 or EM 1110-2-1906 USCE Appendix VII)	6	6	6	NA	18
Phase 3					
Moisture-Density(5) Relationship (ASTM D-698)	2	2	2	NA	6
Permeability(5) (ASTM D-2434 or EM 1110-2-1906 USCE Appendix VII)	6	6	6	NA	18

TABLE 2-1
(Continued)

Laboratory Tests for Borrow Source Investigation
Sampling and Analysis Plan
Martin Marietta Reduction Facility
The Dalles, Oregon

Notes:

(1) Based on 10 test pits per site, 2 strata per test pit and one sample from each strata.

(2) Fines passing a #200 sieve will be analyzed using hydrometer.

(3) To determine initial soil moisture content of natural soils composited by laboratory.

(4) Analyses to be performed on natural soils composited by laboratory.

(5) Analyses to be performed on natural soils composited by laboratory and amended with bentonite.

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presented below. Any modifications to collection methods or methods of analysis will be in accordance with the provisions of the QAPP.

2.1.2.1 Phase 1 - Borrow Classification

The clayey silt soils from each borrow area will be classified in accordance with the Unified Soil Classification System by employing the Atterberg limit test, moisture content and particle-size analysis using U.S. Standard Sieves. This will be accomplished for each stratum sample obtained based on visual observations at each test pit. The results will assist in determining whether or not visually distinct soils are of similar classification. Similar materials will be composited for additional testing in the later phases.

Atterberg Limits will be performed on all samples to provide physical information pertaining to the plastic and liquid limits of the clayey silts, which will determine the classification and uniformity of the material over the proposed borrow area. Approximately 50 percent of the clayey silt samples per stratum for each borrow area will be selected at random for particle-size distributions utilizing the following sieves: #4, #10, #40, #100, and #200, with a hydrometer analysis performed on material passing the #200 sieve.

Each of the three samples obtained from the granular aggregate borrow areas will have grain-size distributions obtained utilizing the following sieves: 3-inch, 1-inch, 1/2-inch, 3/8-inch, #4, #10, #40, #100, and #200. However, adjustment to the sieve sizes may be required by the geotechnical laboratory.

2.1.2.2 Phase 2 - Baseline Geotechnical

For each similar stratum, four to six 5-gallon samples will be selected and composited. This will attempt to simulate material mixes delivered to the site during construction. A sieve analysis will be performed on the composited samples and hydrometers will be used to determine distribution of clay sized particles. Initial moisture contents and moisture-density relationships will be determined for each stratum and for each borrow area. Once the optimum moisture and density is determined for each stratum, three samples will be compacted to 95 percent of optimal density with moisture content ranging from optimal to plus three percent of optimal and permeabilities will be determined.

At the conclusion of Phase 2, data obtained from both Phases 1 and 2 will be forwarded to WyoBen for review along with small physical samples from the laboratory composited soil sample. Upon completion of the review, WyoBen will make a recommendation as to the type and amount of bentonite admixture used. Additionally, samples of bentonite will be forwarded to the geotechnical laboratory to conduct Phase 3 of the testing.

2.1.2.3 Phase 3 - Soil Amendment

Using the recommendation from WyoBen, bentonite will be mixed with the composited soil for each stratum from each borrow area. The soil/bentonite mixtures will have a moisture-density relationship determined. Once the optimum moisture and density has been determined, three samples will be compacted to 95 percent of optimal density with a moisture content between optimal and plus three percent of optimal and permeabilities will be determined.

2.1.3 Borrow Source Investigation Report

A report summarizing the applicability of each of the borrow sources areas will be prepared and submitted with the final design documentation. Laboratory test data will be discussed as to the appropriateness of each borrow source to be utilized as various components in site civil work. Permeability of recompacted and bentonite amended soils will be presented with a borrow area recommendation and bentonite amendment to meet performance criteria.

2.2 BOREHOLE INVESTIGATION

The borehole investigation will focus on the Scrubber Sludge Ponds. The data requirements for the Scrubber Sludge Ponds (SSP) include the probing of the pond areas to estimate the relative thickness of sludge deposits and the use of consolidation testing to estimate surface settlement once the cover is in place.

2.2.1 Investigation Methodology

Information obtained during the RI indicates that sludge deposits in Scrubber Sludge Pond No. 2 (SSP2) are approximately 2 feet in thickness, and underlain by basalt.

SSP3 has sludge thicknesses in excess of 6 feet and is underlain by native soils. Since the sludges in SSP2 are thin, the borehole investigation in the Scrubber Sludge Ponds will be limited to SSP3. The pond areas will be probed in a grid-like manner to verify the depth and uniformity of sludge deposits.

Three sampling locations will be selected by the field engineer in the general locations illustrated in Figure 2-1. The depth to basalt will be recorded in the field sampling log. Because of potential concerns with the stability of the sludge materials, sampling will be performed using hand sampling methods. Both disturbed and undisturbed sampling methods will be employed. A bucket type auger will be used to advance the hole downward. Disturbed sludge and soil samples will be retained from the top 6 inches and every feet thereafter until basalt is encountered. Two samples will be sealed in containers for moisture content determination. An undisturbed sample will be obtained from each stratum (sludge and subsoil) at approximately 4 to 6 feet below the surface of the sludge and at approximately 2 feet below the sludge/ soil interface. Undisturbed samples will be obtained by using a thin-walled Shelby tube or equivalent sampler, and will either be pushed by hand or driven by a drop hammer or tripod sampling device. Upon removal, the Shelby tube will be sealed to prevent moisture loss and transported to the geotechnical laboratory for one dimensional consolidation and classification testing. For each relatively undisturbed sample, moisture content, Atterberg Limits, particle-size analysis and consolidation tests will be performed.

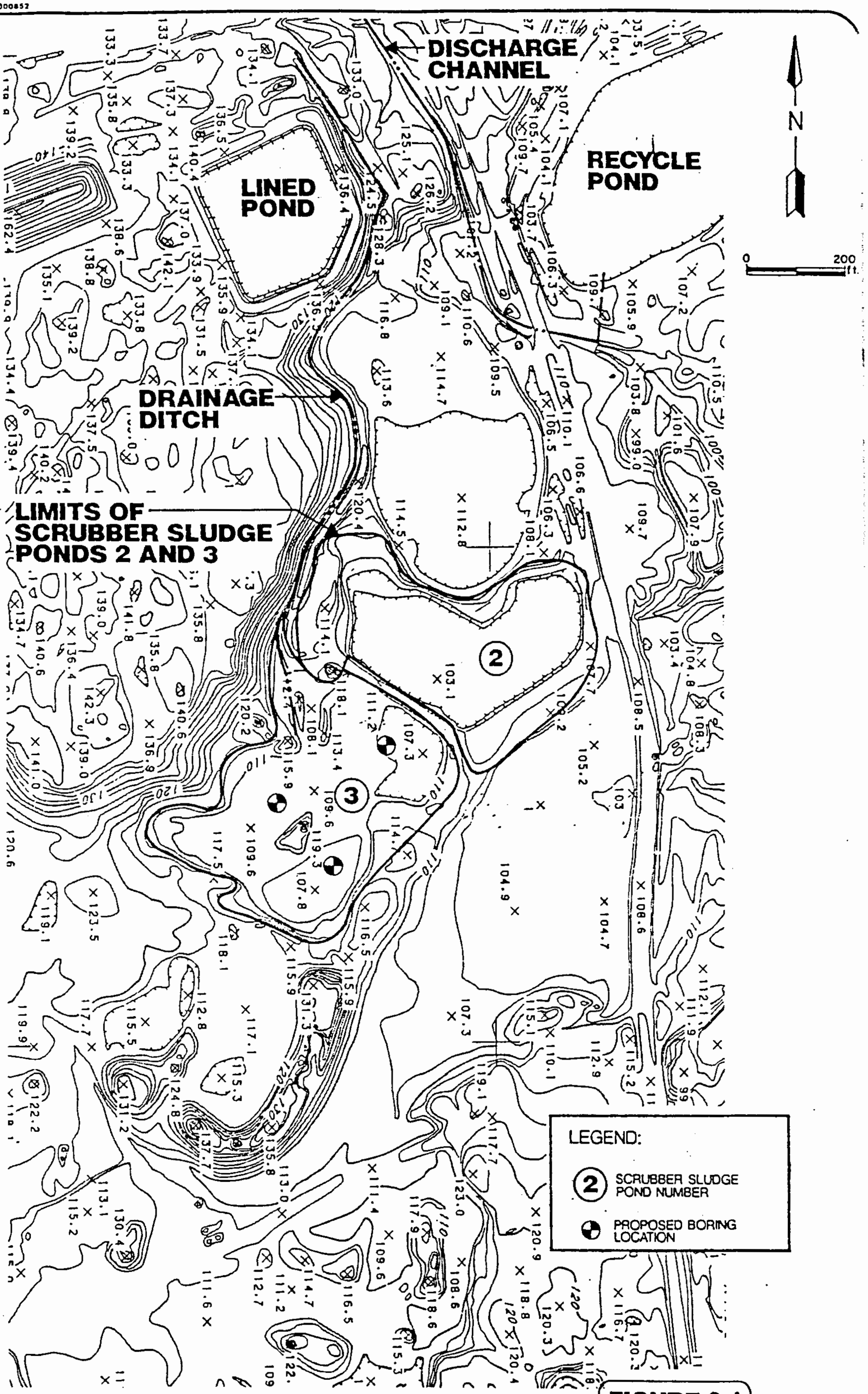

FIGURE 2-1

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DRAWN BY: V.P.	DATE: 2-17-89
CHECKED: DWM	DATE: 3-6-89
APPROVED: TCC	DATE: 3/6/89

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SAMPLING LOCATIONS
SCRUBBER SLUDGE PONDS

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2.2.2 Laboratory Testing

The samples obtained from SSP3 will be analyzed for the parameters identified in Table 2-2. The sample collection method and testing requirements may require modifications based on field conditions. Any modifications to collection methods or methods of analysis will be in accordance with the provisions of the QAPP.

2.2.3 Borehole Investigation Report

The results of the investigation at SSP3 will be evaluated and submitted with the final design documentation.

2.3 TRENCH INVESTIGATION

Test trenches and pits will be excavated in the Cathode Waste Management Areas and in the existing Landfill. These investigations will provide physical information on the verification of material volumes for excavation and consolidation, the elevation and occurrence of perched water, and basalt surface condition and topography. This investigation will result in data or information needed for general layout and design of the leachate collection system and the excavation program for the CWMAs.

2.3.1 Investigation Methodology

Test pits and trenching will be accomplished using a backhoe capable of establishing the depth to competent basalt. Proposed test pit and trench locations are presented in Figure 2-2. Each pit or trench will be visually

TABLE 2-2

MMRF SAP
June 30, 1989

Geotechnical Investigation Test Methods
Sampling and Analysis Plan
Martin Marietta Reduction Facility
The Dalles, Oregon

Investigation Area	Test Method	Description	Anticipated Number of Tests
Scrubber Sludge Pond 3	ASTM D 2216	Moisture Content	24
	ASTM D 2435	One-dimensional Consolidation	6
	ASTM D 4318	Atterberg Limits	6
	ASTM D 422	Particle Size	6

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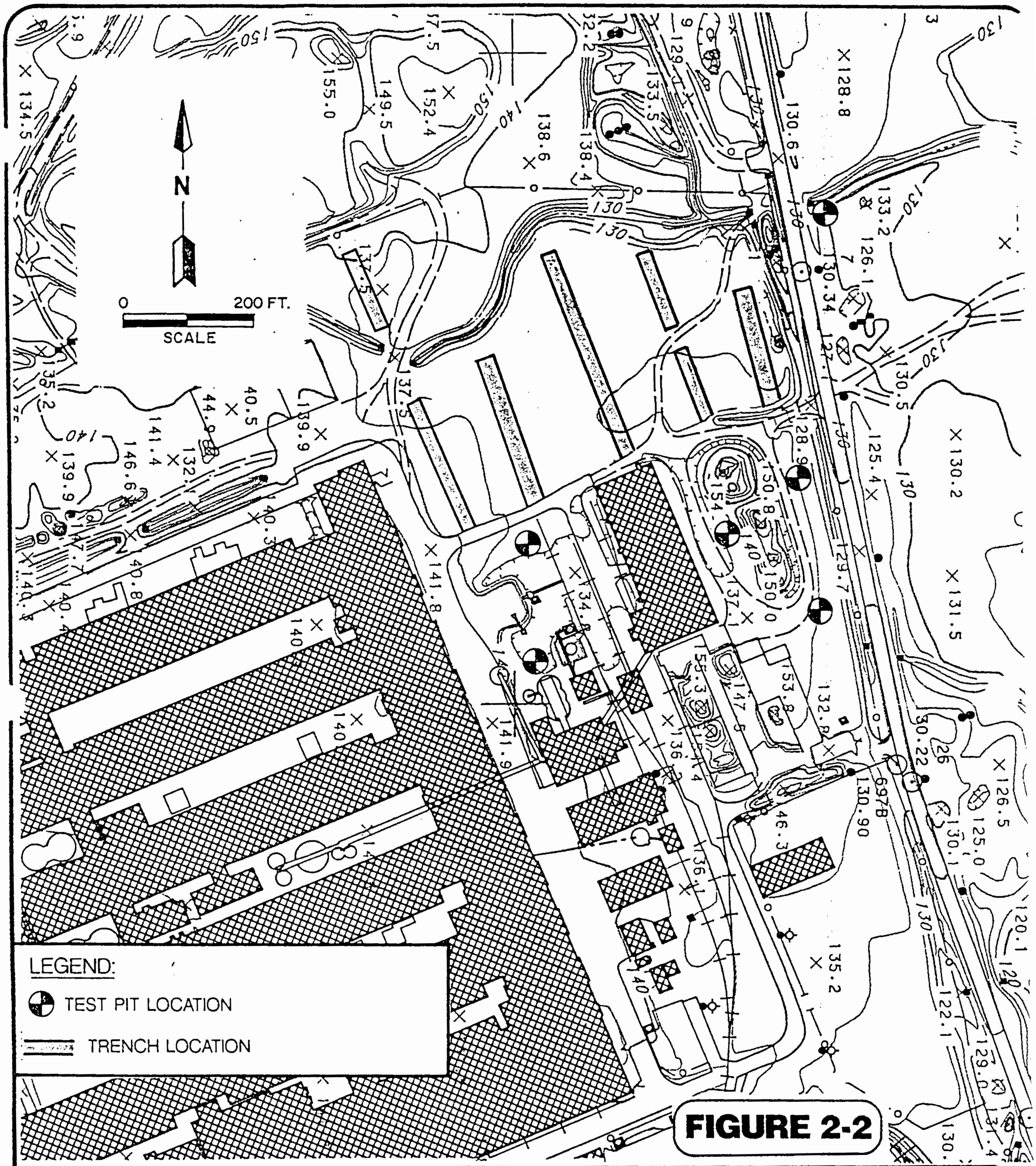

LEGEND:

● TEST PIT LOCATION

▨ TRENCH LOCATION

FIGURE 2-2

DRAWING NO:
FL0018-RD2-A08

DRAWN BY:	DATE:
KEN CARROLL	3-2-89
CHECKED: DWM	DATE: 3-6-89
APPROVED: DCC	DATE: 3/6/89

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PROPOSED TEST PIT AND TRENCH LOCATIONS

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inspected and photographed during excavation and the information logged into the field notes. Depth to basalt and perched water (if present) will be recorded. The pits will be left open for observation.

The trench around the Landfill will be excavated in the general alignment identified for the leachate collection system. The preliminary alignment of the trench is displayed on Figure 2-3. The actual trenching location may be modified based on field conditions prior to initiating activities. Alignment will be determined by the field engineer. Trench excavations will be left open for surveying of the basalt elevations along the proposed leachate collection system. The field engineer will record visual observations regarding overburden and general condition of the underlying basalt.

2.3.2 Laboratory Testing

At this time, laboratory testing is not proposed.

2.3.3 Trench Investigation Report

The trench investigation report will include field logs, photos, reduced survey data and interpretation of information, as required, and will be submitted with the final design documentation.

2.4 VERIFICATION SAMPLING TRENCHES

Verification sampling to determine the lateral and vertical extent of contaminated areas is a requirement of the site remediation. The limits of remediation (as identified

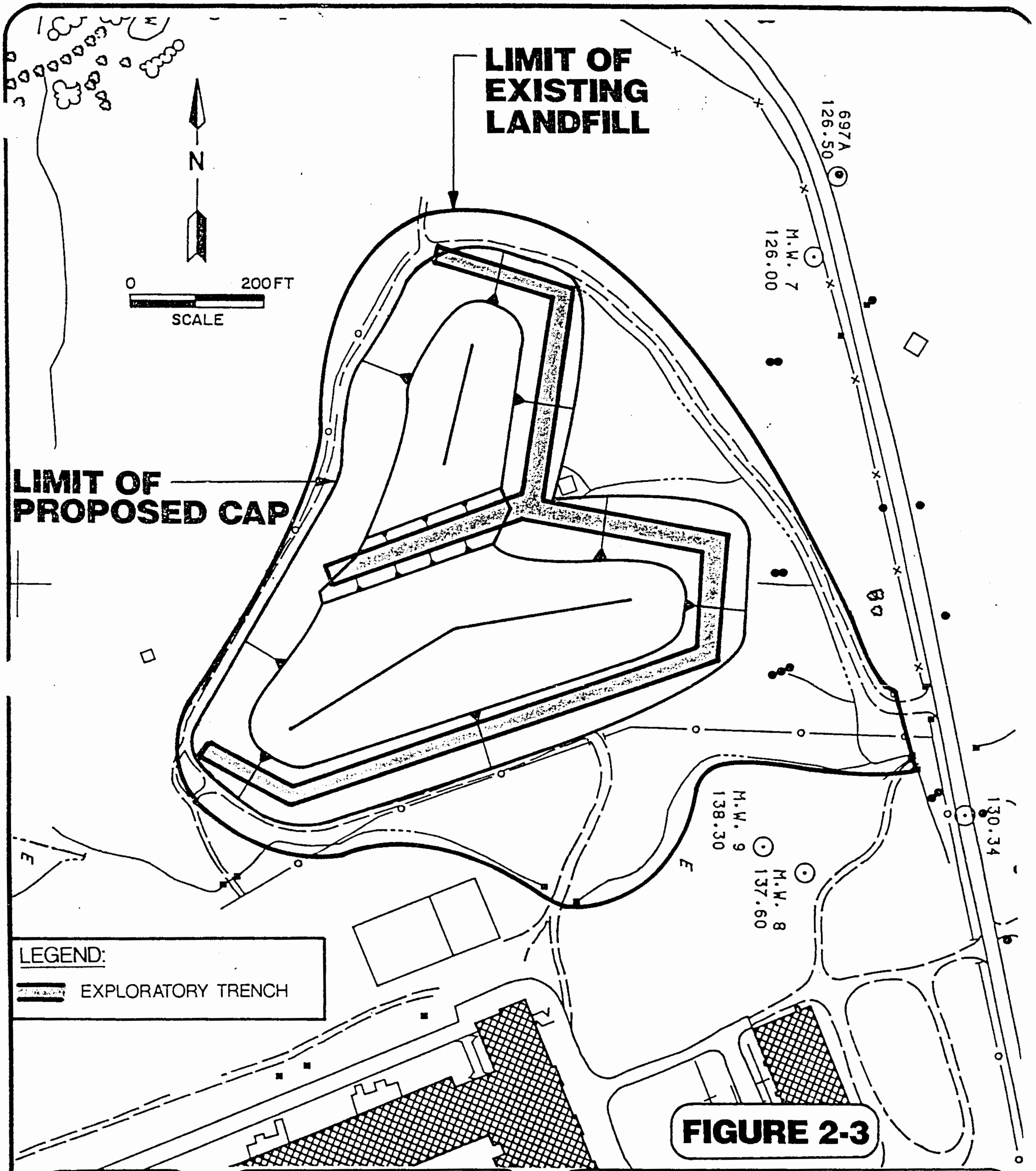

FIGURE 2-3

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APPROXIMATE LOCATION OF EXPLORATORY TRENCH

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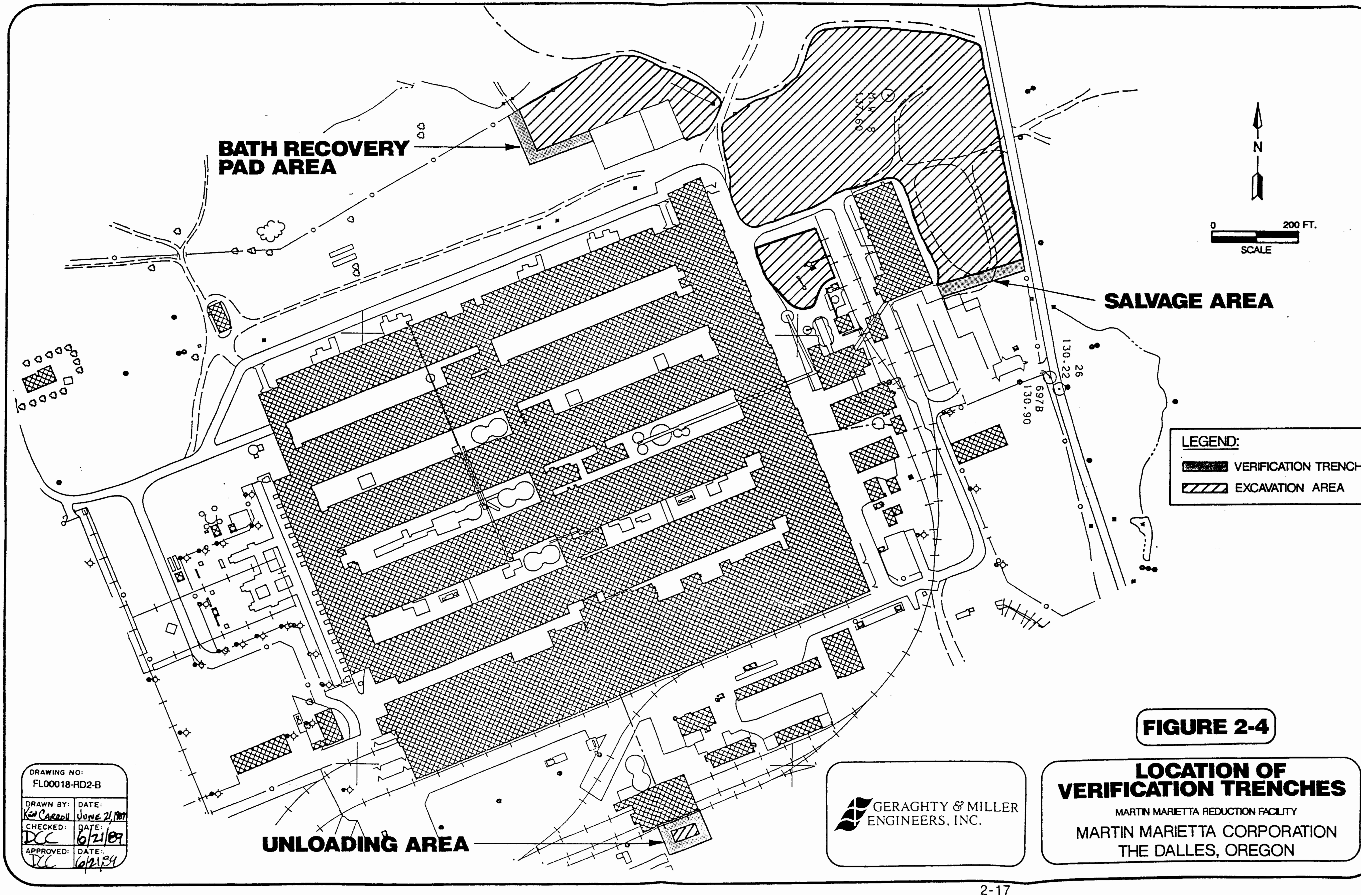
in the ROD and presented on Figure 2-4) are defined by the historic location of buildings and other structures on the site but, in some areas, the limits of the contaminated material cannot be precisely determined. MMC proposes to excavate and sample a series of verification trenches to precisely establish the limits of areal excavation.

Verification sampling trenches will be excavated; (1) along the Southern edge of the Salvage area (between the Hard Pitch Building and River Road); (2) in an area north and west of the Bath Recovery Pad, and (3) along the east, south, and west boundaries of the known area of waste placement in the Unloading Area (the northern boundary is the Unloading Building). In the remaining remediation areas of the site (Old Cathode Waste Pile, Potliner Handling Area, and the Landfill Ditch) all the recoverable materials will be excavated for consolidation into the Landfill and no verification sampling is proposed. Samples will be obtained from the trench walls and tested for the presence of contaminants, as required, based on the identification of contaminants of concern in the particular verification sampling area.

2.4.1 Investigation Methodology

The verification trenches will be excavated using a backhoe capable of excavating to competent basalt. The locations of the proposed verification trenches are presented in Figure 2-4. Each trench will be visually examined, sampled and photographed during excavation and the information logged into the field notes, and the depth to basalt recorded. The methodology for the sampling of the



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FL00018-RD2-B

DRAWN BY: Ken Carroll	DATE: June 21, 1989
CHECKED: DCC	DATE: 6/21/89
APPROVED: DCC	DATE: 6/21/89

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FIGURE 2-4

LOCATION OF VERIFICATION TRENCHES

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verification sampling trenches is adapted from Chapter Nine of the "Test Methods for Evaluating Solid Waste Physical/ Chemical Methods - Volume II: Field Manual" (EPA SW-846), Third Edition, November 1986. A copy of the pertinent reference pages is included as Appendix C. Soil samples will be obtained from the trench wall on the "outside" face with respect to the contaminated area. The most common method of selecting a random sample from the face of an excavation is to divide the area by an imaginary grid, assign a series of consecutive numbers to the units of the grid, and select the numbers (units) to be sampled through the use of a random number generator or random number table. MMC and EPA have agreed to the use of a 200 square-foot area for the collection of sample material. The 200 square-foot area will be divided vertically into four 50 square-foot areas. The respective 200 and 50 square-foot areas will be constructed by: (1) measuring the depth from the basalt surface along the slope of the excavation to the land surface; (2) determining the equivalent trench length to obtain a 200 square-foot area; (3) dividing the trench length vertically into the four 50 square-foot areas; (4) establishing ten equal-sized grids in each 50 square-foot area, and (5) utilizing a random number table to select one grid from each 50 square-foot area for sampling. The four discrete samples taken from the 50 square-foot areas within the 200 square-foot area will be mixed together (as described below) to produce a single composite sample.

Soil samples will be obtained using stainless steel scoops and/or spoons. Composite samples will be obtained by combining sub-samples collected from the four locations selected at random from the outside trench wall every 200 approximately equal volume and coarseness and will be combined in a stainless steel bowl. Following collection, the sample will be carefully mixed to ensure homogeneity and then arranged into a cone in the center of the mixing bowl. The mixed sample pile will then be divided and separated into four smaller piles. Proceeding in a clockwise direction, small but approximately equal portions of each quarter pile will then be placed sequentially into the sample container continuing until the container is filled. Containers will then be closed, labeled and placed on ice in a cooler. Sampling equipment will be decontaminated between the collection of each composite sample or separate, clean stainless steel scoops, spoons and bowls will be used.

2.4.2 Laboratory Testing

The criteria used to determine the acceptability of the verification sampling as the lateral limit of excavation are the constituents and concentrations established in the ROD and SOW, and are identified as follows:

Arsenic	≤	65 mg/kg
Fluoride	≤	2,200 mg/kg
cPAHs	≤	175 mg/kg

The specific constituents identified for analysis in the separate verification trench segments are presented as follows:

Salvage Area:	Fluoride and cPAHs
Unloading Area:	Fluoride
Bath Recovery Pad Area:	Fluoride and cPAHs

Based on the selection of contaminant-specific criteria for the areas to be excavated, laboratory analysis of the verification trench composite samples will be performed to determine, as applicable, the concentrations of fluoride and cPAHs. Arsenic, a remedial criterion for the Landfill Ditch, will not be included in the verification sampling as the ditch and surrounding area will be excavated to the extent practical and consolidated into the existing Landfill. The analytical methods for analysis of the composite soil samples for fluoride and cPAH concentrations are provided in the Quality Assurance Project Plan (QAPP).

2.4.3 Verification Trench Investigation Report

A report summarizing the results of the verification analyses will be prepared and submitted within a reasonable time frame upon receipt of analytical laboratory results.

3.0 UNIT PROCESS EVALUATION

The unit process elements described in this section include the performance testing of the cyanide destruction system and a bench study for the determination of design parameters for a fluoride removal system. The fluoride removal study will be conducted after the remedial action has been implemented, in the event that in-plant treatment is not available.

The recovery and treatment of perched water is a requirement of the site remediation. The recovery and treatment of Landfill leachate is a requirement after the remediation has been completed. The treatment characteristics of Hard Pitch Building sump water and Cathode Waste Pad leachate have been assessed by sampling, analysis and bench scale testing by Martin Marietta Corporation (MMC), utilizing the firm of Cyanide Destruct Systems, Inc. (CDS). The Hard Pitch Building sump is sampled regularly in order to verify compliance with the NPDES permit.

Bench testing for fluoride removal is required and will be conducted after the completion of the site remediation as a contingency measure in the event that the in-plant process is no longer available.

3.1 DESIGN CRITERIA STUDY

The purpose of this design criteria study is to present (1) the analytical parameters to be analyzed; (2) describe existing data; and (3) outline test procedures and results.

3.1.1 Cyanide Destruction

CDS has performed testing of ground water infiltrating into the sump of the Hard Pitch Building and leachate collected from the Cathode Waste Pad sump. The Cathode Waste Pad leachate represents the "worst-case" condition that could be presented to the cyanide destruction system. Test results presented in Appendix D indicate that hydrolysis technology is capable of meeting the performance standards for free cyanide concentrations being discharged to the in-plant process.

MMC proposes to purchase a continuous-flow hydrolysis system for the destruction of cyanide. Once the system is installed and operational at the MMRF, a series of tests will be performed to verify the ability of the unit to destroy free cyanide to meet NPDES permit criteria. Critical operational parameters, such as temperature and pressure, will be monitored on a continuous basis to verify correct equipment operation. The system performance tests will utilize perched water collected from the former Cathode Waste Management Areas. The Sampling and Analysis requirements for the system performance tests are described in Section 3.2.

3.1.2 Fluoride Removal

As stated earlier, fluoride removal bench studies will be performed after completion of the site remediation. The removal mechanisms to be evaluated are identical to those used in the in-plant treatment process. The bench testing for fluoride removal will be conducted by MMC to evaluate the degree of fluoride removal achievable by chemical precipitation. The feed source of fluoride contaminated water will be the effluent from the cyanide destruction system. The purpose of the bench study will be to evaluate reagent usage and residence times required for achieving the fluoride discharge standard of 9.7 mg/L.

A sample of sufficient volume to conduct the bench study will be collected from the effluent of the cyanide destruction unit. A sample will be collected for fluoride analysis from the representative sample which will provide the initial fluoride concentration. Jar tests will be set up using gang stirrers (or equivalent) to initially screen reagent additions. Reagents will consist of caustic (NaOH), and calcium chloride ($CaCl_2$) and lime (CaOH), separately or combined. Theoretical dosages will be stoichiometrically calculated based on initial fluoride concentrations. Sampling and analysis requirements are described in Section 3.2.

3.2 LABORATORY TESTING

Chemical analysis for the cyanide destruct system performance tests will be conducted by the analytical laboratory and in accordance with the provisions of the QAPP. MMC will conduct the fluoride removal study and some laboratory analyses internally, with the evaluation of samples from the identified optimal dosage to be conducted by the analytical laboratory.

The performance tests of the cyanide destruction system involve the sampling of feed and discharge from the system and the evaluation of the analytical data. The verification of the adequacy of the treatment system will be determined ultimately by adherence to the NPDES discharge criteria. A feed sample will be collected from the influent feed water to permit analysis by the analytical laboratory for total and free cyanide. The unit will be started and the discharge recycled to the storage tank. Once the unit has reached operating conditions, a sample will be collected for the analysis of free and total cyanides by the analytical laboratory. The discharge from the unit will continue to be recycled to the storage tank until the analytical results indicate that the unit is in compliance with cyanide discharge criteria, at which time the discharge will be directed to the in-plant treatment system.

The fluoride removal bench study consists of a series of jar tests which will be set up using gang stirrers (or equivalent) to evaluate the effects of reagent additions. Reagents to be used in the study are caustic (NaOH), calcium chloride ($CaCl_2$) and lime (CaOH), separately or in combination. Theoretical dosages for the reagents will be stoichiometrically calculated based on initial fluoride concentrations. Caustic will be added to each jar to adjust pH and dosages of lime and/or calcium chloride will be added to the jars in sufficient quantities to bracket the theoretical values. Samples will be stirred and physical observations noted. The supernatant will be drawn off and analyzed for fluoride concentration. The process may be repeated as necessary to optimize dosages to achieve fluoride removal. Once optimal dosages are determined, the volume of precipitate produced will be estimated by filtering and drying the samples, and weighing the collected precipitate.

The fluoride removal bench study will be conducted by MMC until an optimal dosage rate and residence time necessary to achieve the 9.7 mg/L discharge standard has been obtained. At that time, a sample of the influent to the fluoride removal bench study will be collected and submitted to the analytical laboratory along with a field replicate of the influent.

3.3 UNIT PROCESS EVALUATION REPORT

A report will be prepared at the conclusion of each of the studies and within a reasonable time frame of receipt of laboratory data results. The reports will document study activities and the analytical results and observations.

MMC proposes to submit a monthly report which will summarize the operational parameters and influent/effluent free cyanide concentrations from the CDS unit. A weekly sample of effluent free cyanide will be collected and analyzed. If the system is taken off-line for maintenance, the unit will be repaired and reactivated (with the discharge recycled to the storage tank). Once operating conditions are attained, a sample will be collected and the discharge will continue to be recycled to storage until the analytical results indicate compliance with the cyanide discharge criteria.

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APPENDIX A

Wyo-Ben, Inc. Information

cc D Jessup

WYO-BEN, INC.

January 18, 1988

Mr. Jose R. Boe
Vice President
Martin Marietta Corporation
6801 Rockledge Drive
Bethesda, Maryland 20817

Re: The Dalles, Oregon Capping Project

Dear Mr. Boe:

This letter is to report to you the results of our testing on the "Zutes" and "Clay Mountain" soils for use on The Dalles project.

After conducting a number of tests with both soils using both ENVIROGEL -10 (granular) and ENVIROGEL 200 (powdered) the following is evident:

1) The Zutes and Clay Mountain soils require nearly identical bentonite addition rates to yield equivalent permeability coefficients. The Zutes soil is, however, marginally the better of the two.

2) Both soils require significantly higher addition rates of ENVIROGEL -10 than they do ENVIROGEL 200 to achieve equivalent permeability coefficients. This occurs because both soils are silt loams with very little clay fraction to provide filler for the void spaces between the silt particles. This requires that the bentonite act as the filler. The higher number of individual particles in the powdered material allows it to perform that function more efficiently than the granular material.

Several possible alternatives are suggested by these facts. First, ENVIROGEL 200 could be added to either soil at an addition rate of 15.0% (Lab Indicated Rate of 12% + 25% construction contingency factor) or approximately 8.25 lbs. per square foot per 6 inch thickness to achieve the desired permeability coefficient of $K = 1 \times 10^{-8}$ cm/sec. Because of the powdered nature of the product, this has some potential disadvantages for in-situ (on the ground) mixing operations if windy conditions exist in the mixing area. Nevertheless, this is a workable alternative if the wind problem can be dealt with, and I believe it can.

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3044 Hesper Road • P.O. Box 1979 • Billings, Montana 59103 • 406-652-6351 • Telex 31-9430 • Telefax 406-656-0748

Second, ENVIROGEL -10 could be added to either soil at an approximate addition rate of 22.5% (Lab Indicated Rate of 18% + 25% construction contingency factor) or approximately 12.38 pounds per square foot per 6 inch thickness to achieve the 1 X 10^{-8} cm/sec. permeability coefficient. This addition rate was projected from the available test data. While it is only approximate, it does accurately reflect the high -10 bentonite addition rate necessary to achieve the desired seal. Because of the high addition rate, I do not consider it a viable alternative.

Third, either the Zutes or Clay Mountain soil could be blended with the Browns Creek soil (a very clayey material) at a ratio of approximately 65% : 35% to increase the clay content of the soil mix and reduce the amount of bentonite required. This should then enable the -10 material to be used effectively. I have not yet had any tests run on this blend so I can only speculate that the bentonite addition rate would be in the range of 6 to 9%. We would be happy to test such a blend for a precise determination of the bentonite addition rate, if you decide that this is an acceptable alternative. I believe that, all things considered, this would be the most cost effective solution to the problem.

The test results for the Zutes and Clay Mountain soils accompany this letter.

If you have any questions or would like to discuss any or all of the alternatives I have suggested more thoroughly, please call me at 800-548-7055 at any time.

Sincerely,

Richard K. Brown

Richard K. Brown
Vice President Resources

RKB:jr
Enclosure

cc: Ms. Loretta Grabowski
Martin Marietta Corp.
3313 West 2nd Street
The Dalles, Oregon 97058

Date: 1-13-89

WYO-BEN, INC.
LABORATORY PERMEABILITY TEST RESULTS

Site: MARTIN MARIETTA, THE DALLES, OREGON

Contractor:

Engineer: GEM CONSULTING ENGINEERS

Soil Sample I.D.: CLAY MOUNTAIN Test Membrane No.: 1

1) Soil Proctor Values
Max. Dry Density: 110 lbs./cu.ft. Opt Moisture Content 12 %
(Source: Estimated by WYO-BEN, INC.)

2) Test Mix
Bentonite Used: ENVIROGEL -10
Soil (Wet Wt.) 1613.9 gms.; (Dry Wt.) 1375.0 gms.
Bentonite (Wet Wt.) 124.3 gms.; (Dry Wt.) 119.6 gms.
(Application rate of 8 %, or 8.8 lbs./cu.ft.)
Water: 20.1 ml.

3) Membrane in Permeameter
Diameter: 6 in. Thickness: 2.04 in.
Volume: 0.03337 cu. ft.
Dry Weight: 3.29 lbs. Dry Density 98.74 lbs./cu.ft.
Compactive Effort: 12,136.7 ft. lbs./cu.ft.
Calculated Compaction 93 % Standard/Modified Proctor.

4) Test Parameters
Saturation/Equilibration Period: 5 days
Constant Head Applied: 14.5 feet, water equivalent
Outflow Time: 1 Hrs. 38 Min. 0 Sec.
Outflow Volume: 8.5 cu.cms.

5) Permeability

$$K = \frac{\frac{Q}{t}}{\frac{H}{L}(A)} = \frac{\frac{8.5\ \text{c.c.}}{5{,}880\ \text{secs}}}{\frac{453.7\ \text{cm}}{5.18\ \text{cm}}(182.41\ \text{cm}^2)} = 9.05 \times 10^{-8}\ \text{cm./sec.}$$

By Richard K. Brown

Note: The laboratory permeability test data presented herein were obtained on a soil/bentonite mix using soil samples supplied to WYO-BEN, INC. by MARTIN MARIETTA . This test was performed under ideal laboratory conditions and one should not expect to duplicate these results under field conditions. This test was performed to provide useful information and guidance to the engineer who, after considering all of the relevant on-site factors, will design the application rate and specifications for this job. WYO-BEN, INC. expressly does not offer engineering advice in presenting these test results. The Engineer and Contractor must recognize that a higher application rate than that used in this test will be necessary in the field to account for variations in bentonite content resulting from non-uniform application of bentonite, imperfect mixing of bentonite and soil, variability in the soil used in the mix, variability in the compaction of the installed bentonite/soil membrane and other factors beyond the control of WYO-BEN, INC. We stand behind the accuracy of these laboratory test results, however, due to the factors previously described, we do not accept responsibility or liability for the performance or result of the job, beyond WYO-BEN, INC'S. limited warranty for the bentonite product itself.

Date: 1-13-89

WYO-BEN, INC.
LABORATORY PERMEABILITY TEST RESULTS

Site: MARTIN MARIETTA, THE DALLES, OREGON

Contractor:

Engineer: G&M CONSULTING ENGINEERS

Soil Sample I.D.: CLAY MOUNTAIN Test Membrane No.: 2

1) Soil Proctor Values
Max. Dry Density: 110 lbs./cu.ft. Opt Moisture Content 12 %
(Source: Estimated by Wyo-Ben, Inc.)

2) Test Mix
Bentonite Used: ENVIROGEL-10
Soil (Wet Wt.) 1566.9 gms.; (Dry Wt.) 1335.0 gms.
Bentonite (Wet Wt.) 154.2 gms.; (Dry Wt.) 148.3 gms.
(Application rate of 10 %, or 11.0 lbs./cu.ft.)
Water: 24.0 ml.

3) Membrane in Permeameter
Diameter: 6 in. Thickness: 2.04 in.
Volume: 0.03337 cu. ft.
Dry Weight: 3.27 lbs. Dry Density 97.99 lbs./cu.ft.
Compactive Effort: 12,136.7 ft. lbs./cu.ft.
Calculated Compaction 93 % Standard/Modified Proctor.

4) Test Parameters
Saturation/Equilibration Period: 5 days
Constant Head Applied: 15.6 feet, water equivalent
Outflow Time: 2 Hrs. 47 Min. 0 Sec.
Outflow Volume: 9.9 cu.cms.

5) Permeability

$$K = \frac{\frac{Q}{t}}{\frac{H}{L}(A)} = \frac{\frac{9.9 \text{ c.c.}}{10{,}020 \text{ secs}}}{\frac{474.79 \text{ cm}}{5.18 \text{ cm}}(182.41 \text{ cm}^2)} = 5.91 \times 10^{-8} \text{ cm./sec.}$$

By Richard K. Brown

Note: The laboratory permeability test data presented herein were obtained on a soil/bentonite mix using soil samples supplied to WYO-BEN, INC. by MARTIN MARIETTA . This test was performed under ideal laboratory conditions and one should not expect to duplicate these results under field conditions. This test was performed to provide useful information and guidance to the engineer who, after considering all of the relevant on-site factors, will design the application rate and specifications for this job. WYO-BEN, INC. expressly does not offer engineering advice in presenting these test results. The Engineer and Contractor must recognize that a higher application rate than that used in this test will be necessary in the field to account for variations in bentonite content resulting from non-uniform application of bentonite, imperfect mixing of bentonite and soil, variability in the soil used in the mix, variability in the compaction of the installed bentonite/soil membrane and other factors beyond the control of WYO-BEN, INC. We stand behind the accuracy of these laboratory test results, however, due to the factors previously described, we do not accept responsibility or liability for the performance or result of the job, beyond WYO-BEN, INC'S. limited warranty for the bentonite product itself.

Date: 1-13-89

WYO-BEN, INC.
LABORATORY PERMEABILITY
TEST RESULTS

Site: MARTIN MARIETTA, THE DALLES, OREGON

Contractor:

Engineer: G&M CONSULTING ENGINEERS

Soil Sample I.D.: CLAY MOUNTAIN Test Membrane No.: 1

1) Soil Proctor Values
Max. Dry Density: 110 lbs./cu.ft. Opt Moisture Content 12 %
(Source: Estimated by Wyo-Ben, Inc.)

2) Test Mix
Bentonite Used: ENVIROGEL 200
Soil (Wet Wt.) 1612.0 gms.; (Dry Wt.) 1375.0 gms.
Bentonite (Wet Wt.) 124.3 gms.; (Dry Wt.) 119.6 gms.
(Application rate of 8 %, or 8.8 lbs./cu.ft.)
Water: 22.1 ml.

3) Membrane in Permeameter
Diameter: 6 in. Thickness: 2.0 in.
Volume: 0.03272 cu. ft.
Dry Weight: 3.29 lbs. Dry Density 100.70 lbs./cu.ft.
Compactive Effort: 12,377.8 ft. lbs./cu.ft.
Calculated Compaction 95 % Standard/Modified Proctor.

4) Test Parameters
Saturation/Equilibration Period: 6 days
Constant Head Applied: 14.42 feet, water equivalent
Outflow Time: 3 Hrs. 37 Min. 0 Sec.
Outflow Volume: 8.8 cu.cms.

5) Permeability

$$K = \frac{\frac{Q}{t}}{\frac{H}{L}(A)} = \frac{\frac{8.8\ \text{c.c.}}{13{,}020\ \text{secs}}}{\frac{439.64\,\text{cm}}{5.08\,\text{cm}}(182.41\ \text{cm}^2)} = 4.28\times10^{-8}\ \text{cm./sec.}$$

By Richard E. Brown

Note: The laboratory permeability test data presented herein were obtained on a soil/bentonite mix using soil samples supplied to WYO-BEN, INC. by MARTIN MARIETTA. This test was performed under ideal laboratory conditions and one should not expect to duplicate these results under field conditions. This test was performed to provide useful information and guidance to the engineer who, after considering all of the relevant on-site factors, will design the application rate and specifications for this job. WYO-BEN, INC. expressly does not offer engineering advice in presenting these test results. The Engineer and Contractor must recognize that a higher application rate than that used in this test will be necessary in the field to account for variations in bentonite content resulting from non-uniform application of bentonite, imperfect mixing of bentonite and soil, variability in the soil used in the mix, variability in the compaction of the installed bentonite/soil membrane and other factors beyond the control of WYO-BEN, INC. We stand behind the accuracy of these laboratory test results, however, due to the factors previously described, we do not accept responsibility or liability for the performance or result of the job, beyond WYO-BEN, INC'S. limited warranty for the bentonite product itself.

Date: 1-13-89

WYO-BEN, INC.
LABORATORY PERMEABILITY
TEST RESULTS

Site: MARTIN MARIETTA, THE DALLES, OREGON

Contractor:

Engineer: G&M CONSULTING ENGINEERS

Soil Sample I.D.: CLAYMOUNTAIN Test Membrane No.: 2

1) Soil Proctor Values
Max. Dry Density: 110 lbs./cu.ft. Opt Moisture Content 12 %
(Source: WYO-BEN, INC. estimate)

2) Test Mix
Bentonite Used: ENVIROGEL 200
Soil (Wet Wt.) 1566.9 gms.; (Dry Wt.) 1335.0 gms.
Bentonite (Wet Wt.) 154.2 gms.; (Dry Wt.) 148.3 gms.
(Application rate of 10 %, or 11.0 lbs./cu.ft.)
Water: 240 ml.

3) Membrane in Permeameter
Diameter: 6 in. Thickness: 2.04 in.
Volume: 0.03337 cu. ft.
Dry Weight: 3.27 lbs. Dry Density 97.99 lbs./cu.ft.
Compactive Effort: 12,136.7 ft. lbs./cu.ft.
Calculated Compaction 93 % Standard/Modified Proctor.

4) Test Parameters
Saturation/Equilibration Period: 11 days
Constant Head Applied: 19.0 feet, water equivalent
Outflow Time: 5 Hrs. 40 Min. 0 Sec.
Outflow Volume: 9.4 cu.cms.

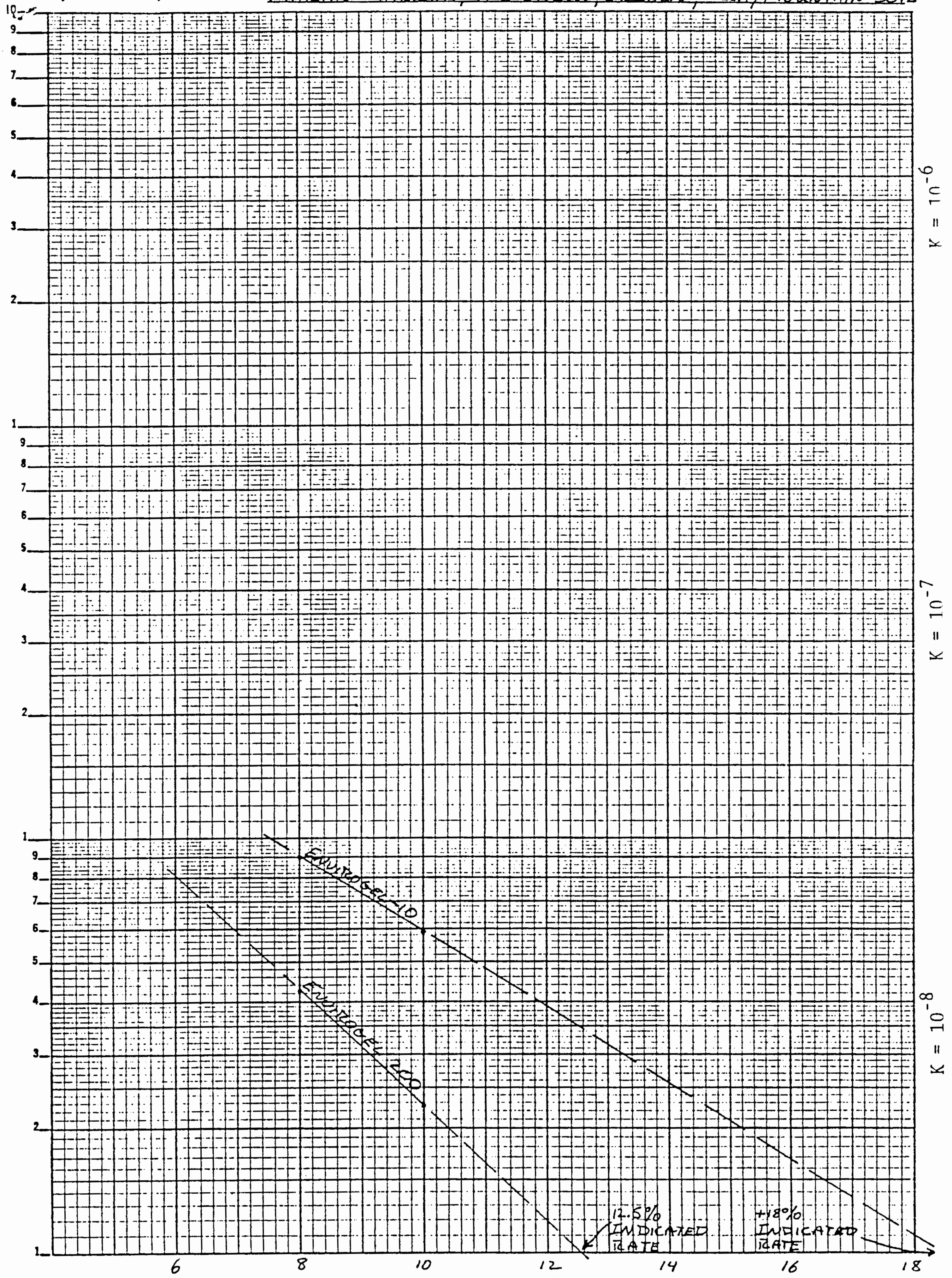
5) Permeability

$$K = \frac{\frac{Q}{t}}{\frac{H}{L}(A)} = \frac{\frac{9.4 \text{ c.c.}}{20400 \text{ secs}}}{\frac{578.9 \text{ cm}}{5.18 \text{ cm}}(182.41 \text{ cm}^2)} = 2.26 \times 10^{-8} \text{ cm./sec.}$$

By Richard K. Brown

Note: The laboratory permeability test data presented herein were obtained on a soil/bentonite mix using soil samples supplied to WYO-BEN, INC. by MARTIN MARIETTA. This test was performed under ideal laboratory conditions and one should not expect to duplicate these results under field conditions. This test was performed to provide useful information and guidance to the engineer who, after considering all of the relevant on-site factors, will design the application rate and specifications for this job. WYO-BEN, INC. expressly does not offer engineering advice in presenting these test results. The Engineer and Contractor must recognize that a higher application rate than that used in this test will be necessary in the field to account for variations in bentonite content resulting from non-uniform application of bentonite, imperfect mixing of bentonite and soil, variability in the soil used in the mix, variability in the compaction of the installed bentonite/soil membrane and other factors beyond the control of WYO-BEN, INC. We stand behind the accuracy of these laboratory test results, however, due to the factors previously described, we do not accept responsibility or liability for the performance or result of the job, beyond WYO-BEN, INC'S. limited warranty for the bentonite product itself.

By WYO-BEN, INC. for MARTIN MARIETTA, THE DALLES, OREGON; "CLAY MOUNTAIN" SOIL



% Bentonite by Density of Soil

Date: 1-13-89

WYO-BEN, INC.
LABORATORY PERMEABILITY
TEST RESULTS

Site: MARTIN MARIETTA, THE DALLES, OREGON

Contractor:

Engineer: G&M CONSULTING ENGINEERS

Soil Sample I.D.: ZUTES Test Membrane No.: 1

1) Soil Proctor Values
Max. Dry Density: 110 lbs./cu.ft. Opt Moisture Content 12 %
(Source: Estimated by WYO-BEN, INC.)

2) Test Mix
Bentonite Used: ENVIROGEL-10
Soil (Wet Wt.) 1547.3 gms.; (Dry Wt.) 1329.1 gms.
Bentonite (Wet Wt.) 154.2 gms.; (Dry Wt.) 148.3 gms.
(Application rate of 10 %, or 11.0 lbs./cu.ft.)
Water: 36.7 ml.

3) Membrane in Permeameter
Diameter: 6 in. Thickness: 2.0 in.
Volume: 0.03272 cu. ft.
Dry Weight: 327 lbs. Dry Density 99.94 lbs./cu.ft.
Compactive Effort: 8251.8 ft. lbs./cu.ft.
Calculated Compaction 95 % Standard/Modified Proctor.

4) Test Parameters
Saturation/Equilibration Period: 6 days
Constant Head Applied: 10.01 feet, water equivalent
Outflow Time: 3 Hrs. 38 Min. 0 Sec.
Outflow Volume: 8.9 cu.cms.

5) Permeability

$$K = \frac{\frac{Q}{t}}{\frac{H}{L}(A)} = \frac{\frac{8.9 \text{ c.c.}}{13{,}080 \text{ secs}}}{\frac{305.2 \text{ cm}}{5.08 \text{ cm}}(182.41 \text{ cm}^2)} = 6.05 \times 10^{-8} \text{ cm./sec.}$$

By Richard K. Brown

Note: The laboratory permeability test data presented herein were obtained on a soil/bentonite mix using soil samples supplied to WYO-BEN, INC. by MARTIN MARIETTA. This test was performed under ideal laboratory conditions and one should not expect to duplicate these results under field conditions. This test was performed to provide useful information and guidance to the engineer who, after considering all of the relevant on-site factors, will design the application rate and specifications for this job. WYO-BEN, INC. expressly does not offer engineering advice in presenting these test results. The Engineer and Contractor must recognize that a higher application rate than that used in this test will be necessary in the field to account for variations in bentonite content resulting from non-uniform application of bentonite, imperfect mixing of bentonite and soil, variability in the soil used in the mix, variability in the compaction of the installed bentonite/soil membrane and other factors beyond the control of WYO-BEN, INC. We stand behind the accuracy of these laboratory test results, however, due to the factors previously described, we do not accept responsibility or liability for the performance or result of the job, beyond WYO-BEN, INC'S. limited warranty for the bentonite product itself.

Date: 1-13-89

WYO-BEN, INC.
LABORATORY PERMEABILITY TEST RESULTS

Site: MARTIN MARIETTA, THE DALLES, OREGON

Contractor:

Engineer: GEM CONSULTING ENGINEERS

Soil Sample I.D.: ZUTES   Test Membrane No.: 2

1) Soil Proctor Values
Max. Dry Density: 110 lbs./cu.ft.   Opt Moisture Content 12 %
(Source: Estimated by WYO-BEN, INC.)

2) Test Mix
Bentonite Used: ENVIROGEL-10
Soil (Wet Wt.) 1485.2 gms.;   (Dry Wt.) 1275.8 gms.
Bentonite (Wet Wt.) 198.2 gms.;   (Dry Wt.) 190.6 gms.
(Application rate of 13 %, or 14.3 lbs./cu.ft.)
Water: 41.7 ml.

3) Membrane in Permeameter
Diameter: 6 in.   Thickness: 2.0 in.
Volume: 0.03272 cu. ft.
Dry Weight: 3.23 lbs.   Dry Density 98.80 lbs./cu.ft.
Compactive Effort: 8,251.8 ft. lbs./cu.ft.
Calculated Compaction 95 % Standard/Modified Proctor.

4) Test Parameters
Saturation/Equilibration Period: 6.5 days
Constant Head Applied: 9.56 feet, water equivalent
Outflow Time: 4 Hrs. 0 Min. 0 Sec.
Outflow Volume: 4.9 cu.cms.

5) Permeability

$$K = \frac{\frac{Q}{t}}{\frac{H}{L}(A)} = \frac{\frac{4.9\ \text{c.c.}}{14{,}400\ \text{secs}}}{\frac{291.5\ \text{cm}}{5.08\ \text{cm}}(182.41\ \text{cm}^2)} = 3.17 \times 10^{-8}\ \text{cm./sec.}$$

By Richard K. Brown

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Date: 1-13-89

WYO-BEN, INC.
LABORATORY PERMEABILITY TEST RESULTS

Site: MARTIN MARIETTA, THE DALLES, OREGON

Contractor:

Engineer: G&M CONSULTING ENGINEERS

Soil Sample I.D.: ZUTES   Test Membrane No.: 1

1) Soil Proctor Values
Max. Dry Density: 110 lbs./cu.ft.   Opt Moisture Content 12 %
(Source: Estimated by WYO-BEN, INC.)

2) Test Mix
Bentonite Used: ENVIROGEL 200
Soil (Wet Wt.) 1600.7 gms.;   (Dry Wt.) 1375.0 gms.
Bentonite (Wet Wt.) 124.3 gms.;   (Dry Wt.) 119.6 gms.
(Application rate of 8 %, or 8.8 lbs./cu.ft.)
Water: 33.5 ml.

3) Membrane in Permeameter
Diameter: 6 in.   Thickness: 1.96 in.
Volume: 0.03207 cu. ft.
Dry Weight: 3.29 lbs.   Dry Density 102.74 lbs./cu.ft.
Compactive Effort: 8,419.1 ft. lbs./cu.ft.
Calculated Compaction 97 % Standard/Modified Proctor.

4) Test Parameters
Saturation/Equilibration Period: 9 days
Constant Head Applied: 11.14 feet, water equivalent
Outflow Time: 3 Hrs. 0 Min. 0 Sec.
Outflow Volume: 4.4 cu.cms.

5) Permeability

$$K = \frac{\frac{Q}{t}}{\frac{H}{L}(A)} = \frac{\frac{4.4\ \text{c.c.}}{10{,}800\ \text{secs}}}{\frac{339.4\ \text{cm}}{4.98\ \text{cm}}(182.41\ \text{cm}^2)} = 3.19 \times 10^{-8}\ \text{cm./sec.}$$

By Richard K. Brown

Note: The laboratory permeability test data presented herein were obtained on a soil/bentonite mix using soil samples supplied to WYO-BEN, INC. by MARTIN MARIETTA . This test was performed under ideal laboratory conditions and one should not expect to duplicate these results under field conditions. This test was performed to provide useful information and guidance to the engineer who, after considering all of the relevant on-site factors, will design the application rate and specifications for this job. WYO-BEN, INC. expressly does not offer engineering advice in presenting these test results. The Engineer and Contractor must recognize that a higher application rate than that used in this test will be necessary in the field to account for variations in bentonite content resulting from non-uniform application of bentonite, imperfect mixing of bentonite and soil, variability in the soil used in the mix, variability in the compaction of the installed bentonite/soil membrane and other factors beyond the control of WYO-BEN, INC. We stand behind the accuracy of these laboratory test results, however, due to the factors previously described, we do not accept responsibility or liability for the performance or result of the job, beyond WYO-BEN, INC'S. limited warranty for the bentonite product itself.

Date: 1-13-89

WYO-BEN, INC.
LABORATORY PERMEABILITY TEST RESULTS

Site: MARTIN MARIETTA, THE DALLES, OREGON

Contractor:

Engineer: GÉM CONSULTING ENGINEERS

Soil Sample I.D.: ZUTES Test Membrane No.: 2

1) Soil Proctor Values
Max. Dry Density: 110 lbs./cu.ft. Opt Moisture Content 12 %
(Source: Estimated by WYO-BEN, INC.)

2) Test Mix
Bentonite Used: ENVIROGEL 200
Soil (Wet Wt.) 1554.1 gms.; (Dry Wt.) 1335.0 gms.
Bentonite (Wet Wt.) 154.2 gms.; (Dry Wt.) 148.3 gms.
(Application rate of 10 %, or 11.0 lbs./cu.ft.)
Water: 36.8 ml.

3) Membrane in Permeameter
Diameter: 6 in. Thickness: 1.96 in.
Volume: 0.03207 cu. ft.
Dry Weight: 3.27 lbs. Dry Density 101.97 lbs./cu.ft.
Compactive Effort: 9,354.5 ft. lbs./cu.ft.
Calculated Compaction 97 % Standard/Modified Proctor.

4) Test Parameters
Saturation/Equilibration Period: 6.75 days
Constant Head Applied: 14.05 feet, water equivalent
Outflow Time: 8 Hrs. 21 Min. 0 Sec.
Outflow Volume: 8.6 cu.cms.

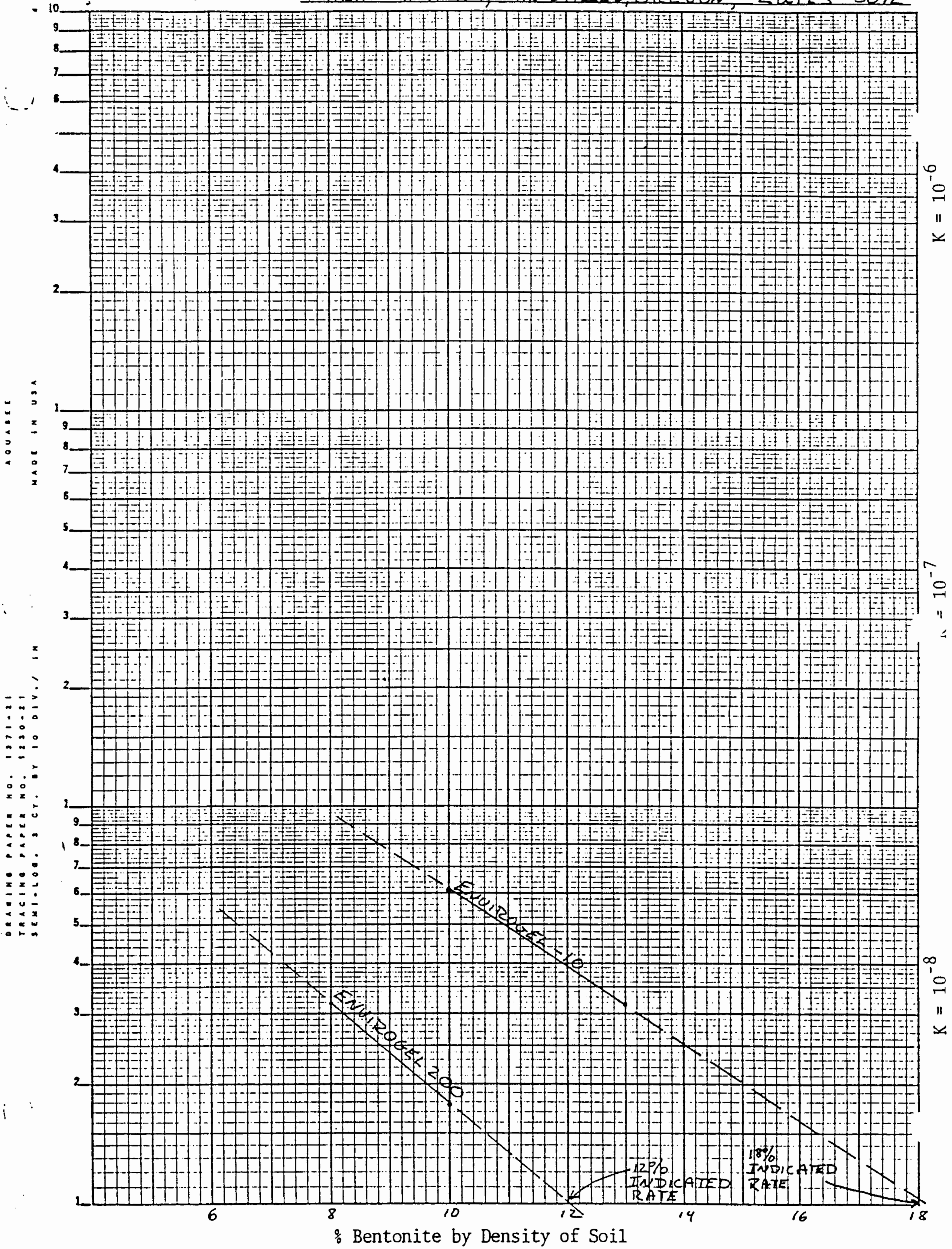
5) Permeability

$$K = \frac{\frac{Q}{t}}{\frac{H}{L}(A)} = \frac{\frac{8.6\ \text{c.c.}}{30{,}060\ \text{secs}}}{\frac{428.3\ \text{cm}}{4.98\ \text{cm}}(182.41\ \text{cm}^2)} = 1.78 \times 10^{-8}\ \text{cm./sec.}$$

By Richard K. Brown

Note: The laboratory permeability test data presented herein were obtained on a soil/bentonite mix using soil samples supplied to WYO-BEN, INC. by MARTIN MARIETTA. This test was performed under ideal laboratory conditions and one should not expect to duplicate these results under field conditions. This test was performed to provide useful information and guidance to the engineer who, after considering all of the relevant on-site factors, will design the application rate and specifications for this job. WYO-BEN, INC. expressly does not offer engineering advice in presenting these test results. The Engineer and Contractor must recognize that a higher application rate than that used in this test will be necessary in the field to account for variations in bentonite content resulting from non-uniform application of bentonite, imperfect mixing of bentonite and soil, variability in the soil used in the mix, variability in the compaction of the installed bentonite/soil membrane and other factors beyond the control of WYO-BEN, INC. We stand behind the accuracy of these laboratory test results, however, due to the factors previously described, we do not accept responsibility or liability for the performance or result of the job, beyond WYO-BEN, INC'S. limited warranty for the bentonite product itself.

By WYO-BEN, INC. for MARTIN MARIETTA, THE DALLES, OREGON; "ZUTES" SOIL



cc: D. Jessup
done 2/6/89

WYO-BEN, INC.

January 31, 1988

Mr. Jose R. Boe
Vice President
Martin Marietta Corporation
6801 Rockledge Drive
Bethesda, Maryland 20817

Re: The Dalles, Oregon Capping Project

Dear Mr. Boe:

As a follow up on my letter to you of January 18, 1989, I am writing to report to you the results of a test we have just completed using a Zutes/Brown's Creek soil blend. The recent temporary availability of some test equipment allowed us to build a single membrane to test my recommendation to you for using this soil blend as the mixing base for soil/bentonite membrane using ENVIROGEL -10 Granular Bentonite.

The following is a listing of test parameters and results.

Soil Mixture: 2/3 Zutes, 1/3 Brown's Creek
Assumed Maximum Dry Density: 97 lb/cu.ft.
Assumed Optimum Moisture Content: 18.2%
Compaction Level: 95% of Standard (ASTM D-698) Density
Compaction Moisture: 3% over optimum.
Bentonite Addition Rate: 9% ENVIROGEL -10 (Granular)
Hydration Period: 6 Days
Head Pressure: 10 feet of water (equivalent)
Resulting Permeability Coefficient: 2.7×10^{-8} cm/sec.

Based upon this test result I believe it is reasonable to believe that the 1×10^{-8} cm/sec. rate can be achieved using this bentonite addition rate by increasing the compaction level from standard to modified compaction and by adjusting the composition of the soil mix slightly. Assuming this to be the case, and adding to this rate a 25% construction contingency factor, the resulting application rate would be approximately 5.5 lbs. ENVIROGEL -10 per square foot for a 6 inch thick cover.

It should be noted that the permeability achieved in this test yields a leakage rate for a 6 inch thick cover membrane which is virtually identical to that obtained by a 2 foot thick cover membrane with a permeability of 1×10^{-7} cm/sec.

3044 Hesper Road • P.O. Box 1979 • Billings, Montana 59103 • 406-652-6351 • Telex 31-9430 • Telefax 406-65

January 31, 1989
Mr. Jose' R. Boe
Page 2

In short, the test results demonstrate that granular bentonite can be successfully used in your application by blending the soils to yield a more suitable mixing base.

I hope that this information is helpful to you in your decision making process. If you would like to discuss it further, please feel free to call me at any time.

Sincerely,

Richard K. Brown

Richard K. Brown
Vice President Resources

RKB:jr

cc: Ms. Loretta Grabowski
Martin Marietta Corp.
3313 West 2nd Street
The Dalles, Oregon 97058

APPENDIX B

Standard Geotechnical Test Methods

Designation: D 2216 – 80

An American National Standard

Standard Method for
LABORATORY DETERMINATION OF WATER (MOISTURE) CONTENT OF SOIL, ROCK, AND SOIL-AGGREGATE MIXTURES[1]

This standard is issued under the fixed designation D 2216; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This method covers the laboratory determination of the water (moisture) content of soil, rock, and soil-aggregate mixtures by weight. For simplicity, the word "material" hereinafter refers to either soil, rock, or soil-aggregate mixtures, whichever is most applicable.

1.2 The water content of a material is defined as the ratio, expressed as a percentage, of the mass of "pore" or "free" water in a given mass of material to the mass of the solid material particles.

1.3 This method does not give true representative results for: materials containing significant amounts of halloysite, montmorillonite, or gypsum minerals; highly organic soils; or, materials in which the pore water contains dissolved solids (such as salt in the case of marine deposits). For a material of the previously mentioned types, a modified method of testing or data calculation may be established to give results consistent with the purpose of the test.

2. Summary of Method

2.1 The practical application in determining the water content of a material is to determine the mass of water removed by drying the moist material (test specimen) to a constant mass in a drying oven controlled at 110 ± 5°C and to use this value as the mass of water in the test specimen. The mass of material remaining after oven-drying is used as the mass of the solid particles.

3. Significance and Use

3.1 For many soil types, the water content is one of the most significant index properties used in establishing a correlation between soil behavior and an index property.

3.2 The water content of a soil is used in almost every equation expressing the phase relationships of air, water, and solids in a given volume of material.

3.3 In fine-grained (cohesive) soils, the consistency of a given soil type depends on its water content. The water content of a soil, along with its liquid and plastic limit, is used to express its relative consistency or liquidity index.

3.4 The term "water" as used in geotechnical engineering, is typically assumed to be "pore" or "free" water and not that which is hydrated to the mineral surfaces. Therefore, the water content of materials containing significant amounts of hydrated water at in-situ temperatures or less than 110°C can be misleading.

3.5 The term "solid particles" as used in geotechnical engineering, is typically assumed to mean naturally occurring mineral particles that are not readily soluble in water. Therefore, the water content of materials containing extraneous matter (such as cement, etc), water-soluble matter (such as salt) and highly organic matter typically require special treatment or a qualified definition of water content.

4. Apparatus

4.1 *Drying Oven*, thermostatically-controlled, preferably of the forced-draft type, and maintaining a uniform temperature of 110 ± 5°C throughout the drying chamber.

4.2 *Balances*, having a precision (repeatability) of ±0.01 g for specimens having a mass of 200 g or less, ±0.1 g for specimens having a mass of between 200 and 1000 g, or ± 1 g for specimens having a mass greater than 1000 g.

4.3 *Specimen Containers*—Suitable containers made of material resistant to corrosion and a change in mass upon repeated heating, cooling, and cleaning. Containers with close-fitting lids shall be used for testing specimens having a mass of less than about 200 g; while for specimens having a mass greater than about 200 g, containers without lids may be used (Note 1). One container is needed for each water content determination.

NOTE 1—The purpose of close-fitting lids is to prevent loss of moisture from specimens before initial weighing and to prevent absorption of moisture from the atmosphere following drying and before final weighing.

4.4 *Desiccator*—A desiccator of suitable size (a convenient size is 200 to 250-mm diameter) containing a hydrous silica gel. This equipment is only recommended for use when containers having close-fitting lids are not used. See 7.4.1.

5. Samples

5.1 Keep the samples that are stored prior to testing in noncorrodible airtight containers at a temperature between approximately 3 and 30°C and in an area that prevents direct contact with sunlight.

5.2 The water content determination should be done as soon as practicable after sampling, especially if potentially corrodible containers (such as steel thin-walled tubes, paint cans, etc.) or sample bags are used.

6. Test Specimen

6.1 For water contents being determined in conjunction with another ASTM method, the method of specimen selection specified in that method controls.

6.2 The manner in which the test specimen is selected and its required mass is basically dependent on the purpose (application) of the test, type of material being tested, and the type of sample (specimen from another test, bag, tube, split-barrel, etc.). In all cases, however, a representative portion of the total sample shall be selected. If a layered soil or more than one soil type is encountered, select an average portion or individual portions or both, and note which portion(s) was tested in the report of the results.

6.2.1 For bulk samples, select the test specimen from the material after it has been thoroughly mixed. The mass of moist material selected shall be in accordance with the following table:

Sieve Retaining More Than About 10 % of Sample	Recommended Minimum Mass of Moist Specimen, g
2.0 mm (No. 10) sieve	100 to 200
4.75 mm (No. 4) sieve	300 to 500
19 mm	500 to 1000
38 mm	1500 to 3000
76 mm	5000 to 10 000

6.2.2 For small (jar) samples, select a representative portion in accordance with the following procedure:

6.2.2.1 For cohesionless soils, thoroughly mix the material, then select a test specimen having a mass of moist material in accordance with the table in 6.2.1. See Note 2.

6.2.2.2 For cohesive soils, remove about 3 mm of material from the exposed periphery of the sample and slice it in half (to check if the material is layered) prior to selecting the test specimen. If the soil is layered see 6.2. The mass of moist material selected should not be less than 25 g or should be in accordance with the table in 6.2.1 if coarse-grained particles are noted. (Note 2).

6.3 Using a test specimen smaller than the minimum mass indicated previously requires discretion, though it may be adequate for the purpose of the test. A specimen having a mass less than the previously indicated value shall be noted in the report of the results.

NOTE 2—In many cases, when working with a small sample containing a relatively large coarse-grained particle, it is appropriate not to include this particle in the test specimen. If this occurs, it should be noted in the report of the results.

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[1] This method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.03 on Texture, Plasticity and Density Characteristics of Soils.

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7. Procedure

7.1 Select representative test specimens in accordance with Section 6.

7.2 Place the moist specimen in a clean, dry container of known mass (Note 3), set the lid securely in position, and determine the mass of the container and moist material using an appropriate balance (4.2). Record these values.

7.3 Remove the lid and place the container with moist material in a drying oven maintained at 110 ± 5°C and dry to a constant mass (Notes 4, 5, and 6).

NOTE 3—To assist in the oven-drying of large test specimens, they should be placed in containers having a large surface area (such as pans) and the material broken up into smaller aggregations.

NOTE 4—The time required to obtain constant mass will vary depending on the type of material, size of specimen, oven type and capacity, and other factors. The influence of these factors generally can be established by good judgment, and experience with the materials being tested and the apparatus being used. In most cases, drying a test specimen over night (about 16 h) is sufficient. In cases where there is doubt concerning the adequacy of drying, drying should be continued until the mass after two successive periods (greater than ½ h) of drying indicate an insignificant change (less than about 0.1 %). Specimens of sand may often be dried to constant mass in a period of about 4 h, when a forced-draft oven is used.

NOTE 5—Oven-drying at 110 ± 5°C does not always result in water content values related to the intended use or the basic definition especially for materials containing gypsum or other minerals having significant amounts of hydrated water or for soil containing a significant amount of organic material. In many cases, and depending on the intended use for these types of materials, it might be more applicable to maintain the drying oven at 60 ± 5°C or use a vacuum desiccator at a vacuum of approximately 133 Pa (10 mm Hg) and at a temperature ranging between 23 and 60°C for drying. If either of these drying methods are used, it should be noted in the report of the results.

NOTE 6—Since some dry materials may absorb moisture from moist specimens, dried specimens should be removed before placing moist specimens in the oven. However, this requirement is not applicable if the previously dried specimens will remain in the drying oven for an additional time period of about 16 h.

7.4 After the material has dried to constant mass remove the container from the oven and replace the lid. Allow the material and container to cool to room temperature or until the container can be handled comfortably with bare hands and the operation of the balance will not be affected by convection currents. Determine the mass of the container and oven-dried material using the same balance as used in 7.2. Record this value.

7.4.1 If the container does not have a lid, weigh the container and material right after their temperatures are such that the operation of the balance will not be affected by convection currents or after cooling in a desiccator.

NOTE 7—Cooling in a desiccator is recommended since it prevents absorption of moisture from the atmosphere during cooling.

8. Calculation

8.1 Calculate the water content of the material as follows:

$$w = [(W_1 - W_2)/(W_2 - W_c)] \times 100 = \frac{W_w}{W_s} \times 100$$

where:

w = water content, %,

W_1 = mass of container and moist specimen, g,

W_2 = mass of container and oven-dried specimen, g,

W_c = mass of container, g,

W_w = mass of water, g, and

W_s = mass of solid particles, g.

9. Report

9.1 The report (data sheet) shall include the following:

9.1.1 Identification of the sample (material) being tested, by boring number, sample number, test number, etc.

9.1.2 Water content of the specimen to the nearest 0.1 % or 1 %, depending on the purpose of the test.

9.1.3 Indication of test specimen having a mass less than the minimum indicated in Section 6.

9.1.4 Indication of test specimen containing more than one soil type (layered, etc).

9.1.5 Indication of the method of drying if different from oven-drying at 110 ± 5°C.

9.1.6 Indication of any material (size and amount) excluded from the test specimen.

10. Precision and Accuracy

10.1 Requirements for the precision and accuracy of this test method have not yet been developed.

Designation: D 4318 - 84

Standard Test Method for
LIQUID LIMIT, PLASTIC LIMIT, AND PLASTICITY INDEX OF SOILS[1]

This standard is issued under the fixed designation D 4318; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This test method has been approved for use by agencies of the Department of Defense and for listing in the DoD Index of Specifications and Standards

1. Scope

1.1 This test method covers the determination of the liquid limit, plastic limit, and the plasticity index of soils as defined in Section 3.

1.1.1 Two procedures for preparing test specimens and two procedures for performing the liquid limit are provided as follows:

- *A* Multipoint test using a wet preparation procedure, described in Sections 10.1, 11, and 12.
- *B* Multipoint test using a dry preparation procedure, described in Sections 10.2, 11, and 12.
- *C* One-point test using a wet preparation procedure, described in Sections 13, 14, and 15.
- *D* One-point test using a dry preparation procedure, described in Sections 13, 14, and 15.

The procedure to be used shall be specified by the requesting authority. If no procedure is specified, Procedure A shall be used.

NOTE 1—Prior to the adoption of this test method, a curved grooving tool was specified as part of the apparatus for performing the liquid limit test. The curved tool is not considered to be as accurate as the flat tool described in 6.2 since it does not control the depth of the soil in the liquid limit cup. However, there are some data which indicate that typically the liquid limit is slightly increased when the flat tool is used instead of the curved tool.

1.1.2 The plastic limit test procedure is described in Sections 16, 17, and 18. The plastic limit test is performed on material prepared for the liquid limit test. In effect, there are two procedures for preparing test specimens for the plastic limit.

1.1.3 The procedure for calculating the plasticity index is given in Section 19.

1.2 The liquid limit and plastic limit of soils (along with the shrinkage limit) are often collectively referred to as the Atterberg limits in recognition of their formation by Swedish soil scientist, A. Atterberg. These limits distinguish the boundaries of the several consistency states of plastic soils.

1.3 As used in this test method, soil is any natural aggregation of mineral or organic materials, mixtures of such materials, or artificial mixtures of aggregates and natural mineral and organic particles.

1.4 The multipoint liquid limit procedure is somewhat more time consuming than the one-point procedure when both are performed by experienced operators. However, the one-point procedure requires the operator to judge when the test specimen is approximately at its liquid limit. In cases where this is not done reliably, the multipoint procedure is as fast as the one-point procedure and provides additional precision due to the information obtained from additional trials. It is particularly recommended that the multipoint procedure be used by inexperienced operators.

1.5 The correlations on which the calculations of the one-point procedure are based may not be valid for certain soils, such as organic soils or soils from a marine environment. The liquid limit of these soils should therefore be determined by the multipoint procedure (Procedure A).

1.6 The liquid and plastic limits of many soils that have been allowed to dry before testing may be considerably different from values obtained on undried samples. If the liquid and plastic limits of soils are used to correlate or estimate the engineering behavior of soils in their natural moist state, samples should not be permitted to dry before testing unless data on dried samples are specifically desired.

1.7 The composition and concentration of soluble salts in a soil affect the values of the liquid and plastic limits as well as the water content values of soils (see Method D 2216). Special consideration should therefore be given to soils from a marine environment or other sources where high soluble salt concentrations may be present. The degree to which the salts present in these soils are diluted or concentrated must be given consideration if meaningful results are to be obtained.

1.8 Since the tests described herein are performed only on that portion of a soil which passes the 425-μm (No. 40) sieve, the relative contribution of this portion of the soil to the properties of the sample as a whole must be considered when using these tests to evaluate the properties of a soil.

1.9 The values stated in acceptable metric units are to be regarded as the standard. The values given in parentheses are for information only.

1.10 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Applicable Documents

2.1 *ASTM Standards:*

C 702 Methods for Reducing Field Samples of Aggregate to Testing Size[2]
D 75 Practice for Sampling Aggregates[3]
D 420 Recommended Practice for Investigating and Sampling Soil and Rock for Engineering Purposes[4]
D 653 Terms and Symbols Relating to Soil and Rock[4]
D 1241 Specification for Materials for Soil-Aggregate Subbase, Base, and Surface Courses[4]
D 2216 Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures[4]
D 2240 Test Method for Rubber Property—Durometer Hardness[5]
D 2487 Test Method for Classification of Soils for Engineering Purposes[4]
D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)
D 3282 Practice for Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes[4]
E 11 Specification for Wire-Cloth Sieves for Testing Purposes[6]
E 319 Methods of Testing Single-Arm Balances[6]
E 898 Method of Testing Top-Loading Direct-Reading Laboratory Scales and Balances[6]

3. Definitions

3.1 *Atterberg limits*—originally, seven "limits of consistency" of fine-grained soils were defined by Albert Atterberg. In current engineering usage, the term usually refers only to the liquid limit, plastic limit, and in some references, the shrinkage limit.

3.2 *consistency*—the relative ease with which a soil can be deformed.

3.3 *liquid limit (LL)*—the water content, in percent, of a soil at the arbitrarily defined boundary between the liquid and plastic states. This water content is defined as the water content at which a pat of soil placed in a standard cup and cut by a groove of standard dimensions will flow together at the base of the groove for a distance of 13 mm (½ in.) when subjected to 25 shocks from the cup being dropped 10 mm in a standard liquid limit apparatus operated at a rate of 2 shocks per second.

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[2] *Annual Book of ASTM Standards*, Vol 04.02.

[3] *Annual Book of ASTM Standards*, Vols 04.02, 04.03, and 04.08.

[4] *Annual Book of ASTM Standards*, Vol 04.08.

[5] *Annual Book of ASTM Standards*, Vol 09.01.

[6] *Annual Book of ASTM Standards*, Vo'

Note 2—The undrained shear strength of soil at the liquid limit is considered to be 2 ±0.2 kPa (0.28 psi).

3.4 *plastic limit (PL)*—the water content, in percent, of a soil at the boundary between the plastic and brittle states. The water content at this boundary is the water content at which a soil can no longer be deformed by rolling into 3.2 mm (⅛ in.) in diameter threads without crumbling.

3.5 *plastic soil*—a soil which has a range of water content over which it exhibits plasticity and which will retain its shape on drying.

3.6 *plasticity index (PI)*—the range of water content over which a soil behaves plastically. Numerically, it is the difference between the liquid limit and the plastic limit.

3.7 *liquidity index*—the ratio, expressed as a percentage, of (*1*) the natural water content of a soil minus its plastic limit, to (*2*) its plasticity index.

3.8 *activity number (A)*—the ratio of (*1*) the plasticity index of a soil to (*2*) the percent by weight of particles having an equivalent diameter smaller than 0.002 mm.

4. Summary of Method

4.1 The sample is processed to remove any material retained on a 425-μm (No. 40) sieve. The liquid limit is determined by performing trials in which a portion of the sample is spread in a brass cup, divided in two by a grooving tool, and then allowed to flow together from the shocks caused by repeatedly dropping the cup in a standard mechanical device. The multipoint liquid limit, Procedures A and B, requires three or more trials over a range of water contents to be performed and the data from the trials plotted or calculated to make a relationship from which the liquid limit is determined. The one-point liquid limit, Procedures C and D, uses the data from two trials at one water content multiplied by a correction factor to determine the liquid limit.

4.2 The plastic limit is determined by alternately pressing together and rolling into a 3.2 mm (⅛ in.) diameter thread a small portion of plastic soil until its water content is reduced to a point at which the thread crumbles and is no longer able to be pressed together and rerolled. The water content of the soil at this stage is reported as the plastic limit.

4.3 The plasticity index is calculated as the difference between the liquid limit and the plastic limit.

5. Significance and Use

5.1 This test method is used as an integral part of several engineering classification systems to characterize the fine-grained fractions of soils (see Test Method D 2487 and Practice D 3282) and to specify the fine-grained fraction of construction materials (see Specification D 1241). The liquid limit, plastic limit, and plasticity index of soils are also used extensively, either individually or together with other soil properties to correlate with engineering behavior such as compressibility, permeability, compactibility, shrink-swell, and shear strength.

5.2 The liquid and plastic limits of a soil can be used with the natural water content of the soil to express its relative consistency or liquidity index and can be used with the percentage finer than 2-μm size to determine its activity number.

5.3 The one-point liquid limit procedure is frequently used for routine classification purposes. When greater precision is required, as when used for the acceptance of a material or for correlation with other test data, the multipoint procedure should be used.

5.4 These methods are sometimes used to evaluate the weathering characteristics of clay-shale materials. When subjected to repeated wetting and drying cycles, the liquid limits of these materials tend to increase. The amount of increase is considered to be a measure of a shale's susceptibility to weathering.

5.5 The liquid limit of a soil containing substantial amounts of organic matter decreases dramatically when the soil is oven-dried before testing. Comparison of the liquid limit of a sample before and after oven-drying can therefore be used as a qualitative measure of organic matter content of a soil.

6. Apparatus

6.1 *Liquid Limit Device*—A mechanical device consisting of a brass cup suspended from a carriage designed to control its drop onto a hard rubber base. A drawing showing the essential features of the device and the critical dimensions is given in Fig. 1. The design of the device may vary provided that the essential functions are preserved. The device may be operated either by a hand crank or by an electric motor.

6.1.1 *Base*—The base shall be hard rubber having a D Durometer hardness of 80 to 90, and a resilience such that an 8-mm (5/16-in.) diameter polished steel ball, when dropped from a height of 25 cm (9.84 in.) will have an average rebound of at least 80 % but no more than 90 %. The tests shall be conducted on the finished base with feet attached.

6.1.2 *Feet*—The base shall be supported by rubber feet designed to provide isolation of the base from the work surface and having an A Durometer hardness no greater than 60 as measured on the finished feet attached to the base.

6.1.3 *Cup*—The cup shall be brass and have a weight, including cup hanger, of 185 to 215 g.

6.1.4 *Cam*—The cam shall raise the cup smoothly and continuously to its maximum height, over a distance of at least 180° of cam rotation. The preferred cam motion is a uniformly accelerated lift curve. The design of the cam and follower combination shall be such that there is no upward or downward velocity of the cup when the cam follower leaves the cam.

Note 3—The cam and follower design in Fig. 1 is for uniformly accelerated (parabolic) motion after contact and assures that the cup has no velocity at drop off. Other cam designs also provide this feature and may be used. However, if the cam-follower lift pattern is not known, zero velocity at drop off can be assured by carefully filing or machining the cam and follower so that the cup height remains constant over the last 20 to 45° of cam rotation.

6.1.5 *Carriage*—The cup carriage shall be constructed in a way that allows convenient but secure adjustment of the height of drop of the cup to 10 mm (0.394 in.). The cup hanger shall be attached to the carriage by means of a pin which allows removal of the cup and cup hanger for cleaning and inspection.

6.1.6 *Optional Motor Drive*—As an alternative to the hand crank shown in Fig. 1, the device may be equipped with a motor to turn the cam. Such a motor must turn the cam at 2 ±0.1 revolutions per second, and must be isolated from the rest of the device by rubber mounts or in some other way that prevents vibration from the motor being transmitted to the rest of the apparatus. It must be equipped with an ON-OFF switch and a means of conveniently positioning the cam for height of drop adjustments. The results obtained using a motor-driven device must not differ from those obtained using a manually operated device.

6.2 *Flat Grooving Tool*—A grooving tool having dimensions shown in Fig. 2. The tool shall be made of plastic or noncorroding metal. The design of the tool may vary as long as the essential dimensions are maintained. The tool may, but need not, incorporate the gage for adjusting the height of drop of the liquid limit device.

6.3 *Gage*—A metal gage block for adjusting the height of drop of the cup, having the dimensions shown in Fig. 3. The design of the tool may vary provided the gage will rest securely on the base without being susceptible to rocking, and the edge which contacts the cup during adjustment is straight, at least 10 mm (⅜ in.) wide, and without bevel or radius.

6.4 *Containers*—Small corrosion-resistant containers with snug-fitting lids for water content specimens. Aluminum or stainless steel cans 2.5 cm (1 in.) high by 5 cm (2 in.) in diameter are appropriate.

6.5 *Balance*—A balance readable to at least 0.01 g and having an accuracy of 0.03 g within three standard deviations within the range of use. Within any 15-g range, a difference between readings shall be accurate within 0.01 g (Notes 4 and 5).

Note 4—See Methods E 898 and E 319 for an explanation of terms relating to balance performance.

Note 5—For frequent use, a top-loading type balance with automatic load indication, readable to 0.01 g, and having an index of precision (standard deviation) of 0.003 or better is most suitable for this method. However, nonautomatic indicating equal-arm analytical balances and some small equal arm top pan balances having readabilities and sensitivities of 0.002 g or better provide the required accuracy when used with a weight set of ASTM Class 4 (National Bureau of Standards Class P) or better. Ordinary commercial and classroom type balances such as beam balances are not suitable for this method.

6.6 *Storage Container*—A container in which to store the prepared soil specimen that will not contaminate the specimen in any way, and which prevents moisture loss. A porcelain, glass, or plastic dish about 11.4 cm (4½ in.) in diameter and a plastic bag large enough to enclose the dish and be folded over is adequate.

6.7 *Ground Glass Plate*—A ground glass plate at least 30 cm (12 in.) square by 1 cm (⅜ in.) thick for mixing soil and rolling plastic limit threads.

6.8 *Spatula*—A spatula or pill knife having a blade about 2 cm (¾ in.) wide by about 10 cm (4 in.) long. In addition, a spatula having a blade about 2.5 cm (1 in.) wide and 15 cm (6 in.) long has been found useful for initial mixing of samples.

6.9 *Sieve*—A 20.3 cm (8 in.) diameter, 425-μm (No. 40) sieve conforming to the requirements of Specification E 11 and having a rim at least 5 cm (2 in.) above the mesh. A 2-mm (No. 10) sieve meeting the same requirements may also be needed.

6.10 *Wash Bottle*, or similar container for adding controlled amounts of water to soil and washing fines from coarse particles.

6.11 *Drying Oven*—A thermostatically controlled oven, preferably of the forced-draft type, capable of continuously maintaining a temperature of 110 ± 5°C throughout the drying chamber. The oven shall be equipped with a thermometer of suitable range and accuracy for monitoring oven temperature.

6.12 *Washing Pan*—A round, flat-bottomed pan at least 7.6 cm (3 in.) deep, slightly larger at the bottom than a 20.3-cm (8-in.) diameter sieve.

6.13 *Rod* (optional)—A metal or plastic rod or tube 3.2 mm (⅛ in.) in diameter and about 10 cm (4 in.) long for judging the size of plastic limit threads.

7. Materials

7.1 A supply of distilled or demineralized water.

8. Sampling

8.1 Samples may be taken from any location that satisfies testing needs. However, Methods C 702, and Practice D 75, and Recommended Practice D 420 should be used as guides for selecting and preserving samples from various types of sampling operations. Samples which will be prepared using the wet preparation procedure, 10.1, must be kept at their natural water content prior to preparation.

8.2 Where sampling operations have preserved the natural stratification of a sample, the various strata must be kept separated and tests performed on the particular stratum of interest with as little contamination as possible from other strata. Where a mixture of materials will be used in construction, combine the various components in such proportions that the resultant sample represents the actual construction case.

8.3 Where data from this test method are to be used for correlation with other laboratory or field test data, use the same material as used for these tests where possible.

8.4 Obtain a representative portion from the total sample sufficient to provide 150 to 200 g of material passing the 425-μm (No. 40) sieve. Free flowing samples may be reduced by the methods of quartering or splitting. Cohesive samples shall be mixed thoroughly in a pan with a spatula, or scoop and a representative portion scooped from the total mass by making one or more sweeps with a scoop through the mixed mass.

9. Calibration of Apparatus

9.1 *Inspection of Wear:*

9.1.1 *Liquid Limit Device*—Determine that the liquid limit device is clean and in good working order. The following specific points should be checked:

9.1.1.1 *Wear of Base*—The spot on the base where the cup makes contact should be worn no greater than 10 mm (⅜ in.) in diameter. If the wear spot is greater than this, the base can be machined to remove the worn spot provided the resurfacing does not make the base thinner than specified in 6.1 and the other dimensional relationships are maintained.

9.1.1.2 *Wear of Cup*—The cup must be replaced when the grooving tool has worn a depression in the cup 0.1 mm (0.004 in.) deep or when the edge of the cup has been reduced to half its original thickness. Verify that the cup is firmly attached to the cup hanger.

9.1.1.3 *Wear of Cup Hanger*—Verify that the cup hanger pivot does not bind and is not worn to an extent that allows more than 3-mm (⅛-in.) side-to-side movement of the lowest point on the rim.

9.1.1.4 *Wear of Cam*—The cam shall not be worn to an extent that the cup drops before the cup hanger (cam follower) loses contact with the cam.

9.1.2 *Grooving Tools*—Inspect grooving tools for wear on a frequent and regular basis. The rapidity of wear depends on the material from which the tool is made and the types of soils being tested. Sandy soils cause rapid wear of grooving tools; therefore, when testing these materials, tools should be inspected more frequently than for other soils. Any tool with a tip width greater than 2.1 mm must not be used. The depth of the tip of the grooving tool must be 7.9 to 8.1 mm.

NOTE 6—The width of the tip of grooving tools is conveniently checked using a pocket-sized measuring magnifier equipped with a millimetre scale. Magnifiers of this type are available from most laboratory supply companies. The depth of the tip of grooving tools can be checked using the depth measuring feature of vernier calipers.

9.2 *Adjustment of Height of Drop*—Adjust the height of drop of the cup so that the point on the cup that comes in contact with the base rises to a height of 10 ±0.2 mm. See Fig. 4 for proper location of the gage relative to the cup during adjustment.

NOTE 7—A convenient procedure for adjusting the height of drop is as follows: place a piece of masking tape across the outside bottom of the cup parallel with the axis of the cup hanger pivot. The edge of the tape away from the cup hanger should bisect the spot on the cup that contacts the base. For new cups, placing a piece of carbon paper on the base and allowing the cup to drop several times will mark the contact spot. Attach the cup to the device and turn the crank until the cup is raised to its maximum height. Slide the height gage under the cup from the front, and observe whether the gage contacts the cup or the tape. See Fig. 4. If the tape and cup are both contacted, the height of drop is approximately correct. If not, adjust the cup until simultaneous contact is made. Check adjustment by turning the crank at 2 revolutions per second while holding the gage in position against the tape and cup. If a ringing or clicking sound is heard without the cup rising from the gage, the adjustment is correct. If no ringing is heard or if the cup rises from the gage, readjust the height of drop. If the cup rocks on the gage during this checking operation, the cam follower pivot is excessively worn and the worn parts should be replaced. Always remuse tape after completion of adjustment operation.

MULTIPOINT LIQUID LIMIT—PROCEDURES A AND B

10. Preparation of Test Specimens

10.1 *Wet Preparation*—Except where the dry method of specimen preparation is specified (10.2), prepare specimens for test as described in the following sections.

10.1.1 *Samples Passing the 425-μm (No. 40) Sieve*—When by visual and manual procedures it is determined that the sample has little or no material retained on a 425-μm (No. 40) sieve, prepare a specimen of 150 to 200 g by mixing thoroughly with distilled or demineralized water on the glass plate using the spatula. If desired, soak soil in a storage dish with small amount of water to soften the soil before the start of mixing. Adjust the water content of the soil to bring it to a consistency that would require 25 to 35 blows of the liquid limit device to close the groove (Note 8). If, during mixing, a small percentage of material is encountered that would be retained on a 425-μm (No. 40) sieve, remove these particles by hand, if possible. If it is impractical to remove the coarser material by hand, remove small percentages (less than about 15 %) of coarser material by working the specimen through a 425-μm (No. 40) sieve using a piece of rubber sheeting, rubber stopper, or other convenient device provided the operation does not distort the sieve or degrade material that would be retained if the washing method described in 10.1.2 were used. If larger percentages of coarse material are encountered during mixing, or it is considered impractical to remove the coarser material by the methods just described, wash the sample as described in 10.1.2. When the coarse particles found during mixing are concretions, shells, or other fragile particles, do not crush these particles to make them pass a 425-μm (No. 40) sieve, but remove by hand or by washing. Place the mixed soil in the storage dish, cover to prevent loss of moisture, and allow to stand for at least 16 h (overnight). After the standing period and immediately before starting the test, thoroughly remix the soil.

NOTE 8—The time taken to adequately mix a soil will vary greatly, depending on the plasticity and initial water content. Initial mixing times of more than 30 min may be needed for stiff, fat clays.

10.1.2 *Samples Containing Material Retained on a 425-μm (No. 40) Sieve:*

10.1.2.1 Select a sufficient quantity of soil at natural water content to provide 150 to 200 g of material passing the 425-μm (No. 40) sieve. Place in a pan or dish and add sufficient water to cover the soil. Allow to soak until all lumps have softened and the fines no longer adhere to the surfaces of the corase particles (Note 9).

NOTE 9—In some cases, the cations of salts present in tap water will exchange with the natural cations in the soil and significantly alter the test results should tap water be used in the soaking and washing operations. Unless it is known that such cations are not present in the tap water, distilled or demineralized water should be used. As a general rule, water containing more than 100 mg/L of dissolved solids should not be used for washing operations.

10.1.2.2 When the sample contains a large percentage of material retained on the 425-μm

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(No. 40) sieve, perform the following washing operation in increments, washing no more than 0.5 kg (1 lb) of material at one time. Place the 425-μm (No. 40) sieve in the bottom of the clean pan. Pour the soil water mixture onto the sieve. If gravel or coarse sand particles are present, rinse as many of these as possible with small quantities of water from a wash bottle, and discard. Alternatively, pour the soil water mixture over a 2-mm (No. 10) sieve nested atop the 425-μm (No. 40) sieve, rinse the fine material through and remove the 2-mm (No. 10) sieve. After washing and removing as much of the coarser material as possible, add sufficient water to the pan to bring the level to about 13 mm (½ in.) above the surface of the 425-μm (No. 40) sieve. Agitate the slurry by stirring with the fingers while raising and lowering the sieve in the pan and swirling the suspension so that fine material is washed from the coarser particles. Disaggregate fine soil lumps that have not slaked by gently rubbing them over the sieve with the fingertips. Complete the washing operation by raising the sieve above the water surface and rinsing the material retained with a small amount of clean water. Discard material retained on the 425-μm (No. 40) sieve.

10.1.2.3 Reduce the water content of the material passing the 425-μm (No. 40) sieve until it approaches the liquid limit. Reduction of water content may be accomplished by one or a combination of the following methods: (*a*) exposing the air currents at ordinary room temperature, (*b*) exposing to warm air currents from a source such as an electric hair dryer, (*c*) filtering in a Buckner funnel or using filter candles, (*d*) decanting clear water from surface of suspension, or (*e*) draining in a colander or plaster of paris dish lined with high retentivity, high wet-strength filter paper.[7] If a plaster of paris dish is used, take care that the dish never becomes sufficiently saturated that it fails to actively absorb water into its surface. Thoroughly dry dishes between uses. During evaporation and cooling, stir the sample often enough to prevent overdrying of the fringes and soil pinnacles on the surface of the mixture. For soil samples containing soluble salts, use a method of water reduction such as *a* or *b* that will not eliminate the soluble salts from the test specimen.

10.1.2.4 Thoroughly mix the material passing the 425-μm (No. 40) sieve on the glass plate using the spatula. Adjust the water content of the mixture, if necessary, by adding small increments of distilled or demineralized water or by allowing the mixture to dry at room temperature while mixing on the glass plate. The soil should be at a water content that will result in closure of the groove in 25 to 35 blows. Return the mixed soil to the mixing dish, cover to prevent loss of moisture, and allow to stand for at least 16 h. After the standing period, and immediately before starting the test, remix the soil thoroughly.

10.2 *Dry Preparation:*

10.2.1 Select sufficient soil to provide 150 to 200 g of material passing the 425-μm (No. 40) sieve after processing. Dry the sample at room temperature or in an oven at a temperature not exceeding 60°C until the soil clods will pulverize readily. Disaggregation is expedited if the sample is not allowed to completely dry. However, the soil should have a dry appearance when pulverized. Pulverize the sample in a mortar with a rubber tipped pestal or in some other way that does not cause breakdown of individual grains. When the coarse particles found during pulverization are concretions, shells, or other fragile particles, do not crush these particles to make them pass a 425-μm (No. 40) sieve, but remove by hand or other suitable means, such as washing.

10.2.2 Separate the sample on a 425-μm (No. 40) sieve, shaking the sieve by hand to assure thorough separation of the finer fraction. Return the material retained on the 425-μm (No. 40) sieve to the pulverizing apparatus and repeat the pulverizing and sieving operations as many times as necessary to assure that all finer material has been disaggregated and material retained on the 425-μm (No. 40) sieve consists only of individual sand or gravel grains.

10.2.3 Place material remaining on the 425-μm (No. 40) sieve after the final pulverizing operations in a dish and soak in a small amount of water. Stir the soil water mixture and pour over the 425-μm (No. 40) sieve, catching the water and any suspended fines in the washing pan. Pour this suspension into a dish containing the dry soil previously sieved through the 425-μm (No. 40) sieve. Discard material retained on the 425-μm (No. 40) sieve.

10.2.4 Adjust the water content as necessary by drying as described in 10.1.2.3 or by mixing on the glass plate, using the spatula while adding increments of distilled or demineralized water, until the soil is at a water content that will result in closure of the groove in 25 to 35 blows.

10.2.5 Put soil in the storage dish, cover to prevent loss of moisture and allow to stand for at least 16 h. After the standing period, and immediately before starting the test, thoroughly remix the soil (Note 8).

11. Procedure

11.1 Place a portion of the prepared soil in the cup of the liquid limit device at the point where the cup rests on the base, squeeze it down, and spread it into the cup to a depth of about 10 mm at its deepest point, tapering to form an approximately horizontal surface. Take care to eliminate air bubbles from the soil pat but form the pat with as few strokes as possible. Heap the unused soil on the glass plate and cover with the inverted storage dish or a wet towel.

11.2 Form a groove in the soil pat by drawing the tool, beveled edge forward, through the soil on a line joining the highest point to the lowest point on the rim of the cup. When cutting the groove, hold the grooving tool against the surface of the cup and draw in an arc, maintaining the tool perpendicular to the surface of the cup throughout its movement. See Fig. 5. In soils where a groove cannot be made in one stroke without tearing the soil, cut the groove with several strokes of the grooving tool. Alternatively, cut the groove to slightly less than required dimensions with a spatula and use the grooving tool to bring the groove to final dimensions. Exercise extreme care to prevent sliding the soil pat relative to the surface of the cup.

11.3 Verify that no crumbs of soil are present on the base or the underside of the cup. Lift and drop the cup by turning the crank at a rate of 1.9 to 2.1 drops per second until the two halves of the soil pat come in contact at the bottom of the groove along a distance of 13 mm (½ in.). See Fig. 6.

NOTE 10—Use the end of the grooving tool, Fig. 2, or a scale to verify that the groove has closed 13 mm (½ in.).

11.4 Verify that an air bubble has not caused premature closing of the groove by observing that both sides of the groove have flowed together with approximately the same shape. If a bubble has caused premature closing of the groove, reform the soil in the cup, adding a small amount of soil to make up for that lost in the grooving operation and repeat 11.1 to 11.3. If the soil slides on the surface of the cup, repeat 11.1 through 11.3 at a higher water content. If, after several trials at successively higher water contents, the soil pat continues to slide in the cup or if the number of blows required to close the groove is always less than 25, record that the liquid limit could not be determined, and report the soil as nonplastic without performing the plastic limit test.

11.5 Record the number of drops, *N*, required to close the groove. Remove a slice of soil approximately the width of the spatula, extending from edge to edge of the soil cake at right angles to the groove and including that portion of the groove in which the soil flowed together, place in a weighed container, and cover.

11.6 Return the soil remaining in the cup to the glass plate. Wash and dry the cup and grooving tool and reattach the cup to the carriage in preparation for the next trial.

11.7 Remix the entire soil specimen on the glass plate adding distilled water to increase the water content of the soil and decrease the number of blows required to close the groove. Repeat 11.1 through 11.6 for at least two additional trials producing successively lower numbers of blows to close the groove. One of the trials shall be for a closure requiring 25 to 35 blows, one for closure between 20 and 30 blows, and one trial for a closure requiring 15 to 25 blows.

11.8 Determine the water content, W_N, of the soil specimen from each trial in accordance with Method D 2216. Make all weighings on the same balance. Initial weighings should be performed immediately after completion of the test. If the test is to be interrupted for more than about 15 min, the specimens already obtained should be weighed at the time of the interruption.

12. Calculations

12.1 Plot the relationship between the water content, W_N, and the corresponding number of drops, *N*, of the cup on a semilogarithmic graph with the water content as ordinates on the arithmetical scale, and the number of drops as abscissas on the logarithmic scale. Draw the best straight line through the three or more plotted points.

12.2 Take the water content corresponding to the intersection of the line with the 25-drop abscissa as the liquid limit of the soil. Computa-

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[7] S and S 595 filter paper, available in 32-cm circles, has proven satisfactory.

ional methods may be substituted for the graphical method for fitting a straight line to the data and determining the liquid limit.

ONE-POINT LIQUID LIMIT—PROCEDURES C AND D

13. Preparation of Test Specimens

13.1 Prepare the specimen in the same manner as described in Section 10, except that at mixing, adjust the water content to a consistency requiring 20 to 30 drops of the liquid limit cup to close the groove.

14. Procedure

14.1 Proceed as described in 11.1 through 11.5 except that the number of blows required to close the groove shall be 20 to 30. If less than 20 or more than 30 blows are required, adjust the water content of the soil and repeat the procedure.

14.2 Immediately after removing a water content specimen as described in 11.5, reform the soil in the cup, adding a small amount of soil to make up for that lost in the grooving and water content sampling operations. Repeat 11.2 through 11.5, and, if the second closing of the groove requires the same number of drops or no more than two drops difference, secure another water content specimen. Otherwise, remix the entire specimen and repeat.

NOTE 11—Excessive drying or inadequate mixing will cause the number of blows to vary.

14.3 Determine water contents of specimens as described in 11.8.

15. Calculations

15.1 Determine the liquid limit for each water content specimen using one of the following equations:

$$LL = W_N\left(\frac{N}{25}\right)^{0.121} \quad \text{or}$$

$$LL = K(W_N)$$

where:

N = the number of blows causing closure of the groove at water content,

W_N = water content, and

K = a factor given in Table 1.

The liquid limit is the average of the two trial liquid limit values.

15.2 If the difference between the two trial liquid limit values is greater than one percentage point, repeat the test.

PLASTIC LIMIT

16. Preparation of Test Specimen

16.1 Select a 20-g portion of soil from the material prepared for the liquid limit test, either after the second mixing before the test, or from the soil remaining after completion of the test. Reduce the water content of the soil to a consistency at which it can be rolled without sticking to the hands by spreading and mixing continuously on the glass plate. The drying process may be accelerated by exposing the soil to the air current from an electric fan, or by blotting with paper that does not add any fiber to the soil, such as hard surface paper toweling or high wet strength filter paper.

17. Procedure

17.1 From the 20-g mass, select a portion of 1.5 to 2.0 g. Form the test specimen into an ellipsoidal mass. Roll this mass between the palm or fingers and the ground-glass plate with just sufficient pressure to roll the mass into a thread of uniform diameter throughout its length (Note 12). The thread shall be further deformed on each stroke so that its diameter is continuously reduced and its length extended until the diameter reaches 3.2 ±0.5 mm (0.125 ±.020 in.), taking no more than 2 min (Note 13). The amount of hand or finger pressure required will vary greatly, according to the soil. Fragile soils of low plasticity are best rolled under the outer edge of the palm or at the base of the thumb.

NOTE 12—A normal rate of rolling for most soils should be 80 to 90 strokes per minute, counting a stroke as one complete motion of the hand forward and back to the starting position. This rate of rolling may have to be decreased for very fragile soils.

NOTE 13—A 3.2-mm (⅛-in.) diameter rod or tube is useful for frequent comparison with the soil thread to ascertain when the thread has reached the proper diameter, especially for inexperienced operators.

17.1.1 When the diameter of the thread becomes 3.2 mm, break the thread into several pieces. Squeeze the pieces together, knead between the thumb and first finger of each hand, reform into an ellipsoidal mass, and reroll. Continue this alternate rolling to a thread 3.2 mm in diameter, gathering together, kneading and rerolling, until the thread crumbles under the pressure required for rolling and the soil can no longer be rolled into a 3.2-mm diameter thread (See Fig. 7). It has no significance if the thread breaks into threads of shorter length. Roll each of these shorter threads to 3.2 mm in diameter. The only requirement for continuing the test is that they are able to be reformed into an ellipsoidal mass and rolled out again. The operator shall at no time attempt to produce failure at exactly 3.2 mm diameter by allowing the thread to reach 3.2 mm, then reducing the rate of rolling or the hand pressure, or both, while continuing the rolling without further deformation until the thread falls apart. It is permissible, however, to reduce the total amount of deformation for feebly plastic soils by making the initial diameter of the ellipsoidal mass nearer to the required 3.2-mm final diameter. If crumbling occurs when the thread has a diameter greater than 3.2 mm, this shall be considered a satisfactory end point, provided the soil has been previously rolled into a thread 3.2 mm in diameter. Crumbling of the thread will manifest itself differently with the various types of soil. Some soils fall apart in numerous small aggregations of particles, others may form an outside tubular layer that starts splitting at both ends. The splitting progresses toward the middle, and finally, the thread falls apart in many small platy particles. Fat clay soils require much pressure to deform the thread, particularly as they approach the plastic limit. With these soils, the thread breaks into a series of barrel-shaped segments about 3.2 to 9.5 mm (⅛ to ⅜ in.) in length.

17.2 Gather the portions of the crumbled thread together and place in a weighed container. Immediately cover the container.

17.3 Select another 1.5 to 2.0 g portion of soil from the original 20-g specimen and repeat the operations described in 17.1 and 17.2 until the container has at least 6 g of soil.

17.4 Repeat 17.1 through 17.3 to make another container holding at least 6 g of soil. Determine the water content, in percent, of the soil contained in the containers in accordance with Method D 2216. Make all weighings on the same balance.

NOTE 14—The intent of performing two plastic limit trials is to verify the consistency of the test results. It is acceptable practice to perform only one plastic limit trial when the consistency in the test results can be confirmed by other means.

18. Calculations

18.1 Compute the average of the two water contents. If the difference between the two water contents is greater than two percentage points, repeat the test. The plastic limit is the average of the two water contents.

PLASTICITY INDEX

19. Calculations

19.1 Calculate the plasticity index as follows:

$$PI = LL - PL$$

where:

LL = the liquid limit,

PL = the plastic limit.

Both LL and PL are whole numbers. If either the liquid limit or plastic limit could not be determined, or if the plastic limit is equal to or greater than the liquid limit, report the soil as nonplastic, NP.

20. Report

20.1 Report the following information:

20.1.1 Sample identifying information,

20.1.2 Any special specimen selection process used, such as removal of sand lenses from undisturbed sample,

20.1.3 Report sample as airdried if the sample was airdried before or during preparation,

20.1.4 Liquid limit, plastic limit, and plasticity index to the nearest whole number and omitting the percent designation. If the liquid limit or plastic limit tests could not be performed, or if the plastic limit is equal to or greater than the liquid limit, report the soil as nonplastic, NP,

20.1.5 An estimate of the percentage of sample retained on the 425-μm (No. 40) sieve, and

20.1.6 Procedure by which liquid limit was performed, if it differs from the multipoint method.

21. Precision and Bias

21.1 No interlaboratory testing program has as yet been conducted using this test method to determine multilaboratory precision.

21.2 The within laboratory precision of the results of tests performed by different operators at one laboratory on two soils using Procedure A for the liquid limit is shown in Table 2.

TABLE 1 Factors for Obtaining Liquid Limit from Water Content and Number of Drops Causing Closure of Groove

N (Number of Drops)	K (Factor for Liquid Limit)
20	0.974
21	0.979
22	0.985
23	0.990
24	0.995
25	1.000
26	1.005
27	1.009
28	1.014
29	1.018
30	1.022

TABLE 2 Within Laboratory Precision for Liquid Limit

	Average Value, %	Standard Deviation, %
Soil A:		
PL	21.9	1.07
LL	27.9	1.07
Soil B:		
PL	20.1	1.21
LL	32.6	0.98

DIMENSIONS

LETTER	A△	B△	C△	E△	F	G	H	J△	K△	L△	M△
MM	54 ± 0.5	2 ± 0.1	27 ± 0.5	56 ± 2.0	32	10	16	60 ± 1.0	50 ± 2.0	150 ± 2.0	125 ± 2.0

LETTER	N	P	R	T	U△	V	W	Z
MM	24	28	24	45	47 ± 1.0	3.5	13	6.5

△ ESSENTIAL DIMENSIONS

CAM ANGLE DEGREES	CAM RADIUS
0	0.742 R
30	0.753 R
60	0.764 R
90	0.773 R
120	0.784 R
150	0.796 R
180	0.818 R
210	0.854 R
240	0.901 R
270	0.945 R
300	0.974 R
330	0.995 R
360	1.000 R

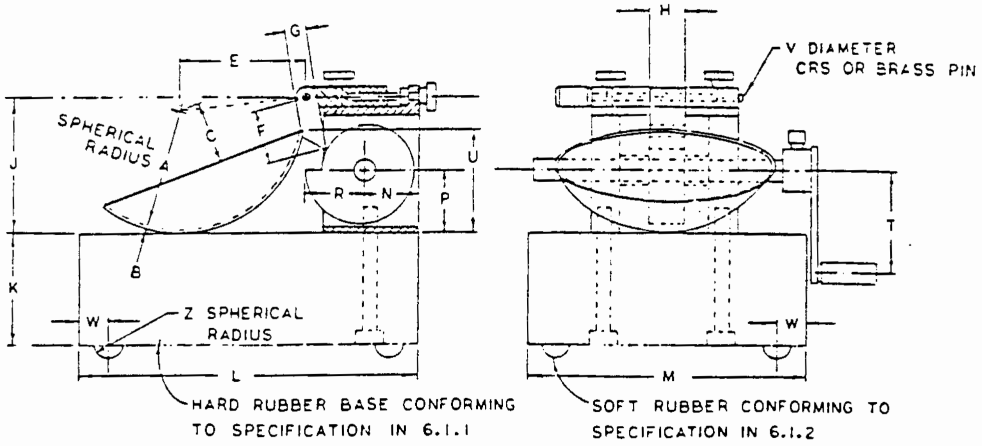

FIG. 1 Hand-Operated Liquid Limit Device

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DIMENSIONS

LETTER	A ^Δ^	B ^Δ^	C ^Δ^	D ^Δ^	E ^Δ^	F ^Δ^
MM	2 ± 0.1	11 ± 0.2	40 ± 0.5	8 ± 0.1	50 ± 0.5	2 ± 0.1
LETTER	G	H	J	K ^Δ^	L ^Δ^	N
MM	10 MINIMUM	13	60	10 ± 0.05	60 DEG ± 1 DEG	20

^Δ^ ESSENTIAL DIMENSIONS

^□^ BACK AT LEAST 15 MM FROM TIP

NOTE: DIMENSION A SHOULD BE 1.9–2.0 AND DIMENSION D SHOULD BE 8.0–8.1 WHEN NEW TO ALLOW FOR ADEQUATE SERVICE LIFE

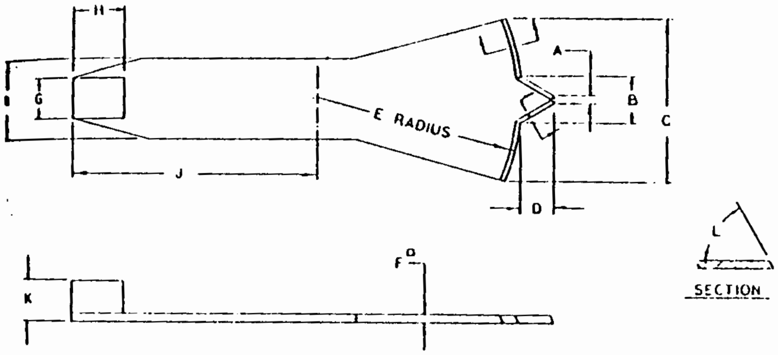
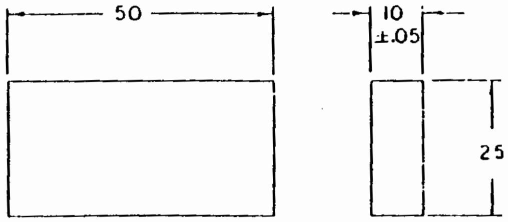


FIG. 2 Grooving Tool (Optional Height-of-Drop Gage Attached)



DIMENSIONS IN MILLIMETRES

FIG. 3 Height of Drop Gage

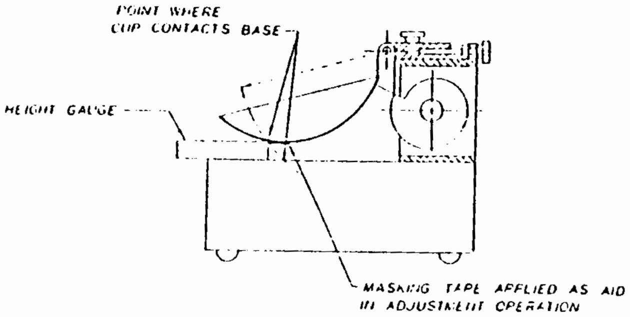


FIG. 4 Calibration for Height of Drop

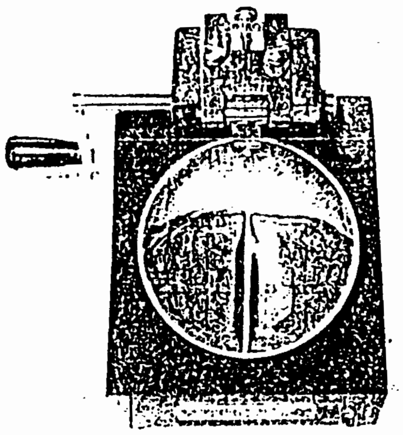


FIG. 5 Grooved Soil Pat in Liquid Limit Device

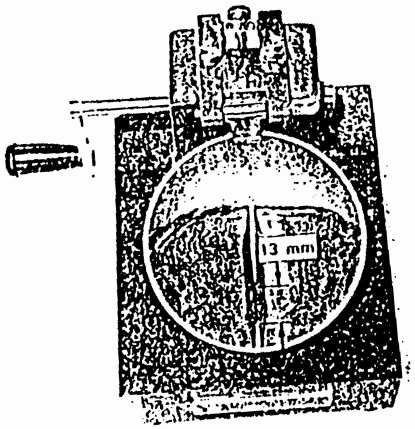


FIG. 6 Soil Pat After Groove Has Closed

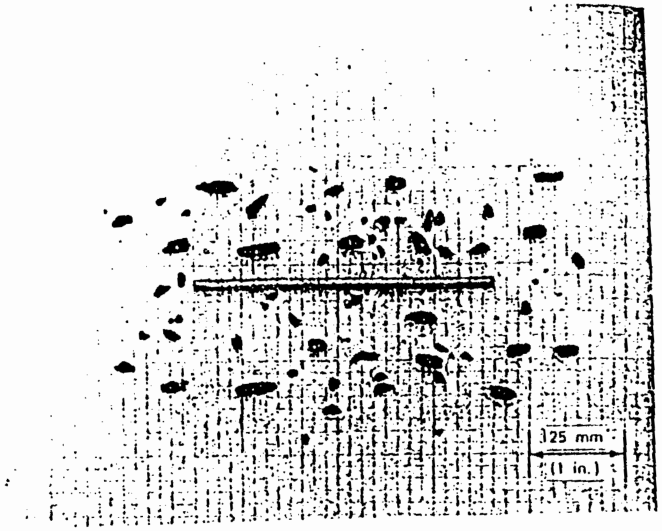


FIG. 7 Lean Clay Soil at the Plastic Limit

Designation: D 2488 – 84

Standard Practice for
DESCRIPTION AND IDENTIFICATION OF SOILS (VISUAL-MANUAL PROCEDURE)[1]

This standard is issued under the fixed designation D 2488; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice covers procedures for the description of soils for engineering purposes.

1.2 This practice also describes a procedure for identifying soils, at the option of the user, based on the classification system described in Test Method D 2487. The identification is based on visual examination and manual tests. It must be clearly stated in reporting an identification that it is based on visual-manual procedures.

1.2.1 When precise classification of soils for engineering purposes is required, the procedures prescribed in Test Method D 2487 shall be used.

1.2.2 In this practice, the identification portion assigning a group symbol and name is limited to soil particles smaller than 3 in. (75 mm).

1.2.3 The identification portion of this practice is limited to naturally occurring soils.

NOTE 1—This practice may be used as a descriptive system applied to such materials as shale, claystone, shells, crushed rock, etc. (See Appendix X2).

1.3 The descriptive information in this practice may be used with other soil classification systems or for materials other than naturally occurring soils.

1.4 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* For specific precautionary statements see Section 8.

1.5 The values stated in inch-pound units are to be regarded as the standard.

2. Applicable Documents

2.1 *ASTM Standards:*

D 653 Terms and Symbols Relating to Soil and Rock[2]

D 1452 Practice for Soil Investigation and Sampling by Auger Borings[2]

D 1586 Method for Penetration Test and Split-Barrel Sampling of Soils[2]

D 1587 Practice for Thin-Walled Tube Sampling of Soils[2]

D 2113 Practice for Diamond Core Drilling for Site Investigation[2]

D 2487 Test Method for Classification of Soils for Engineering Purposes[2]

3. Definitions

3.1 Except as listed below, all definitions are in accordance with Terms and Symbols D 653.

NOTE 2—For particles retained on a 3-in. (75-mm) US standard sieve, the following definitions are suggested:

Cobbles—particles of rock that will pass a 12-in. (300-mm) square opening and be retained on a 3-in. (75-mm) sieve, and

Boulders—particles of rock that will not pass a 12-in. (300-mm) square opening.

3.1.1 *clay*—soil passing a No. 200 (75-μm) sieve that can be made to exhibit plasticity (putty-like properties) within a range of water contents, and that exhibits considerable strength when air-dry. For classification, a clay is a fine-grained soil, or the fine-grained portion of a soil, with a plasticity index equal to or greater than 4, and the plot of plasticity index versus liquid limit falls on or above the "A" line (see Fig. 3 of Test Method D 2487).

3.1.2 *gravel*—particles of rock that will pass a 3-in. (75-mm) sieve and be retained on a No. 4 (4.75-mm) sieve with the following subdivisions:

course—passes a 3-in. (75-mm) sieve and is retained on a ¾-in. (19-mm) sieve.

fine—passes a ¾-in. (19-mm) sieve and is retained on a No. 4 (4.75-mm) sieve.

3.1.3 *organic clay*—a clay with sufficient organic content to influence the soil properties. For classification, an organic clay is a soil that would be classified as a clay, except that its liquid limit value after oven drying is less than 75 % of its liquid limit value before oven drying.

3.1.4 *organic silt*—a silt with sufficient organic content to influence the soil properties. For classification, an organic silt is a soil that would be classified as a silt except that its liquid limit value after oven drying is less than 75 % of its liquid limit value before oven drying.

3.1.5 *peat*—a soil composed primarily of vegetable tissue in various stages of decomposition usually with an organic odor, a dark brown to black color, a spongy consistency, and a texture ranging from fibrous to amorphous.

3.1.6 *sand*—particles of rock that will pass a No. 4 (4.75-mm) sieve and be retained on a No. 200 (75-μm) sieve with the following subdivisions:

course—passes a No. 4 (4.75-mm) sieve and is retained on a No. 10 (2.00-mm) sieve.

medium—passes a No. 10 (2.00-mm) sieve and is retained on a No. 40 (425-μm) sieve.

fine—passes a No. 40 (425-μm) sieve and is retained on a No. 200 (75-μm) sieve.

3.1.7 *silt*—soil passing a No. 200 (75-μm) sieve that is nonplastic or very slightly plastic and that exhibits little or no strength when air dry. For classification, a silt is a fine-grained soil, or the fine-grained portion of a soil, with a plasticity index less than 4, or the plot of plasticity index versus liquid limit falls below the "A" line (see Fig. 3 of Test Method D 2487).

4. Summary of Practice

4.1 Using visual examination and simple manual tests, this practice gives standardized criteria and procedures for describing and identifying soils.

4.2 The soil can be given an identification by assigning a group symbol(s) and name. The flow charts, Figs. 1a and 1b for fine-grained soils, and Fig. 2, for coarse-grained soils, can be used to assign the appropriate group symbol(s) and name. If the soil has properties which do not distinctly place it into a specific group, borderline symbols may be used, see Appendix X3.

NOTE 3—It is suggested that a distinction be made between *dual symbols* and *borderline symbols.*

Dual Symbol—A dual symbol is two symbols separated by a hyphen, for example, GP-GM, SW-SC, CL-ML used to indicate that the soil has been identified as having the properties of a classification in accordance with Test Method D 2487 where two symbols are required. Two symbols are required when the soil has between 5 and 12 % fines or when the liquid limit and plasticity index values plot in the CL-ML area of the plasticity chart.

Borderline Symbol—A borderline symbol is two symbols separated by a slash, for example, CL/CH, GM/SM, CL/ML. A borderline symbol should be used to indicate that the soil has been identified as having properties that do not distinctly place the soil into a specific group (see Appendix X3).

5. Significance and Use

5.1 The descriptive information required in this practice can be used to describe a soil to aid in the evaluation of its significant properties for engineering use.

5.2 The descriptive information required in this practice should be used to supplement the classification of a soil as determined by Test Method D 2487.

5.3 This practice may be used in identifying soils using the classification group symbols and names as prescribed in Test Method D 2487. Since the names and symbols used in this practice to identify the soils are the same as those used in Test Method D 2487, it shall be clearly stated in reports and all other appropriate documents, that the classification symbol and name are based on visual-manual procedures.

5.4 This practice is to be used not only for identification of soils in the field, but also in the office, laboratory, or wherever soil samples are inspected and described.

5.5 This practice has particular value in grouping similar soil samples so that only a minimum number of laboratory tests need be run for positive soil classification.

NOTE 4—The ability to describe and identify soils correctly is learned more readily und guidance of

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[1] This practice is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.07 on Identification and Classification of Soils.

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[2] *Annual Book of ASTM Standards*, Vol 04.08.

experienced personnel, but it may also be acquired systematically by comparing numerical laboratory test results for typical soils of each type with their visual and manual characteristics.

5.6 When describing and identifying soil samples from a given boring, test pit, or group of borings or pits, it is not necessary to follow all of the procedures in this practice for every sample. Soils which appear to be similar can be grouped together; one sample completely described and identified with the others referred to as similar based on performing only a few of the descriptive and identification procedures described in this practice.

6. Apparatus

6.1 *Required Apparatus:*

6.1.1 *Pocket Knife or Small Spatula.*

6.2 *Useful Auxiliary Apparatus:*

6.2.1 *Small Test Tube and Stopper* (or jar with a lid).

6.2.2 *Small Hand Lens.*

7. Reagents

7.1 *Purity of Water*—Unless otherwise indicated, references to water shall be understood to mean water from a city water supply or natural source, including non-potable water.

7.2 *Hydrochloric Acid*—A small bottle of dilute hydrochloric acid, HCl, one part HCl (10 *N*) to three parts water (This reagent is optional for use with this practice). See Section 8.

8. Safety Precautions

8.1 When preparing the dilute HCl solution of one part concentrated hydrochloric acid (10 *N*) to three parts of distilled water, slowly add acid into water following necessary safety precautions. Handle with caution and store safely. If solution comes into contact with the skin, rinse thoroughly with water.

8.2 Caution—Do not add water to acid.

9. Sampling

9.1 The sample shall be considered to be representative of the stratum from which it was obtained by an appropriate, accepted, or standard procedure.

NOTE 5—Preferably, the sampling procedure should be identified as having been conducted in accordance with Practices D 1452, D 1587, or D 2113, or Method D 1586.

9.2 The sample shall be carefully identified as to origin.

NOTE 6—Remarks as to the origin may take the form of a boring number and sample number in conjunction with a job number, a geologic stratum, a pedologic horizon or a location description with respect to a permanent monument, a grid system or a station number and offset with respect to a stated centerline and a depth or elevation.

9.3 For accurate description and identification, the minimum amount of the specimen to be examined shall be in accordance with the following schedule:

Maximum Particle Size, Sieve Opening	Minimum Specimen Size, Dry Weight
4.75 mm (No. 4)	100 g (0.25 lb)
9.5 mm (3/8 in.)	200 g (0.5 lb)
19.0 mm (3/4 in.)	1.0 kg (2.2 lb)
38.1 mm (1½ in.)	8.0 kg (18 lb)
75.0 mm (3 in.)	60.0 kg (132 lb)

NOTE 7—If random isolated particles are encountered that are significantly larger than the particles in the soil matrix, the soil matrix can be accurately described and identified in accordance with the preceeding schedule.

9.4 If the field sample or specimen being examined is smaller than the minimum recommended amount, the report shall include an appropriate remark.

10. Descriptive Information for Soils

10.1 *Angularity*—Describe the angularity of the sand (coarse sizes only), gravel, cobbles, and boulders, as angular, subangular, subrounded, or rounded in accordance with the criteria in Table 1 and Fig. 3. A range of angularity may be stated, such as: subrounded to rounded.

10.2 *Shape*—Describe the shape of the gravel, cobbles, and boulders as flat, elongated, or flat and elongated if they meet the criteria in Table 2 and Fig. 4. Otherwise, do not mention the shape. Indicate the fraction of the particles that have the shape, such as: one-third of the gravel particles are flat.

10.3 *Color*—Describe the color. Color is an important property in identifying organic soils, and within a given locality it may also be useful in identifying materials of similar geologic origin. If the sample contains layers or patches of varying colors, this shall be noted and all representative colors shall be described. The color shall be described for moist samples. If the color represents a dry condition, this shall be stated in the report.

10.4 *Odor*—Describe the odor if organic or

unusual. Soils containing a significant amount of organic material usually have a distinctive odor of decaying vegetation. This is especially apparent in fresh samples, but if the samples are dried, the odor may often be revived by heating a moistened sample. If the odor is unusual (petroleum product, chemical, and the like), it shall be described.

10.5 *Moisture Condition*—Describe the moisture condition as dry, moist, or wet, in accordance with the criteria in Table 3.

10.6 *HCl Reaction*—Describe the reaction with HCl as none, weak, or strong, in accordance with the critera in Table 4. Since calcium carbonate is a common cementing agent, a report of its presence on the basis of the reaction with dilute hydrochloric acid is important.

10.7 *Consistency*—For intact fine-grained soil, describe the consistency as very soft, soft, firm, hard, or very hard, in accordance with the criteria in Table 5. This observation is inappropriate for soils with significant amounts of gravel.

10.8 *Cementation*—Describe the cementation of intact coarse-grained soils as weak, moderate, or strong, in accordance with the criteria in Table 6.

10.9 *Structure*—Describe the structure of intact soils in accordance with the criteria in Table 7.

10.10 *Range of Particle Sizes*—For gravel and sand components, describe the range of particle sizes within each component as defined in 3.1.2 and 3.1.6. For example, about 20 % fine to coarse gravel, about 40 % fine to coarse sand.

10.11 *Maximum Particle Size*—Describe the maximum particle size found in the samole in accordance with the following information:

10.11.1 *Sand Size*—If the maximum particle size is a sand size, describe as fine, medium, or coarse as defined in 3.1.7. For example: maximum particle size, medium sand.

10.11.2 *Gravel Size*—If the maximum particle size is a gravel size, describe the maximum particle size as the smallest sieve opening that the particle will pass. For example, maximum particle size, 1½ in. (will pass a 1½-in. square opening but not a 3/4-in. square opening).

10.11.3 *Cobble or Boulder Size*—If the maximum particle size is a cobble or boulder size, describe the maximum dimension of the largest particle. For example: maximum dimension, 18 in. (450 mm).

10.12 *Hardness*—Describe the hardness of coarse sand and larger particles as hard, or state what happens when the particles are hit by a hammer, for example, gravel-size particles fracture with considerable hammer blow, some gravel-size particles crumble with hammer blow. "Hard" means particles do not crack, fracture, or crumble under a hammer blow.

10.13 Additional comments shall be noted, such as the presence of roots or root holes, difficulty in drilling or augering hole, caving of trench or hole, or the presence of mica.

10.14 A local or commercial name or a geologic interpretation of the soil, or both, may be added if identified as such.

10.15 A classification or identification of the soil in accordance with other classification systems may be added if identified as such.

11. Identification of Peat

11.1 A sample composed primarily of vegetable tissue in various stages of decomposition that has a fibrous to amorphous texture, usually a dark brown to black color, and an organic odor, shall be designated as a highly organic soil and shall be identified as peat, PT, and not subjected to the identification procedures described hereafter.

12. Preparation for Identification

12.1 The soil identification portion of this practice is based on the portion of the soil sample that will pass a 3-in. (75-mm) sieve. The larger than 3-in. (75-mm) particles must be removed, manually, for a loose sample, or mentally, for an intact sample before classifying the soil.

12.2 Estimate and note the percentage of cobbles and the percentage of boulders. Performed visually, these estimates will be on the basis of volume percentage.

NOTE 8—Since the percentages of the particle-size distribution in Test Method D 2487 are by dry weight, and the estimates of percentages for gravel, sand, and fines in this practice are by dry weight, it is recommended that the report state that the percentages of cobbles and boulders are by volume.

12.3 Of the fraction of the soil smaller than 3 in. (75 mm), estimate and note the percentage, by dry weight, of the gravel, sand, and fines (see Appendix X4 for suggested procedures).

NOTE 9—Since the particle-size components appear visually on the basis of volume, considerable experience is required to estimate the percentages on the basis of dry weight. Frequent comparisons with laboratory particle-size analyses should be made.

12.3.1 The percentages shall be estimated to the closest 5 %. The percentages of gravel, sand, and fines must add up to 100 %.

12.3.2 If one of the components is present but not in sufficient quantity to be considered 5 % of the smaller than 3-in. (75-mm) portion, indicate its presence by the term *trace*, for example, trace of fines. A trace is not to be considered in the total of 100 % for the components.

13. Preliminary Identification

13.1 The soil is *fine grained* if it contains 50 % or more fines. Follow the procedures for identifying fine-grained soils of Section 14.

13.2 The soil is *coarse grained* if it contains less than 50 % fines. Follow the procedures for identifying coarse-grained soils of Section 15.

14. Procedure for Identifying Fine-Grained Soils

14.1 Select a representative sample of the material for examination. Remove particles larger than the No. 40 sieve (medium sand and larger) until a specimen equivalent to about a handful of material is available. Use this specimen for performing the dry strength, dilatancy, and toughness tests.

14.2 *Dry Strength:*

14.2.1 From the specimen, select enough material to mold into a ball about 1 in. (25 mm) in diameter. Mold the material until it has the consistency of putty, adding water if necessary.

14.2.2 From the molded material, make at least three test specimens. A test specimen shall be a ball of material about ½ in. (12 mm) in diameter. Allow the test specimens to dry in air, or sun, or by artificial means, as long as the temperature does not exceed 60°C.

14.2.3 If the test specimen contains natural dry lumps, those that are about ½ in. (12 mm) in diameter may be used in place of the molded balls.

NOTE 10—The process of molding and drying usually produces higher strengths than are found in natural dry lumps of soil.

14.2.4 Test the strength of the dry balls or lumps by crushing between the fingers. Note the strength as none, low, medium, high, or very high in accorance with the criteria in Table 8. If natural dry lumps are used, do not use the results of any of the lumps that are found to contain particles of coarse sand.

14.2.5 The presence of high-strength water-soluble cementing materials, such as calcium carbonate, may cause exceptionally high dry strengths. The presence of calcium carbonate can usually be detected from the intensity of the reaction with dilute hydrochloric acid (see 10.6).

14.3 *Dilatancy:*

14.3.1 From the specimen, select enough material to mold into a ball about ½ in. (12 mm) in diameter. Mold the material, adding water if necessary, until it has a soft, but not sticky, consistency.

14.3.2 Smooth the soil ball in the palm of one hand with the blade of a knife or small spatula. Shake horizontally, striking the side of the hand vigorously against the other hand several times. Note the reaction of water appearing on the surface of the soil. Squeeze the sample by closing the hand or pinching the soil between the fingers, and note the reaction as none, slow, or rapid in accordance with the criteria in Table 9. The reaction is the speed with which water appears while shaking, and disappears while squeezing.

14.4 *Toughness:*

14.4.1 Following the completion of the dilatancy test, the test specimen is shaped into an elongated pat and rolled by hand on a smooth surface or between the palms into a thread about ⅛ in. (3 mm) in diameter. (If the sample is too wet to roll easily, it should be spread into a thin layer and allowed to lose some water by evaporation.) Fold the sample threads and reroll repeatedly until the thread crumbles at a diameter of about ⅛ in. The thread will crumble at a diameter of ⅛ in. when the soil is near the plastic limit. Note the pressure required to roll the thread near the plastic limit. Also, note the strength of the thread. After the thread crumbles, the pieces should be lumped together and kneaded until the lump crumbles. Note the toughness of the material during kneading.

14.4.2 Describe the toughness of the thread and lump as low, medium, or high in accordance with the criteria in Table 10.

14.5 *Plasticity*—On the basis of observations made during the toughness test, describe the plasticity of the material in accordance with the criteria given in Table 11.

14.6 Decide whether the soil is an *inorganic* or an *organic* fine-grained soil (see 14.8). If inorganic, follow the steps given in 14.7.

14.7 *Identification of Inorganic Fine-Grained Soils:*

14.7.1 Identify the soil as a *lean clay*, CL, if the soil has medium to high dry strength, no or slow dilatancy, and medium toughness and plasticity (see Table 12).

14.7.2 Identify the soil as a *fat clay*, CH, if the soil has high to very high dry strength, no dilatancy, and high toughness and plasticity (see Table 12).

14.7.3 Identify the soil as a *silt*, ML, if the soil has no to low dry strength, slow to rapid dilatancy, and low toughness and plasticity, or is nonplastic (see Table 12).

14.7.4 Identify the soil as an *elastic silt*, MH, if the soil has low to medium dry strength, no to slow dilatancy, and low to medium toughness and plasticity (see Table 12).

NOTE 11—These properties are similar to those for a lean clay. However, the silt will dry quickly on the hand and have a smooth, silky feel when dry. Some soils that would classify as MH in accordance with the criteria in Test Method D 2487 are visually difficult to distinguish from lean clays, CL. It may be necessary to perform laboratory testing for proper identification.

14.8 *Identification of Organic Fine-Grained Soils:*

14.8.1 Identify the soil as an *organic soil*, OL/OH, if the soil contains enough organic particles to influence the soil properties. Organic soils usually have a dark brown to black color and may have an organic odor. Often, organic soils will change color, for example, black to brown, when exposed to the air. Some organic soils will lighten in color significantly when air dried. Organic soils normally will not have a high toughness or plasticity. The thread for the toughness test will be spongy.

NOTE 12—In some cases, through practice and experience, it may be possible to further identify the organic soils as organic silts or organic clays, OL or OH. Correlations between the dilatancy, dry strength, toughness tests, and laboratory tests can be made to identify organic soils in certain deposits of similar materials of known geologic origin.

14.9 If the soil is estimated to have 15 to 25 % sand or gravel, or both, the words "with sand" or "with gravel" (whichever is more predominant) shall be added to the group name. For example: "lean clay with sand, CL" or "silt with gravel, ML" (see Figs. 1a and 1b). If the percentage of sand is equal to the percentage of gravel, use "with sand."

14.10 If the soil is estimated to have 30 % or more sand or gravel, or both, the words "sandy" or "gravelly" shall be added to the group name. Add the word "sandy" if there appears to be more sand than gravel. Add the word "gravelly" if there appears to be more gravel than sand. For example: "sandy lean clay, CL", "gravelly fat clay, CH", or "sandy silt, ML" (see Figs. 1a and 1b). If the percentage of sand is equal to the percent of gravel, use "sandy."

15. Procedure for Identifying Coarse-Grained Soils (Contains less than 50 % fines)

15.1 The soil is a *gravel* if the percentage of gravel is estimated to be more than the percentage of sand.

15.2 The soil is a *sand* if the percentage of gravel is estimated to be equal to or less than the percentage of sand.

15.3 The soil is a *clean gravel* or *clean sand* if the percentage of fines is estimated to be 5 % or less.

15.3.1 Identify the soil as a *well-graded gravel*, GW, or as a *well-graded sand*, SW, if it has a wide range of particle sizes and substantial amounts of the intermediate particle sizes.

15.3.2 Identify the soil as a *poorly graded gravel*, GP, or as a *poorly graded sand*, SP, if it consists predominantly of one size (uniformly graded), or it has a wide range of sizes with some intermediate sizes obviously missing (gap or skip graded).

15.4 The soil is either a *gravel with fines* or a *sand with fines* if the percentage of fines is estimated to be 15 % or more.

15.4.1 Identify the soil as a *clayey gravel*, GC, or a *clayey sand*, SC, if the fines are clayey as determined by the procedures in Section 14.

15.4.2 Identify the soil as a *silty gravel*, GM, or a *silty sand*, SM, if the fines are silty as determined by the procedures in Section 14.

15.5 If the soil is estimated to contain 10 % fines, give the soil a dual identification using two group symbols.

15.5.1 The first group symbol shall correspond to a clean gravel or sand (GW, GP, SW, SP) and the second symbol shall correspond to a gravel or sand with fines (GC, GM, SC, SM).

15.5.2 The group name shall correspond to the first group symbol plus the words "with clay" or "with silt" to indicate the plasticity characteristics of the fines. For example: "well-graded gravel with clay, GW-GC" or "poorly graded sand with silt, SP-SM" (see Fig. 2).

15.6 If the specimen is predominantly sand or gravel but contains an estimated 15 % or more of the other coarse-grained constituent, the words "with gravel" or "with sand" shall be added to the group name. For example: "poorly graded gravel with sand, GP" or "clayey sand with gravel, SC" (see Fig. 2).

15.7 If the field sample contains any cobbles or boulders, or both, the words "with cobbles" or "with cobbles and boulders" shall be added to the group name. For example: "silty gravel with cobbles, GM."

16. Report

16.1 The report shall include the information as to origin, and the items indicated in Table 13.

NOTE 13—*Example: Clayey Gravel with Sand and Cobbles, GC*—About 50 % fine to coarse, subrounded to subangular gravel; about 30 % fine to coarse, subrounded sand; about 20 % fines with medium plasticity, high dry strength, no dilatancy, medium toughness; weak reaction with HCl; original field sample had about 5 % (by volume) subrounded cobbles, maximum dimension, 150 mm.

In-Place Conditions—Firm, homogeneous, dry, brown

Geologic Interpretation—Alluvial fan

TABLE 1 Criteria for Describing Angularity of Coarse-Grained Particles (see Fig. 3)

Description	Criteria
Angular	Particles have sharp edges and relatively plane sides with unpolished surfaces
Subangular	Particles are similar to angular description but have rounded edges
Subrounded	Particles have nearly plane sides but have well-rounded corners and edges
Rounded	Particles have smoothly curved sides and no edges

TABLE 2 Criteria for Describing Particle Shape (see Fig. 4)

The particle shape shall be described as follows where length, width, and thickness refer to the greatest, intermediate, and least dimensions of a particle, respectively.

Flat	Particles with width/thickness > 3
Elongated	Particles with length/width > 3
Flat and elongated	Particles meet criteria for both flat and elongated

TABLE 3 Criteria for Describing Moisture Condition

Description	Criteria
Dry	Absence of moisture, dusty, dry to the touch
Moist	Damp but no visible water
Wet	Visible free water, usually soil is below water table

NOTE 14—Other examples of soil descriptions and identification are given in Appendixes X1 and X2.

NOTE 15—If desired, the percentages of gravel, sand, and fines may be stated in terms indicating a range of percentages, as follows:

Trace—Particles are present but estimated to be less than 5 %

Few—5 to 10 %

Little—15 to 25 %

Some—30 to 45 %

Mostly—50 to 100 %

16.2 If, in the soil description, the soil is identified using a classification group symbol and name as described in Test Method D 2487, it must be distinctly and clearly stated in log forms, summary tables, reports, and the like, that the symbol and name are based on visual-manual procedures.

17. Precision and Bias

17.1 This practice provides qualitative information only, therefore, a precision and bias statement is not applicable.

TABLE 4 Criteria for Describing the Reaction With HCl

Description	Criteria
None	No visible reaction
Weak	Some reaction, with bubbles forming slowly
Strong	Violent reaction, with bubbles forming immediately

TABLE 5 Criteria for Describing Consistency

Description	Criteria
Very soft	Thumb will penetrate soil more than 1 in. (25 mm)
Soft	Thumb will penetrate soil about 1 in. (25 mm)
Firm	Thumb will indent soil about ¼ in. (6 mm)
Hard	Thumb will not indent soil but readily indented with thumbnail
Very hard	Thumbnail will not indent soil

TABLE 6 Criteria for Describing Cementation

Description	Criteria
Weak	Crumbles or breaks with handling or little finger pressure
Moderate	Crumbles or breaks with considerable finger pressure
Strong	Will not crumble or break with finger pressure

TABLE 7 Criteria for Describing Structure

Description	Criteria
Stratified	Alternating layers of varying material or color with layers at least 6 mm thick; note thickness
Laminated	Alternating layers of varying material or color with the layers less than 6 mm thick; note thickness
Fissured	Breaks along definite planes of fracture with little resistance to fracturing
Slickensided	Fracture planes appear polished or glossy, sometimes striated
Blocky	Cohesive soil that can be broken down into small angular lumps which resist further breakdown
Lensed	Inclusion of small pockets of different soils, such as small lenses of sand scattered through a mass of clay; note thickness
Homogeneous	Same color and appearance throughout

TABLE 8 Criteria for Describing Dry Strength

Description	Criteria
None	The dry specimen crumbles into powder with mere pressure of handling
Low	The dry specimen crumbles into powder with some finger pressure
Medium	The dry specimen breaks into pieces or crumbles with considerable finger pressure
High	The dry specimen cannot be broken with finger pressure. Specimen will break into pieces between thumb and a hard surface
Very high	The dry specimen cannot be broken between the thumb and a hard surface

TABLE 9 Criteria for Describing Dilatancy

Description	Criteria
None	No visible change in the specimen
Slow	Water appears slowly on the surface of the specimen during shaking and does not disappear or disappears slowly upon squeezing
Rapid	Water appears quickly on the surface of the specimen during shaking and disappears quickly upon squeezing

TABLE 10 Criteria for Describing Toughness

Description	Criteria
Low	Only slight pressure is required to roll the thread near the plastic limit. The thread and the lump are weak and soft
Medium	Medium pressure is required to roll the thread to near the plastic limit. The thread and the lump have medium stiffness
High	Considerable pressure is required to roll the thread to near the plastic limit. The thread and the lump have very high stiffness

TABLE 11 Criteria for Describing Plasticity

Description	Criteria
Nonplastic	A ⅛-in. (3-mm) thread cannot be rolled at any water content
Low	The thread can barely be rolled and the lump cannot be formed when drier than the plastic limit
Medium	The thread is easy to roll and not much time is required to reach the plastic limit. The thread cannot be rerolled after reaching the plastic limit. The lump crumbles when drier than the plastic limit
High	It takes considerable time rolling and kneading to reach the plastic limit. The thread can be rerolled several times after reaching the plastic limit. The lump can be formed without crumbling when drier than the plastic limit

TABLE 12 Identification of Inorganic Fine-Grained Soils from Manual Tests

Soil Symbol	Dry Strength	Dilatancy	Toughness
ML	None to low	Slow to rapid	Low or thread cannot be formed
CL	Medium to high	None to slow	Medium
MH	Low to medium	None to slow	Low to medium
CH	High to very high	None	High

TABLE 13 Checklist for Description of Soils

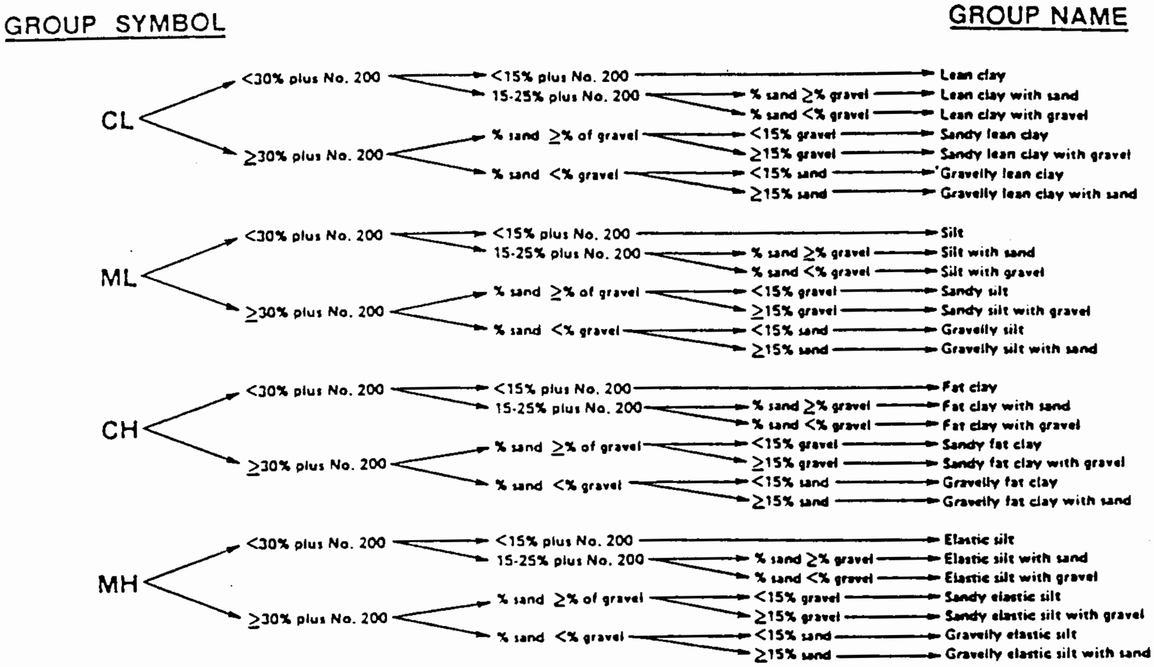
1. Group name
2. Group symbol
3. Percent of cobbles or boulders, or both (by volume)
4. Percent of gravel, sand, or fines, or all three (by dry weight)
5. Particle-size range:

Gravel—fine, coarse
Sand—fine, medium, coarse

6. Particle angularity: angular, subangular, subrounded, rounded
7. Particle shape: (if appropriate) flat, elongated, flat and elongated
8. Maximum particle size or dimension
9. Hardness of coarse sand and larger particles
10. Plasticity of fines: nonplastic, low, medium, high
11. Dry strength: none, low, medium, high, very high
12. Dilatancy: none, slow, rapid
13. Toughness: low, medium, high
14. Color (in moist condition)
15. Odor (mention only if organic or unusual)
16. Moisture: dry, moist, wet
17. Reaction with HCl: none, weak, strong

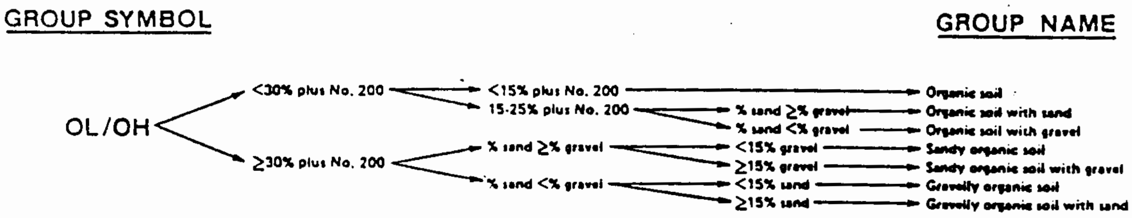
For intact samples:

18. Consistency (fine-grained soils only): very soft, soft, firm, hard, very hard
19. Structure: stratified, laminated, fissured, slickensided, lensed, homogeneous
20. Cementation: weak, moderate, strong
21. Local name
22. Geologic interpretation
23. Additional comments: presence of roots or root holes, presence of mica, gypsum, etc., surface coatings on coarse-grained particles, caving or sloughing of auger hole or trench sides, difficulty in augering or excavating, etc.



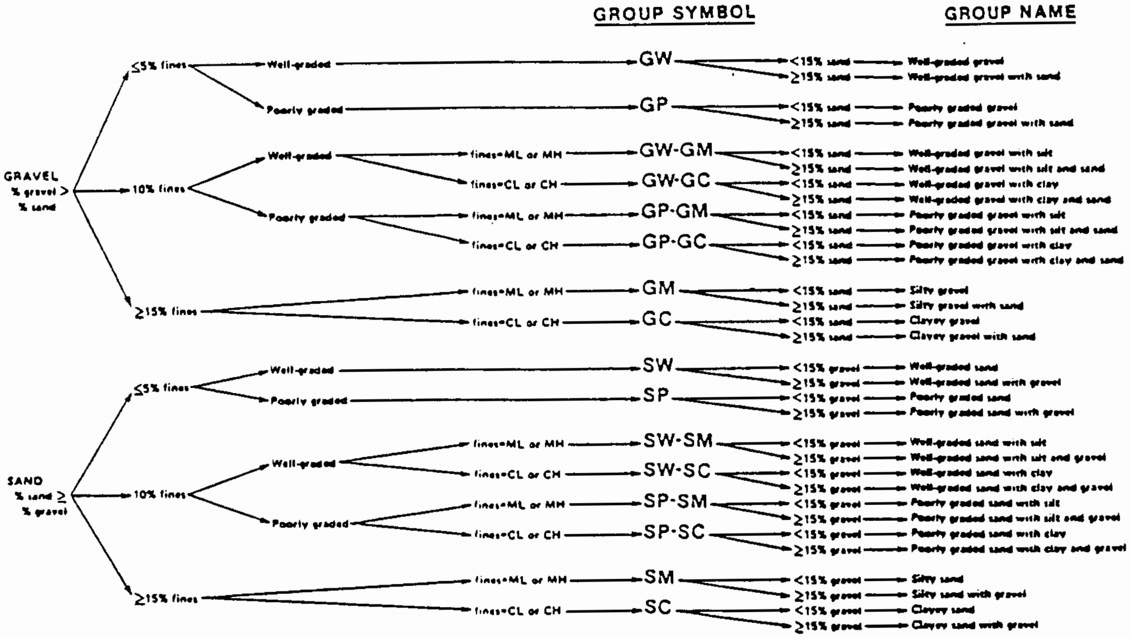
NOTE—Percentages are based on estimating amounts of fines, sand, and gravel to the nearest 5 %.

FIG. 1a Flow Chart for Identifying Inorganic Fine-Grained Soil (50 % or more fines)



NOTE—Percentages are based on estimating amounts of fines, sand, and gravel to the nearest 5 %.

FIG. 1b Flow Chart for Identifying Organic Fine-Grained Soil (50 % or more fines)



NOTE—Percentages are based on estimating amounts of fines, sand, and gravel to the nearest 5%.

FIG. 2 Flow Chart for Identifying Coarse-Grained Soils (less than 50 % fines)


(a) Rounded

(b) Angular

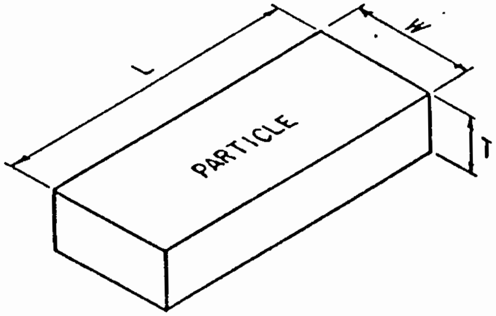
(c) Subrounded

(d) Subangular

FIG. 3 Typical Angularity of Bulky Grains

PARTICLE SHAPE

W = WIDTH
T = THICKNESS
L = LENGTH



FLAT: W/T > 3
ELONGATED: L/W > 3
FLAT AND ELONGATED:
– meets both criteria

FIG. 4 Criteria for Particle Shape

APPENDIXES

(Nonmandatory Information)

X1. EXAMPLES OF VISUAL SOIL DESCRIPTIONS

X1.1 The following examples show how the information required in 16.1 can be reported. The information that is included in descriptions should be based on individual circumstances and need.

X1.1.1 *Well-Graded Gravel with Sand (GW)*—About 75 % fine to coarse, hard, subangular gravel; about 25 % fine to coarse, hard, subangular sand; trace of fines; maximum size, 75 mm, brown, dry; no reaction with HCl.

X1.1.2 *Silty Sand with Gravel (SM)*—About 60 % predominantly fine sand; about 25 % silty fines with low plasticity, low dry strength, rapid dilatancy, and low toughness; about 15 % fine, hard, subrounded gravel, a few gravel-size particles fractured with hammer blow; maximum size, 25 mm; no reaction with HCl (Note—Field sample size smaller than recommended).

In-Place Conditions—Firm, stratified and contains lenses of silt 1 to 2 in. (25 to 50 mm) thick, moist, brown to gray; in-place density 106 lb/ft^3; in-place moisture 9 %.

X1.1.3 *Organic Soil (OL/OH)*—About 100 % fines with low plasticity, slow dilatancy, low dry strength, and low toughness; wet, dark brown, organic odor; weak reaction with HCl.

X1.1.4 *Silty Sand with Organic Fines (SM)*—About 75 % fine to coarse, hard, subangular reddish sand; about 25 % organic and silty dark brown nonplastic fines with no dry strength and slow dilatancy; wet;

maximum size, coarse sand; weak reaction with HCl.

X1.1.5 *Poorly Graded Gravel with Silt, Sand, Cobbles and Boulders (GP-GM)*—About 75 % fine to coarse, hard, subrounded to subangular gravel; about 15 % fine, hard, subrounded to subangular sand; about 10 % silty nonplastic fines; moist, brown; no reaction with HCl; original field sample had about 5 % (by volume) hard, subrounded cobbles and a trace of hard, subrounded boulders, with a maximum dimension of 18 in. (450 mm).

X2. USING THE IDENTIFICATION PROCEDURE AS A DESCRIPTIVE SYSTEM FOR SHALE, CLAYSTONE, SHELLS, SLAG, CRUSHED ROCK, AND THE LIKE

X2.1 The identification procedure may be used as a descriptive system applied to materials that exist in-situ as shale, claystone, sandstone, siltstone, mudstone, etc., but convert to soils after field or laboratory processing (crushing, slaking, and the like).

X2.2 Materials such as shells, crushed rock, slag, and the like, should be identified as such. However, the procedures used in this practice for describing the particle size and plasticity characteristics may be used in the description of the material. If desired, an identification using a group name and symbol according to this practice may be assigned to aid in describing the material.

X2.3 The group symbol(s) and group names should be placed in quotation marks or noted with some type of distinguishing symbol. See examples.

X2.4 Examples of how group names and symbols can be incororated into a descriptive system for materials that are not naturally occurring soils are as follows:

X2.4.1 *Shale Chunks*—Retrieved as 2 to 4-in. (50 to 100-mm) pieces of shale from power auger hole, dry, brown, no reaction with HCl. After slaking in water for 24 h, material identified as "Sandy Lean Clay (CL)"; about 60 % fines with medium plasticity, high dry strength, no dilatancy, and medium toughness; about 35 % fine to medium, hard sand; about 5 % gravel-size pieces of shale.

X2.4.2 *Crushed Sandstone*—Product of commercial crushing operation; "Poorly Graded Sand with Silt (SP-SM)"; about 90 % fine to medium sand; about 10 % nonplastic fines; dry, reddish-brown, strong reaction with HCl.

X2.4.3 *Broken Shells*—About 60 % gravel-size broken shells; about 30 % sand and sand-size shell pieces; about 10 % fines; "Poorly Graded Gravel with Sand (GP)."

X2.4.4 *Crushed Rock*—Processed from gravel and cobbles in Pit No. 7; "Poorly Graded Gravel (GP)"; about 90 % fine, hard, angular gravel-size particles; about 10 % coarse, hard, angular sand-size particles; dry, tan; no reaction with HCl.

X3. SUGGESTED PROCEDURE FOR USING A BORDERLINE SYMBOL FOR SOILS WITH TWO POSSIBLE IDENTIFICATIONS.

X3.1 Since this practice is based on estimates of particle size distribution and plasticity characteristics, it may be difficult to clearly identify the soil as belonging to one category. To indicate that the soil may fall into one of two possible basic groups, a borderline symbol may be used with the two symbols separated by a slash. For example: SC/CL or CL/CH.

X3.1.1 A borderline symbol may be used when the percentage of fines is estimated to be between 45 and 55 %. One symbol should be for a coarse-grained soil with fines and the other for a fine-grained soil. For example: GM/ML or CL/SC.

X3.1.2 A borderline symbol may be used when the percentage of sand and the percentage of gravel are estimated to be about the same. For example: GP/SP, SC/GC, GM/SM. It is practically impossible to have a soil that would have a borderline symbol of GW/SW.

X3.1.3 A borderline symbol may be used when the soil could be either well graded or poorly graded. For example: GW/GP, SW/SP.

X3.1.4 A borderline symbol may be used when the soil could either be a silt or a clay. For example: CL/ML, CH/MH, SC/SM.

X3.1.5 A borderline symbol may be used when a fine-grained soil has properties that indicate that it is at the boundary between a soil of low compressibility and a soil of high compressibility. For example: CL/CH, MH/ML.

X3.2 The order of the borderline symbols should reflect similarity to surrounding or adjacent soils. For example: soils in a borrow area have been identified as CH. One sample is considered to have a borderline symbol of CL and CH. To show similarity, the borderline symbol should be CH/CL.

X3.3 The group name for a soil with a borderline symbol should be the group name for the first symbol, except for:

CL/CH	lean to fat clay
ML/CL	clayey silt
CL/ML	silty clay

X3.4 The use of a borderline symbol should not be used indiscriminately. Every effort shall be made to first place the soil into a single group.

X4. SUGGESTED PROCEDURES FOR ESTIMATING THE PERCENTAGES OF GRAVEL, SAND, AND FINES IN A SOIL SAMPLE

X4.1 *Jar Method*—The relative percentage of coarse- and fine-grained material may be estimated by thoroughly shaking a mixture of soil and water in a test tube or jar, and then allowing the mixture to settle. The coarse particles will fall to the bottom and successively finer particles will be deposited with increasing time; the sand sizes will fall out of suspension in 20 to 30 s. The relative proportions can be estimated from the relative volume of each size separate. This method should be correlated to particle-size laboratory determinations.

X4.2 *Visual Method*—Mentally visualize the gravel size particles placed in a sack (or other container) or sacks. Then, do the same with the sand size particles and the fines. Then, mentally compare the number of sacks to estimate the percentage of plus No. 4 sieve size and minus No. 4 sieve size present. The percentages of sand and fines in the minus sieve size No. 4 material can then be estimated from the wash test (X4.3).

X4.3 *Wash Test (for relative percentages of sand and fines)*—Select and moisten enough minus No. 4 sieve size material to form a 1-in (25-mm) cube of soil. Cut the cube in half, set one-half to the side, and place the other half in a small dish. Wash and decant the fines out of the material in the dish until the wash water is clear and then compare the two samples and estimate the percentage of sand and fines. Remember that the percentage is based on weight, not volume. However, the volume comparison will provide a reasonable indication of grain size percentages.

X4.3.1 While washing, it may be necessary to break down lumps of fines with the finger to get the correct percentages.

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This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, 1916 Race St., Philadelphia, Pa. 19103.

Designation: D 2487 - 85

Standard Test Method for
CLASSIFICATION OF SOILS FOR ENGINEERING PURPOSES[1]

This standard is issued under the fixed designation D 2487; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This test method has been approved for use by agencies of the Department of Defense and for listing in the DOD Index of Specifications and Standards.

1. Scope

1.1 This test method 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.

NOTE 1—Use of this standard will result in a single classification group symbol and group name except when a soil contains 5 to 12 % fines or when the plot of the liquid limit and plasticity index values falls into the crosshatched area of the plasticity chart. In these two cases, a dual symbol is used, for example, GP-GM, CL-ML. When the laboratory test results indicate that the soil is close to another soil classification group, the borderline condition can be indicated with two symbols separated by a slash. The first symbol should be the one based on this standard, for example, CL/CH, GM/SM, SC/CL. Borderline symbols are particularly useful when the liquid limit value of clayey soils is close to 50. These soils can have expansive characteristics and the use of a borderline symbol (CL/CH, CH/CL) will alert the user of the assigned classifications of expansive potential.

1.2 The group symbol portion of this sytem is based on laboratory tests performed on the portion of a soil sample passing the 3-in. (75-mm) sieve (see Specification E 11).

1.3 As a classification system, this test method is limited to naturally occurring soils.

NOTE 2—The group names and symbols used in this test method may be used as a descriptive system applied to such materials as shale, claystone, shells, crushed rock, etc. See Appendix X2.

1.4 This test method is for qualitative application only.

NOTE 3—When quantitative information is required for detailed designs of important structures, this test method must be supplemented by laboratory tests or other quantitative data to determine performance characteristics under expected field conditions.

1.5 The system is based on the widely recognized Unified Soil Classification System which was adopted by several U.S. Government agencies in 1952 as an outgrowth of the Airfield Classification System developed by A. Casagrande.[2]

1.6 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Applicable Documents

2.1 *ASTM Standards:*

C 117 Test Method for Material Finer Than 75-μm (No. 200) Sieve in Mineral Aggregates by Washing[3]

C 136 Method for Sieve Analysis of Fine and Coarse Aggregates[3]

C 702 Methods for Reducing Field Samples of Aggregate to Testing Size[3]

D 420 Recommended Practice for Investigating and Sampling Soil and Rock for Engineering Purposes[4]

D 421 Practice for Dry Preparation of Soil Samples for Particle-Size Analysis and De-

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[1] This test method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.07 on Identification and Classification of Soils.

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[2] Casagrande, A., "Classification and Identification of Soils," *Transactions*, ASCE, 1948, p. 901.

[3] *Annual Book of ASTM Standards*, Vol 04.02.

[4] *Annual Book of ASTM Standards*, Vol 04.08.

termination of Soil Constants[4]

D 422 Method for Particle-Size Analysis of Soils[4]

D 653 Terms and Symbols Relating to Soil and Rock[4]

D 1140 Test Method for Amount of Material in Soils Finer than the No. 200 (75-μm) Sieve[4]

D 2216 Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures[4]

D 2217 Practice for Wet Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants[4]

D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)[4]

D 4318 Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils[4]

E 11 Specification for Wire-Cloth Sieves for Testing Purposes[5]

3. Summary of Method

3.1 As illustrated in Table 1, this classification system identifies three major soil divisions: coarse-grained soils, fine-grained soils, and highly organic soils. These three divisions are further subdivided into a total of 15 basic soil groups.

3.2 Based on the results of visual observations and prescribed laboratory tests, a soil is catalogued according to the basic soil groups, assigned a group symbol(s) and name, and thereby classified. The flow charts, Fig. 1 for fine-grained soils, and Fig. 2 for coarse-grained soils, can be used to assign the appropriate group symbol(s) and name.

4. Significance and Use

4.1 This test method 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.

4.2 The assigning of a group name and symbol(s) along with the descriptive information required in Practice D 2488 can be used to describe a soil to aid in the evaluation of its significant properties for engineering use.

4.3 The various groupings of this classification system have been devised to correlate in a general way with the engineering behavior of soils. This test method provides a useful first step in any field or laboratory investigation for geotechnical engineering purposes.

4.4 This test method may also be used as an aid in training personnel in the use of Practice D 2488.

5. Terminology

5.1 *Definitions*—Except as listed below, all definitions are in accordance with Terms and Symbols D 653.

NOTE 4—For particles retained on a 3-in. (75-mm) U.S. standard sieve, the following definitions are suggested:

Cobbles—particles of rock that will pass a 12-in. (300-mm) square opening and be retained on a 3-in. (75-mm) U.S. standard sieve, and

Boulders—particles of rock that will not pass a 12-in. (300-mm) square opening

5.1.1 *gravel*—particles of rock that will pass a 3-in. (75-mm) sieve and be retained on a No. 4 (4.75-mm) U.S. standard sieve with the following subdivisions:

Coarse—passes 3-in. (75-mm) sieve and retained on ¾-in. (19-mm) sieve, and

Fine—passes ¾-in. (19-mm) sieve and retained on No. 4 (4.75-mm) sieve.

5.1.2 *sand*—particles of rock that will pass a No. 4 (4.75-mm) sieve and be retained on a No. 200 (75-μm) U.S. standard sieve with the following subdivisions:

Coarse—passes No. 4 (4.75-mm) sieve and retained on No. 10 (2.00-mm) sieve,

Medium—passes No. 10 (2.00-mm) sieve and retained on No. 40 (425-μm) sieve, and

Fine—passes No. 40 (425-μm) sieve and retained on No. 200 (75-μm) sieve.

5.1.3 *clay*—soil passing a No. 200 (75-μm) U.S. standard sieve that can be made to exhibit plasticity (putty-like properties) within a range of water contents and that exhibits considerable strength when air dry. For classification, a clay is a fine-grained soil, or the fine-grained portion of a soil, with a plasticity index equal to or greater than 4, and the plot of plasticity index versus liquid limit falls on or above the "A" line.

5.1.4 *silt*—soil passing a No. 200 (75-μm) U.S. standard sieve that is nonplastic or very slightly plastic and that exhibits little or no strength when air dry. For classification, a silt is a fine-grained soil, or the fine-grained portion of a soil, with a plasticity index less than 4 or if the plot of plasticity index versus liquid limit falls below the "A" line.

5.1.5 *organic clay*—a clay with sufficient organic content to influence the soil properties. For classification, an organic clay is a soil that would be classified as a clay except that its liquid limit value after oven drying is less than 75 % of its liquid limit value before oven drying.

5.1.6 *organic silt*—a silt with sufficient organic content to influence the soil properties. For classification, an organic silt is a soil that would be classified as a silt except that its liquid limit value after oven drying is less than 75 % of its liquid limit value before oven drying.

5.1.7 *peat*—a soil composed of vegetable tissue in various stages of decomposition usually with an organic odor, a dark-brown to black color, a spongy consistency, and a texture ranging from fibrous to amorphous.

5.2 *Descriptions of Terms Specific to This Standard:*

5.2.1 *coefficient of curvature*, Cc—the ratio $(D_{30})^2/(D_{10} \times D_{60})$, where D_{60}, D_{30}, and D_{10} are the particle diameters corresponding to 60, 30, and 10 % finer on the cumulative particle-size distribution curve, respectively.

5.2.2 *coefficient of uniformity*, Cu—the ratio D_{60}/D_{10}, where D_{60} and D_{10} are the particle diameters corresponding to 60 and 10 % finer on the cumulative particle-size distribution curve, respectively.

6. Apparatus

6.1 In addition to the apparatus that may be required for obtaining and preparing the samples and conducting the prescribed laboratory tests, a plasticity chart, similar to Fig. 3, and a cumulative particle-size distribution curve, similar to Fig. 4, are required.

NOTE 5—The "U" line shown on Fig. 3 has been empirically determined to be the approximate "upper limit" for natural soils. It is a good check against erroneous data, and any test results that plot above or to the left of it should be verified.

7. Sampling

7.1 Samples shall be obtained and identified in accordance with a method or methods, recommended in Recommended Practice D 420 or by other accepted procedures.

7.2 For accurate identification, the minimum amount of test sample required for this test method will depend on which of the laboratory tests need to be performed. Where only the particle-size analysis of the sample is required, specimens having the following minimum dry weights are required:

Maximum Particle Size, Sieve Opening	Minimum Specimen Size, Dry Weight
4.75 mm (No. 4)	100 g (0.25 lb)
9.5 mm (⅜ in.)	200 g (0.5 lb)
19.0 mm (¾ in.)	1.0 kg (2.2 lb)
38.1 mm (1½ in.)	8.0 kg (18 lb)
75.0 mm (3 in.)	60.0 kg (132 lb)

Whenever possible, the field samples should have weights two to four times larger than shown.

7.3 When the liquid and plastic limit tests must also be performed, additional material will be required sufficient to provide 150 g to 200 g of soil finer than the No. 40 (425-μm) sieve.

7.4 If the field sample or test specimen is smaller than the minimum recommended amount, the report shall include an appropriate remark.

8. Classification of Peat

8.1 A sample composed primarily of vegetable tissue in various stages of decomposition and has a fibrous to amorphous texture, a dark-brown to black color, and an organic odor should be designated as a highly organic soil and shall be classified as peat, PT, and not subjected to the classification procedures described hereafter.

9. Preparation for Classification

9.1 Before a soil can be classified according to this test method, generally the particle-size distribution of the minus 3-in. (75-mm) material and the plasticity characteristics of the minus No. 40 (425-μm) sieve material must be determined. See 9.8 for the specific required tests.

9.2 The preparation of the soil specimen(s) and the testing for particle-size distribution and liquid limit and plasticity index shall be in accordance with accepted standard procedures. Two procedures for preparation of the soil specimens for testing for soil classification purposes are given in Appendixes X3 and X4. Appendix X3 describes the wet preparation method and is the preferred method for cohesive soils that have never dried out and for organic soils.

9.3 When reporting soil classifications determined by this test method, the preparation and test procedures used shall be reported or referenced.

9.4 Although the test procedure used in determining the particle-size distribution or other considerations may require a hydrometer analysis of the material, a hydrometer analysis is not necessary for soil classification.

9.5 The percentage (by dry weight) of any plus 3-in. (75-mm) material must be determined and reported as auxiliary information.

9.6 The maximum particle size shall be determined (measured or estimated) and reported as auxiliary information.

9.7 When the cumulative particle-size distribution is required, a set of sieves shall be used which include the following sizes (with the largest size commensurate with the maximum particle size) with other sieve sizes as needed or required to define the particle-size distribution:

3-in. (75-mm)
¾-in.(19.0-mm)
No. 4 (4.75-mm)
No. 10 (2.00-mm)
No. 40 (425-µm)
No. 200 (75-µm)

9.8 The tests required to be performed in preparation for classification are as follows:

9.8.1 For soils estimated to contain less than 5 % fines, a plot of the cumulative particle-size distribution curve of the fraction coarser than the No. 200 (75-µm) sieve is required. The cumulative particle-size distribution curve may be plotted on a graph similar to that shown in Fig. 4.

9.8.2 For soils estimated to contain 5 to 15 % fines, a cumulative particle-size distribution curve, as described in 9.8.1, is required, and the liquid limit and plasticity index are required.

9.8.2.1 If sufficient material is not available to determine the liquid limit and plasticity index, the fines should be estimated to be either silty or clayey using the procedures described in Practice D 2488 and so noted in the report.

9.8.3 For soils estimated to contain 15 % or more fines, a determination of the percent fines, percent sand, and percent gravel is required, and the liquid limit and plasticity index are required. For soils estimated to contain 90 % fines or more, the percent fines, percent sand, and percent gravel may be estimated using the procedures described in Practice D 2488 and so noted in the report.

10. Preliminary Classification Procedure

10.1 Class the soil as fine-grained if 50 % or more by dry weight of the test specimen passes the No. 200 (75-µm) sieve and follow Section 11.

10.2 Class the soil as coarse-grained if more than 50 % by dry weight of the test specimen is retained on the No. 200 (75-µm) sieve and follow Section 12.

11. Procedure for Classification of Fine-Grained Soils (50 % or more by dry weight passing the No. 200 (75-µm) sieve)

11.1 The soil is an inorganic clay if the position of the plasticity index versus liquid limit plot, Fig. 3, falls on or above the "A" line, the plasticity index is greater than 4, and the presence of organic matter does not influence the liquid limit as determined in 11.3.2.

11.1.1 Classify the soil as a *lean clay*, CL, if the liquid limit is less than 50. See area identified as CL on Fig. 3.

11.1.2 Classify the soil as a *fat clay*, CH, if the liquid limit is 50 or greater. See area identified as CH on Fig. 3.

NOTE 6—In cases where the liquid limit exceeds 110 or the plasticity index exceeds 60, the plasticity chart may be expanded by maintaining the same scale on both axes and extending the "A" line at the indicated slope.

11.1.3 Classify the soil as a *silty clay*, CL-ML, if the position of the plasticity index versus liquid limit plot falls on or above the "A" line and the plasticity index is in the range of 4 to 7. See area identified as CL-ML on Fig. 3.

11.2 The soil is an inorganic silt if the position of the plasticity index versus liquid limit plot Fig. 3, falls below the "A" line or the plasticity index is less than 4, and presence of organic matter does not influence the liquid limit as determined in 11.3.2.

11.2.1 Classify the soil as a *silt*, ML, if the liquid limit is less than 50. See area identified as ML on Fig. 3.

11.2.2 Classify the soil as an *elastic silt*, MH, if the liquid limit is 50 or greater. See area identified as MH on Fig. 3.

11.3 The soil is an organic silt or clay if organic matter is present in sufficient amounts to influence the liquid limit as determined in 11.3.2.

11.3.1 If the soil has a dark color and an organic odor when moist and warm, a second liquid limit test shall be performed on a test specimen which has been oven dried at 110 ± 5°C to a constant weight, typically over night.

11.3.2 The soil is an organic silt or organic clay if the liquid limit after oven drying is less than 75 % of the liquid limit of the original specimen determined before oven drying (see Procedure B of Practice D 2217).

11.3.3 Classify the soil as an *organic silt* or *organic clay*, OL, if the liquid limit (not oven dried) is less than 50 %. Classify the soil as an *organic silt*, OL, if the plasticity index is less than 4, or the position of the plasticity index versus liquid limit plot falls below the "A" line. Classify the soil as an *organic clay*, OL, if the plasticity index is 4 or greater and the position of the plasticity index versus liquid limit plot falls on or above the "A" line. See area identified as OL (or CL-ML) on Fig. 3.

11.3.4 Classify the soil as an *organic clay* or *organic silt*, OH, if the liquid limit (not oven dried) is 50 or greater. Classify the soil as an *organic silt*, OH, if the position of the plasticity index versus liquid limit plot falls below the "A" line. Classify the soil as an *organic clay*, OH, if the position of the plasticity index versus liquid-limit plot falls on or above the "A" line. See area identified as OH on Fig. 3.

11.4 If less than 30 % but 15 % or more of the test specimen is retained on the No. 200 (75-µm) sieve, the words "with sand" or "with gravel" (whichever is predominant) shall be added to the group name. For example, lean clay with sand, CL; silt with gravel, ML. If the percent of sand is equal to the percent of gravel, use "with sand."

11.5 If 30 % or more of the test specimen is retained on the No. 200 (75-µm) sieve, the words "sandy" or "gravelly" shall be added to the group name. Add the word "sandy" if 30 % or more of the test specimen is retained on the No. 200 (75-µm) sieve and the coarse-grained portion is predominantly sand. Add the word "gravelly" if 30 % or more of the test specimen is retained on the No. 200 (75-µm) sieve and the coarse-grained portion is predominantly gravel. For example, sandy lean clay, CL; gravelly fat clay, CH; sandy silt, ML. If the percent of sand is equal to the percent of gravel, use "sandy."

12. Procedure for Classification of Coarse-Grained Soils (more than 50 % retained on the No. 200 (75-µm) sieve)

12.1 Class the soil as gravel if more than 50 % of the coarse fraction [plus No. 200 (75-µm) sieve] is retained on the No. 4 (4.75-mm) sieve.

12.2 Class the soil as sand if 50 % or more of the coarse fraction [plus No. 200 (75-µm) sieve] passes the No. 4 (4.75-mm) sieve.

12.3 If 12 % or less of the test specimen passes the No. 200 (75-µm) sieve, plot the cumulative particle-size distribution, Fig. 4, and compute the coefficient of uniformity, Cu, and coefficient of curvature, Cc, as given in Eqs 1 and 2.

$$Cu = D_{60}/D_{10} \tag{1}$$

$$Cc = (D_{30})^2/(D_{10} \times D_{60}) \tag{2}$$

where:

D_{10}, D_{30}, and D_{60} = the particle-size diameters corresponding to 10, 30, and 60 %, respectively, passing on the cumulative particle-size distribution curve, Fig. 4.

NOTE 7—It may be necessary to extrapolate the curve to obtain the D_{10} diameter.

12.3.1 If less than 5 % of the test specimen passes the No. 200 (75-µm) sieve, classify the soil as a *well-graded gravel*, GW, or *well-graded sand*, SW, if Cu is greater than 4.0 for gravel or greater than 6.0 for sand, and Cc is at least 1.0 but not more than 3.0.

12.3.2 If less than 5 % of the test specimen passes the No. 200 (75-µm) sieve, classify the soil as *poorly graded gravel*, GP, or *poorly graded sand*, SP, if either the Cu or the Cc criteria for well-graded soils are not satisfied.

12.4 If more than 12 % of the test specimen passes the No. 200 (75-µm) sieve, the soil shall be considered a coarse-grained soil with fines. The fines are determined to be either clayey or silty based on the plasticity index versus liquid limit plot on Fig. 3. (See 9.8.2.1 if insufficient material available for testing).

12.4.1 Classify the soil as a *clayey gravel*, GC, or *clayey sand*, SC, if the fines are clayey, that is, the position of the plasticity index versus liquid limit plot, Fig. 3, falls on or above the "A" line and the plasticity index is greater than 7.

12.4.2 Classify the soil as a *silty gravel*, GM, or *silty sand*, SM, if the fines are silty, that is, the position of the plasticity index versus liquid limit plot, Fig. 3, falls below the "A" line or the plasticity index is less than 4.

12.4.3 If the fines plot as a silty clay, CL-ML, classify the soil as a *silty, clayey gravel*, GC-GM, if it is a gravel or a *silty, clayey sand*, SC-SM, if it is a sand.

12.5 If 5 to 12 % of the test specimen passes the No. 200 (75-µm) sieve, give the soil a dual classification using two group symbols.

12.5.1 The first group symbol shall correspond to that for a gravel or sand having less than 5 % fines (GW, GP, SW, SP), and the second symbol shall correspond to a gravel or sand having more than 12 % fines (GC, GM, SC, SM).

12.5.2 The group name shall correspond to the first group symbol plus "with clay" or "with silt" to indicate the plasticity characteristics of the fines. For example, well-graded gravel with clay, GW-GC; poorly graded sand with silt, SP-SM (See 9.8.2.1 if insufficient material available for testing).

NOTE 8—If the fines plot as a *silty clay*, CL-ML, the second group symbol should be either GC or SC. For example, a poorly graded sand with 10 % fines, a liquid limit of 20, and a plasticity index of 6 would be classified as a poorly graded sand with silty clay, SP-SC.

12.6 If the specimen is predominantly sand or gravel but contains 15 % or more of the other coarse-grained constituent, the words "with gravel" or "with sand" shall be added to the group name. For example, poorly graded gravel with sand, clayey sand with gravel.

12.7 If the field sample contained any cobbles or boulders or both, the words "with cobbles," or "with cobbles and boulders" shall be added to the group name. For example, silty gravel with cobbles, GM.

13. Report

13.1 The report should include the group name, group symbol, and the results of the laboratory tests. The particle-size distribution shall be given in terms of percent of gravel, sand, and fines. The plot of the cumulative particle-size distribution curve shall be reported if used in classifying the soil. Report appropriate descriptive information according to the procedures in Practice D 2488. A local or commercial name or geologic interpretation for the material may be added at the end of the descriptive information if identified as such. The test procedures used shall be referenced.

NOTE 9—*Example: Clayey Gravel with Sand and Cobbles* (GC)—46 % fine to coarse, hard, subrounded gravel; 30 % fine to coarse, hard, subrounded sand; 24 % clayey fines, LL = 38, PI = 19; weak reaction with HCl; original field sample had 4 % hard, subrounded cobbles; maximum dimension 150 mm.

In-Place Conditions—firm, homogeneous, dry, brown.

Geologic Interpretation—alluvial fan.

NOTE 10—Other examples of soil descriptions are given in Appendix X1.

14. Precision and Bias

14.1 This test method provides qualitative data only; therefore, a precision and bias statement is nonapplicable.

TABLE 1 Soil Classification Chart

Criteria for Assigning Group Symbols and Group Names Using Laboratory Tests[A]				Soil Classification	
				Group Symbol	Group Name[B]
Coarse-Grained Soils More than 50 % retained on No. 200 sieve	Gravels More than 50 % of coarse fraction retained on No. 4 sieve	Clean Gravels Less than 5 % fines[C]	Cu ≥ 4 and 1 ≤ Cc ≤ 3[E]	GW	Well-graded gravel[F]
			Cu < 4 and/or 1 > Cc > 3[E]	GP	Poorly graded gravel[F]
		Gravels with Fines More than 12 % fines[C]	Fines classify as ML or MH	GM	Silty gravel[F,G,H]
			Fines classify as CL or CH	GC	Clayey gravel[F,G,H]
	Sands 50 % or more of coarse fraction passes No. 4 sieve	Clean Sands Less than 5 % fines[D]	Cu ≥ 6 and 1 ≤ Cc ≤ 3[E]	SW	Well-graded sand[I]
			Cu < 6 and/or 1 > Cc > 3[E]	SP	Poorly graded sand[I]
		Sands with Fines More than 12 % fines[D]	Fines classify as ML or MH	SM	Silty sand[G,H,I]
			Fines classify as CL or CH	SC	Clayey sand[G,H,I]
Fine-Grained Soils 50 % or more passes the No. 200 sieve	Silts and Clays Liquid limit less than 50	inorganic	PI > 7 and plots on or above "A" line[J]	CL	Lean clay[K,L,M]
			PI < 4 or plots below "A" line[J]	ML	Silt[K,L,M]
		organic	$\frac{\text{Liquid limit - oven dried}}{\text{Liquid limit - not dried}} < 0.75$	OL	Organic clay[K,L,M,N] Organic silt[K,L,M,O]
	Silts and Clays Liquid limit 50 or more	inorganic	PI plots on or above "A" line	CH	Fat clay[K,L,M]
			PI plots below "A" line	MH	Elastic silt[K,L,M]
		organic	$\frac{\text{Liquid limit - oven dried}}{\text{Liquid limit - not dried}} < 0.75$	OH	Organic clay[K,L,M,P] Organic silt[K,L,M,Q]
Highly organic soils	Primarily organic matter, dark in color, and organic odor			PT	Peat

[A] Based on the material passing the 3-in. (75-mm) sieve.

[B] If field sample contained cobbles or boulders, or both, add "with cobbles or boulders, or both" to group name.

[C] Gravels with 5 to 12 % fines require dual symbols:
- GW-GM well-graded gravel with silt
- GW-GC well-graded gravel with clay
- GP-GM poorly graded gravel with silt
- GP-GC poorly graded gravel with clay

[D] Sands with 5 to 12 % fines require dual symbols:
- SW-SM well-graded sand with silt
- SW-SC well-graded sand with clay
- SP-SM poorly graded sand with silt
- SP-SC poorly graded sand with clay

[E] $Cu = D_{60}/D_{10} \qquad Cc = \frac{(D_{30})^2}{D_{10} \times D_{60}}$

[F] If soil contains ≥ 15 % sand, add "with sand" to group name.

[G] If fines classify as CL-ML, use dual symbol GC-GM, or SC-SM.

[H] If fines are organic, add "with organic fines" to group name.

[I] If soil contains ≥ 15 % gravel, add "with gravel" to group name.

[J] If Atterberg limits plot in hatched area, soil is a CL-ML, silty clay.

[K] If soil contains 15 to 29 % plus No. 200, add "with sand" or "with gravel," whichever is predominant.

[L] If soil contains ≥ 30 % plus No. 200, predominantly sand, add "sandy" to group name.

[M] If soil contains ≥ 30 % plus No. 200, predominantly gravel, add "gravelly" to group name.

[N] PI ≥ 4 and plots on or above "A" line.

[O] PI < 4 or plots below "A" line.

[P] PI plots on or above "A" line.

[Q] PI plots below "A" line.

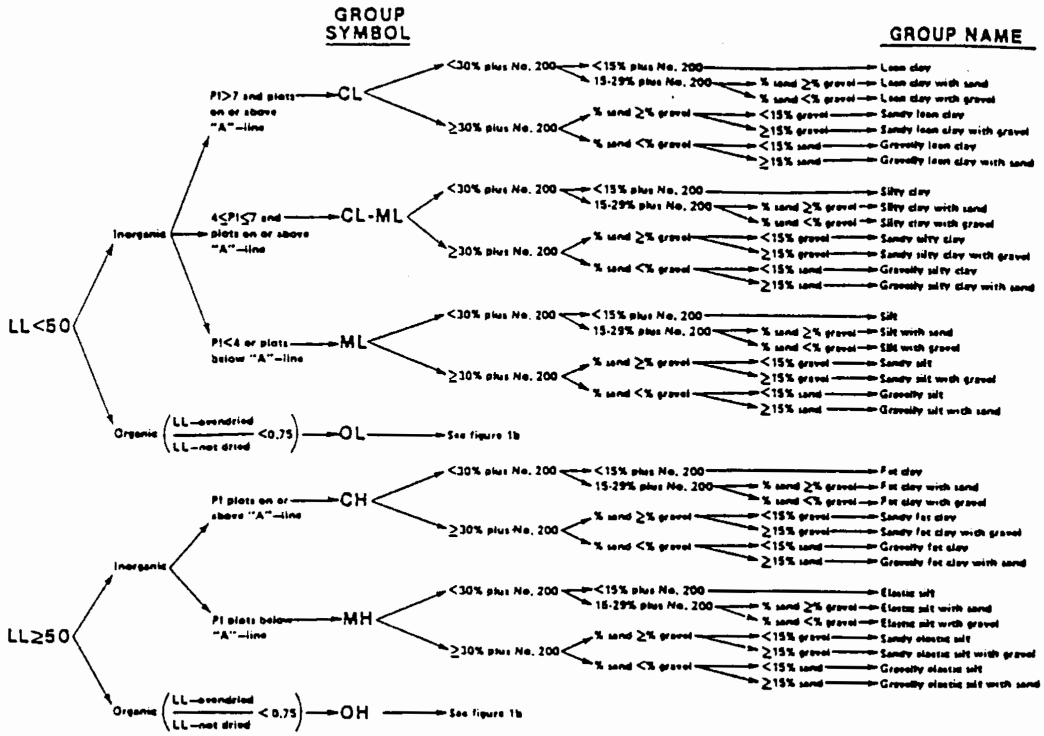


FIG. 1a Flow Chart for Classifying Fine-Grained Soil (50 % or More Passes No. 200 Sieve)

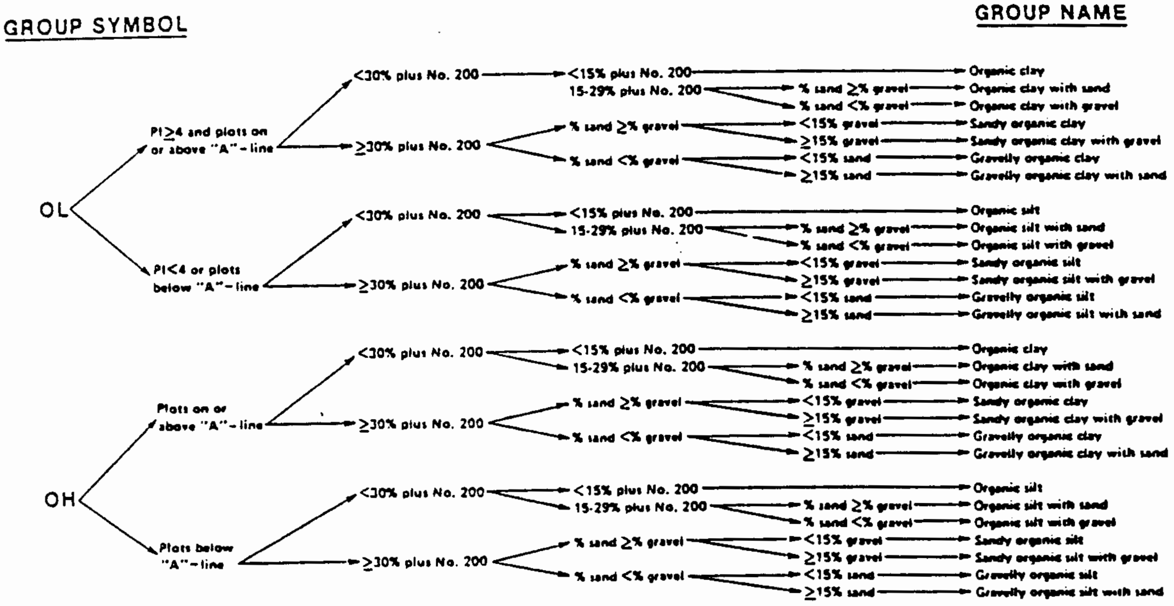


FIG. 1b Flow Chart for Classifying Organic Fine-Grained Soil (50 % or More Passes No. 200 Sieve)

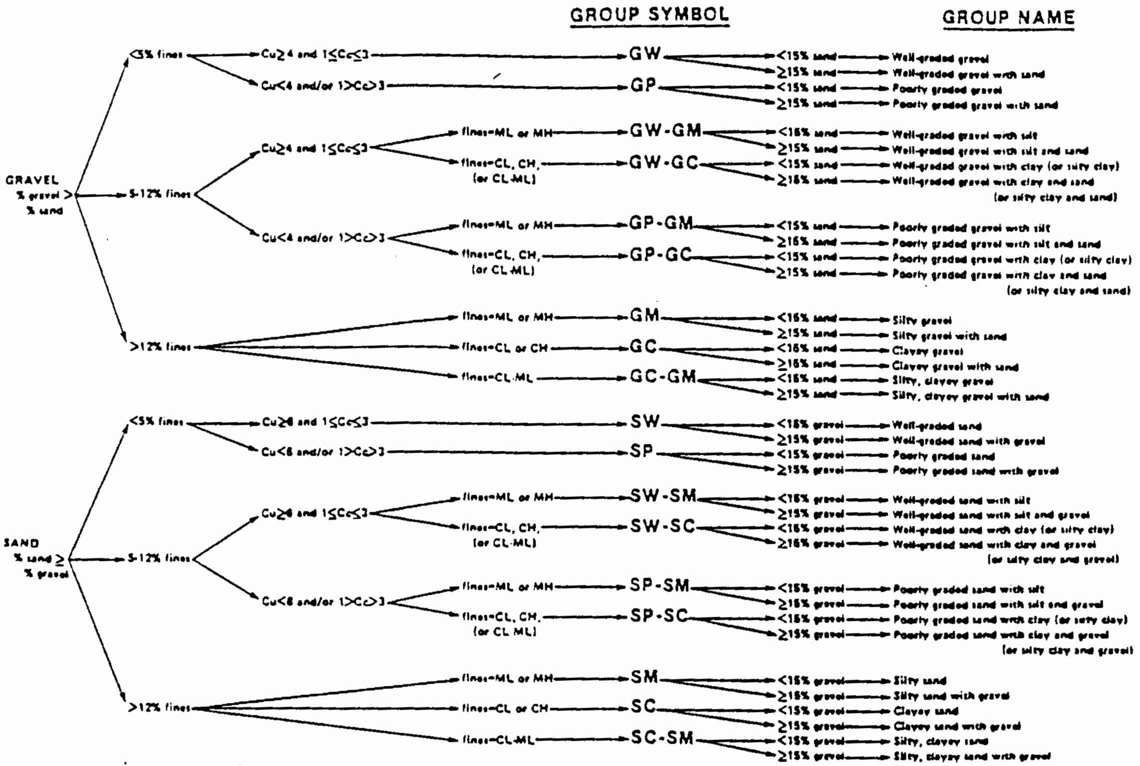


FIG. 2 Flow Chart for Classifying Coarse-Grained Soils (More Than 50 % Retained on No. 200 Sieve)

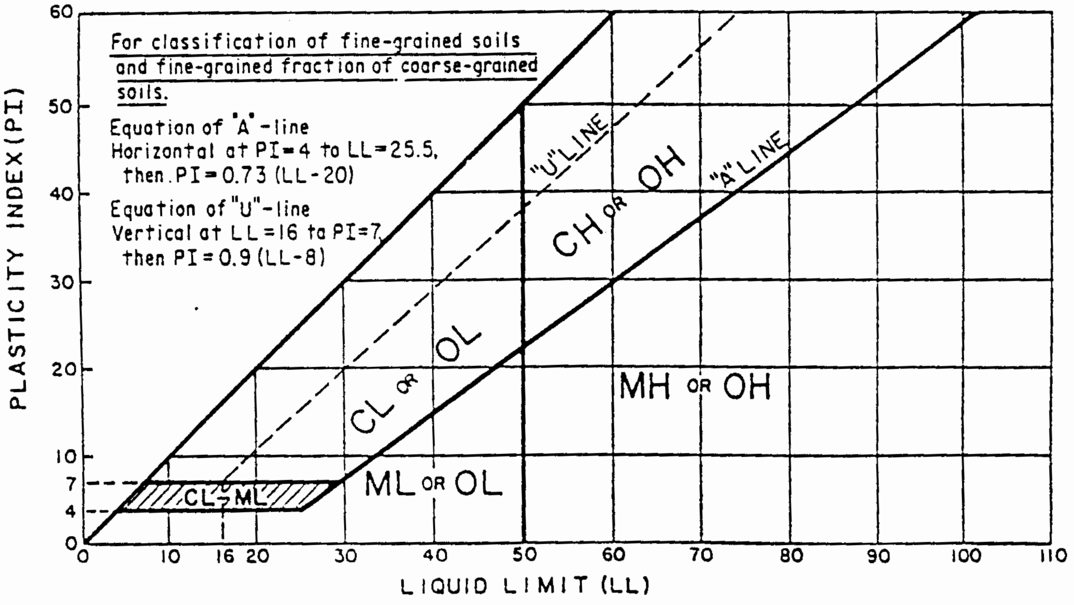
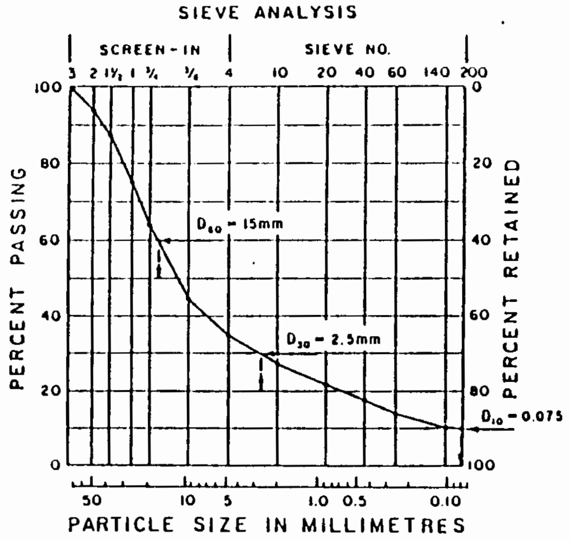


FIG. 3 Plasticity Chart



$$C_u = \frac{D_{60}}{D_{10}} = \frac{15}{0.075} = 200 \qquad C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}} = \frac{(2.5)^2}{0.075 \times 15} = 5.6$$

FIG. 4 Cumulative Particle-Size Plot

APPENDIXES

(Nonmandatory Information)

X1. EXAMPLES OF DESCRIPTIONS USING SOIL CLASSIFICATION

X1.1 The following examples show how the information required in 13.1 can be reported. The appropriate descriptive information from Practice D 2488 is included for illustrative purposes. The additional descriptive terms that would accompany the soil classification should be based on the intended use of the classification and the individual circumstances.

X1.1.1 *Well-Graded Gravel with Sand (GW)*—73 % fine to coarse, hard, subangular gravel; 23 % fine to coarse, hard, subangular sand; 4 % fines; Cc = 2.7, Cu = 12.4.

X1.1.2 *Silty Sand with Gravel (SM)*—61 % predominantly fine sand; 23 % silty fines, LL = 33, PI = 6; 16 % fine, hard, subrounded gravel; no reaction with HCl; (field sample smaller than recommended). *In-Place Conditions*—Firm, stratified and contains lenses of silt 1 to 2 in. thick, moist, brown to gray; in-place density = 106 lb/ft³ and in-place moisture = 9 %.

X1.1.3 *Organic Clay (OL)*—100 % fines, LL (not dried) = 32, LL (oven dried) = 21, PI (not dried) = 10; wet, dark brown, organic odor, weak reaction with HCl.

X1.1.4 *Silty Sand with Organic Fines (SM)*—74 % fine to coarse, hard, subangular reddish sand; 26 % organic and silty dark-brown fines, LL (not dried) = 37, LL (oven dried) = 26, PI (not dried) = 6, wet, weak reaction with HCl.

X1.1.5 *Poorly Graded Gravel with Silt, Sand, Cobbles and Boulders (GP-GM)*—78 % fine to coarse, hard, subrounded to subangular gravel; 16 % fine to coarse, hard, subrounded to subangular sand; 6 % silty (estimated) fines; moist, brown; no reaction with HCl; original field sample had 7 % hard, subrounded cobbles and 2 % hard, subrounded boulders with a maximum dimension of 18 in.

X2. USING SOIL CLASSIFICATION AS A DESCRIPTIVE SYSTEM FOR SHALE, CLAYSTONE, SHELLS, SLAG, CRUSHED ROCK, ETC.

X2.1 The group names and symbols used in this test method may be used as a descriptive system applied to materials that exist in situ as shale, claystone, sandstone, siltstone, mudstone, etc., but convert to soils after field or laboratory processing (crushing, slaking, etc.).

X2.2 Materials such as shells, crushed rock, slag, etc., should be identified as such. However, the procedures used in this method for describing the particle size and plasticity characteristics may be used in the description of the material. If desired, a classification in accordance with this test method may be assigned to aid in describing the material.

X2.3 If a classification is used, the group symbol(s) and group names should be placed in quotation marks or noted with some type of distinguishing symbol. See examples.

X2.4 Examples of how soil classifications could be incorporated into a description system for materials that are not naturally occurring soils are as follows:

X2.4.1 *Shale Chunks*—Retrieved as 2 to 4-in. pieces of shale from power auger hole, dry, brown, no reaction with HCl. After laboratory processing by slaking in water for 24 h, material classified as "Sandy Lean Clay (CL)"—61 % clayey fines, LL = 37, PI = 16; 33 % fine to medium sand; 6 % gravel-size pieces of shale.

X2.4.2 *Crushed Sandstone*—Product of commercial crushing operation; "Poorly Graded Sand with Silt (SP-SM)"—91 % fine to medium sand; 9 % silty (estimated) fines; dry, reddish-brown, strong reaction with HCl.

X2.4.3 *Broken Shells*—62 % gravel-size broken shells; 31 % sand and sand-size shell pieces; 7 % fines; would be classified as "Poorly Graded Gravel with Sand (GP)".

X2.4.4 *Crushed Rock*—Processed gravel and cobbles from Pit No. 7; "Poorly Graded Gravel (GP)"—89 % fine, hard, angular gravel-size particles; 11 % coarse, hard, angular sand-size particles, dry, tan; no reaction with HCl; Cc = 2.4, Cu = 0.9.

X3. PREPARATION AND TESTING FOR CLASSIFICATION PURPOSES BY THE WET METHOD

X3.1 This appendix describes the steps in preparing a soil sample for testing for purposes of soil classification using a wet-preparation procedure.

X3.2 Samples prepared in accordance with this procedure should contain as much of their natural water content as possible and every effort should be made during obtaining, preparing, and transportating the samples to maintain the natural moisture.

X3.3 The procedures to be followed in this test method assume that the field sample contains fines, sand, gravel, and plus 3-in. (75-mm) particles and the cumulative particle-size distribution plus the liquid limit and plasticity index values are required (see 9.8). Some of the following steps may be omitted when they are not applicable to the soil being tested.

X3.4 If the soil contains plus No. 200 (75-μm) particles that would degrade during dry sieving, use a test procedure for determining the particle-size characteristics that prevents this degradation.

X3.5 Since this classification system is limited to the portion of a sample passing the 3-in. (75-mm) sieve, the plus 3-in. (75-mm) material shall be removed prior to the determination of the particle-size characteristics and the liquid limit and plasticity index.

X3.6 The portion of the field sample finer than the 3-in. (75-mm) sieve shall be obtained as follows:

X3.6.1 Separate the field sample into two fractions on a 3-in. (75-mm) sieve, being careful to maintain the natural water content in the minus 3-in. (75-mm) fraction. Any particles adhering to the plus 3-in. (75-mm) particles shall be brushed or wiped off and placed in the fraction passing the 3-in. (75-mm) sieve.

X3.6.2 Determine the air-dry or oven-dry weight of the fraction retained on the 3-in. (75-mm) sieve. Determine the total (wet) weight of the fraction passing the 3-in. (75-mm) sieve.

X3.6.3 Thoroughly mix the fraction passing the 3-in. (75-mm) sieve. Determine the water content, in accordance with Method D 2216, of a representative specimen with a minimum dry weight as required in 7.2. Save the water-content specimen for determination of the particle-size analysis in accordance with X3.8.

X3.6.4 Compute the dry weight of the fraction passing the 3-in. (75-mm) sieve based on the water content and total (wet) weight. Compute the total dry weight of the sample and calculate the percentage of material retained on the 3-in. (75-mm) sieve.

X3.7 Determine the liquid limit and plasticity index as follows:

X3.7.1 If the soil disaggregates readily, mix on a clean, hard surface and select a representative sample by quartering in accordance with Methods C 702.

X3.7.1.1 If the soil contains coarse-grained particles coated with and bound together by tough clayey material, take extreme care in obtaining a representative portion of the No. 40 (425-μm) fraction. Typically, a larger portion than normal has to be selected, such as the minimum weights required in 7.2.

X3.7.1.2 To obtain a representative specimen of a basically cohesive soil, it may be advantageous to pass the soil through a ¾-in. (19-mm) sieve or other convenient size so the material can be more easily mixed and then quartered or split to obtain the representative specimen.

X3.7.2 Process the representative specimen in accordance with Procedure B of Practice D 2217.

X3.7.3 Perform the liquid-limit test in accordance with Test Method D 4318, except the soil shall not be air dried prior to the test.

X3.7.4 Perform the plastic-limit test in accordance with Test Method D 4318, except the soil shall not be air dried prior to the test, and calculate the plasticity index.

X3.8 Determine the particle-size distribution as follows:

X3.8.1 If the water content of the fraction passing the 3-in. (75-mm) sieve was required (X3.6.3), use the water-content specimen for determining the particle-size distribution. Otherwise, select a representative specimen in accordance with Methods C 702 with a minimum dry weight as required in 7.2.

X3.8.2 If the cumulative particle-size distribution including a hydrometer analysis is required, determine the particle-size distribution in accordance with Method D 422. See 9.7 for the set of required sieves.

X3.8.3 If the cumulative particle-size distribution without a hydrometer analysis is required, determine the particle-size distribution in accordance with Method C 136. See 9.7 for the set of required sieves. The specimen should be soaked until all clayey aggregations have softened and then washed in accordance with Test Method C 117 prior to performing the particle-size distribution.

X3.8.4 If the cumulative particle-size distribution is not required, determine the percent fines, percent sand, and percent gravel in the specimen in accordance with Test Method C 117, being sure to soak the specimen long enough to soften all clayey aggregations, followed by Method C 136 using a nest of sieves which shall include a No. 4 (4.75-mm) sieve and a No. 200 (75-μm) sieve.

X3.8.5 Calculate the percent fines, percent sand, and percent gravel in the minus 3-in. (75-mm) fraction for classification purposes.

X4. AIR-DRIED METHOD OF PREPARATION OF SOILS FOR TESTING FOR CLASSIFICATION PURPOSES

X4.1 This appendix describes the steps in preparing a soil sample for testing for purposes of soil classification when air-drying the soil before testing is specified or desired or when the natural moisture content is near that of an air-dried state.

X4.2 If the soil contains organic matter or mineral colloids that are irreversibly affected by air drying, the wet-preparation method as described in Appendix X3 should be used.

X4.3 Since this classification system is limited to the portion of a sample passing the 3-in. (75-mm) sieve, the plus 3-in. (75-mm) material shall be removed prior to the determination of the particle-size characteristics and the liquid limit and plasticity index.

X4.4 The portion of the field sample finer than the 3-in. (75-mm) sieve shall be obtained as follows:

X4.4.1 Air dry and weigh the field sample.

X4.4.2 Separate the field sample into two fractions on a 3-in. (75-mm) sieve.

X4.4.3 Weigh the two fractions and compute the percentage of the plus 3-in. (75-mm) material in the field sample.

X4.5 Determine the particle-size distribution and liquid limit and plasticity index as follows (see 9.8 for when these tests are required):

X4.5.1 Thoroughly mix the fraction passing the 3-in. (75-mm) sieve.

X4.5.2 If the cumulative particle-size distribution including a hydrometer analysis is required, determine the particle-size distribution in accordance with Method D 422. See 9.7 for the set of sieves that is required.

X4.5.3 If the cumulative particle-size distribution without a hydrometer analysis is required, determine the particle-size distribution in accordance with Test Method D 1140 followed by Method C 136. See 9.7 for the set of sieves that is required.

X4.5.4 If the cumulative particle-size distribution is not required, determine the percent fines, percent sand, and percent gravel in the specimen in accordance with Test Method D 1140 followed by Method C 136 using a nest of sieves which shall include a No. 4 (4.75-mm) sieve and a No. 200 (75-μm) sieve.

X4.5.5 If required, determine the liquid limit and the plasticity index of the test specimen in accordance with Test Method D 4318.

Designation: D 422 – 63 (Reapproved 1972)[ε1]

Standard Method for
PARTICLE-SIZE ANALYSIS OF SOILS[1]

This standard is issued under the fixed designation D 422; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

[ε1] Note—Section 2 was added editorially and subsequent sections renumbered in July 1984.

1. Scope

1.1 This method covers the quantitative determination of the distribution of particle sizes in soils. The distribution of particle sizes larger than 75 μm (retained on the No. 200 sieve) is determined by sieving, while the distribution of particle sizes smaller than 75 μm is determined by a sedimentation process, using a hydrometer to secure the necessary data (Notes 1 and 2).

Note 1—Separation may be made on the No. 4 (4.75-mm), No. 40 (425-μm), or No. 200 (75-μm) sieve instead of the No. 10. For whatever sieve used, the size shall be indicated in the report.

Note 2—Two types of dispersion devices are provided: (*1*) a high-speed mechanical stirrer, and (*2*) air dispersion. Extensive investigations indicate that air-dispersion devices produce a more positive dispersion of plastic soils below the 20-μm size and appreciably less degradation on all sizes when used with sandy soils. Because of the definite advantages favoring air dispersion, its use is recommended. The results from the two types of devices differ in magnitude, depending upon soil type, leading to marked differences in particle size distribution, especially for sizes finer than 20 μm.

2. Applicable Documents

2.1 *ASTM Standards:*

D 421 Practice for Dry Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants[2]

E 11 Specification for Wire-Cloth Sieves for Testing Purposes[3]

E 100 Specification for ASTM Hydrometers[4]

3. Apparatus

3.1 *Balances*—A balance sensitive to 0.01 g for weighing the material passing a No. 10 (2.00-mm) sieve, and a balance sensitive to 0.1 % of the mass of the sample to be weighed for weighing the material retained on a No. 10 sieve.

3.2 *Stirring Apparatus*—Either apparatus A or B may be used.

3.2.1 Apparatus A shall consist of a mechanically operated stirring device in which a suitably mounted electric motor turns a vertical shaft at a speed of not less than 10 000 rpm without load. The shaft shall be equipped with a replaceable stirring paddle made of metal, plastic, or hard rubber, as shown in Fig. 1. The shaft shall be of such length that the stirring paddle will operate not less than ¾ in. (19.0 mm) nor more than 1½ in. (38.1 mm) above the bottom of the dispersion cup. A special dispersion cup conforming to either of the designs shown in Fig. 2 shall be provided to hold the sample while it is being dispersed.

3.2.2 Apparatus B shall consist of an air-jet dispersion cup[5] (Note 3) conforming to the general details shown in Fig. 3 (Notes 4 and 5).

Note 3—The amount of air required by an air-jet dispersion cup is of the order of 2 ft^3/min; some small air compressors are not capable of supplying sufficient air to operate a cup.

Note 4—Another air-type dispersion device, known as a dispersion tube, developed by Chu and Davidson at Iowa State College, has been shown to give

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[1] This method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.03 on Texture, Plasticity, and Density Characteristics of Soils.

Current edition approved Nov. 21, 1963. Originally published 1935. Replaces D 422 – 62.

[2] *Annual Book of ASTM Standards*, Vol 04.08.

[3] *Annual Book of ASTM Standards*, Vol 14.02.

[4] *Annual Book of ASTM Standards*, Vol 14.01.

[5] Detailed working drawings for this cup are available at a nominal cost from the American Society for Testing and Materials, 1916 Race St., Philadelphia, PA 19103. Order Adjunct No. 12-404220-00.

results equivalent to those secured by the air-jet dispersion cups. When it is used, soaking of the sample can be done in the sedimentation cylinder, thus eliminating the need for transferring the slurry. When the air-dispersion tube is used, it shall be so indicated in the report.

NOTE 5—Water may condense in air lines when not in use. This water must be removed, either by using a water trap on the air line, or by blowing the water out of the line before using any of the air for dispersion purposes.

3.3 *Hydrometer*—An ASTM hydrometer, graduated to read in either specific gravity of the suspension or grams per litre of suspension, and conforming to the requirements for hydrometers 151H or 152H in Specifications E 100. Dimensions of both hydrometers are the same, the scale being the only item of difference.

3.4 *Sedimentation Cylinder*—A glass cylinder essentially 18 in. (457 mm) in height and 2½ in. (63.5 mm) in diameter, and marked for a volume of 1000 mL. The inside diameter shall be such that the 1000-mL mark is 36 ± 2 cm from the bottom on the inside.

3.5 *Thermometer*—A thermometer accurate to 1°F (0.5°C).

3.6 *Sieves*—A series of sieves, of square-mesh woven-wire cloth, conforming to the requirements of Specification E 11. A full set of sieves includes the following (Note 6):

3-in. (75-mm)
2-in. (50-mm)
1½-in. (37.5-mm)
1-in. (25.0-mm)
¾-in. (19.0-mm)
⅜-in. (9.5-mm)
No. 4 (4.75-mm)
No. 10 (2.00-mm)
No. 20 (850-μm)
No. 40 (425-μm)
No. 60 (250-μm)
No. 140 (106-μm)
No. 200 (75-μm)

NOTE 6—A set of sieves giving uniform spacing of points for the graph, as required in Section 17, may be used if desired. This set consists of the following sieves:

3-in. (75-mm)
1½-in. (37.5-mm)
¾-in. (19.0-mm)
⅜-in. (9.5-mm)
No. 4 (4.75-mm)
No. 8 (2.36-mm)
No. 16 (1.18-mm)
No. 30 (600-μm)
No. 50 (300-μm)
No. 100 (150-μm)
No. 200 (75-μm)

3.7 *Water Bath or Constant-Temperature Room*—A water bath or constant-temperature room for maintaining the soil suspension at a constant temperature during the hydrometer analysis. A satisfactory water tank is an insulated tank that maintains the temperature of the suspension at a convenient constant temperature at or near 68°F (20°C). Such a device is illustrated in Fig. 4. In cases where the work is performed in a room at an automatically controlled constant temperature, the water bath is not necessary.

3.8 *Beaker*—A beaker of 250-mL capacity.

3.9 *Timing Device*—A watch or clock with a second hand.

4. Dispersing Agent

4.1 A solution of sodium hexametaphosphate (sometimes called sodium metaphosphate) shall be used in distilled or demineralized water, at the rate of 40 g of sodium hexametaphosphate/litre of solution (Note 7).

NOTE 7—Solutions of this salt, if acidic, slowly revert or hydrolyze back to the orthophosphate form with a resultant decrease in dispersive action. Solutions should be prepared frequently (at least once a month) or adjusted to pH of 8 or 9 by means of sodium carbonate. Bottles containing solutions should have the date of preparation marked on them.

4.2 All water used shall be either distilled or demineralized water. The water for a hydrometer test shall be brought to the temperature that is expected to prevail during the hydrometer test. For example, if the sedimentation cylinder is to be placed in the water bath, the distilled or demineralized water to be used shall be brought to the temperature of the controlled water bath; or, if the sedimentation cylinder is used in a room with controlled temperature, the water for the test shall be at the temperature of the room. The basic temperature for the hydrometer test is 68°F (20°C). Small variations of temperature do not introduce differences that are of practical significance and do not prevent the use of corrections derived as prescribed.

5. Test Sample

5.1 Prepare the test sample for mechanical analysis as outlined in Practice D 421. During the preparation procedure the sample is divided into two portions. One portion contains only particles retained on the No. 10 (2.00-mm) sieve while the other portion contains only particles passing the No. 10 sieve. The mass of air-dried soil selected for purpose of tests, as prescribed in Practice D 421, shall be sufficient to yield quantities for mechanical analysis as follows:

5.1.1 The size of the portion retained on the No. 10 sieve shall depend on the maximum size of particle, according to the following schedule:

Nominal Diameter of Largest Particles, in. (mm)	Approximate Minimum Mass of Portion, g
⅜ (9.5)	500
¾ (19.0)	1000
1 (25.4)	2000
1½ (38.1)	3000
2 (50.8)	4000
3 (76.2)	5000

5.1.2 The size of the portion passing the No. 10 sieve shall be approximately 115 g for sandy soils and approximately 65 g for silt and clay soils.

5.2 Provision is made in Section 5 of Practice D 421 for weighing of the air-dry soil selected for purpose of tests, the separation of the soil on the No. 10 sieve by dry-sieving and washing, and the weighing of the washed and dried fraction retained on the No. 10 sieve. From these two masses the percentages retained and passing the No. 10 sieve can be calculated in accordance with 12.1.

NOTE 8—A check on the mass values and the thoroughness of pulverization of the clods may be secured by weighing the portion passing the No. 10 sieve and adding this value to the mass of the washed and oven-dried portion retained on the No. 10 sieve.

SIEVE ANALYSIS OF PORTION RETAINED ON NO. 10 (2.00-mm) SIEVE

6. Procedure

6.1 Separate the portion retained on the No. 10 (2.00-mm) sieve into a series of fractions using the 3-in. (75-mm), 2-in. (50-mm), 1½-in. (37.5-mm), 1-in. (25.0-mm), ¾-in. (19.0-mm), ⅜-in. (9.5-mm), No. 4 (4.75-mm), and No. 10 sieves, or as many as may be needed depending on the sample, or upon the specifications for the material under test.

6.2 Conduct the sieving operation by means of a lateral and vertical motion of the sieve, accompanied by a jarring action in order to keep the sample moving continuously over the surface of the sieve. In no case turn or manipulate fragments in the sample through the sieve by hand. Continue sieving until not more than 1 mass % of the residue on a sieve passes that sieve during 1 min of sieving. When mechanical sieving is used, test the thoroughness of sieving by using the hand method of sieving as described above.

6.3 Determine the mass of each fraction on a balance conforming to the requirements of 3.1. At the end of weighing, the sum of the masses retained on all the sieves used should equal closely the original mass of the quantity sieved.

HYDROMETER AND SIEVE ANALYSIS OF PORTION PASSING THE NO. 10 (2.00-mm) SIEVE

7. Determination of Composite Correction for Hydrometer Reading

7.1 Equations for percentages of soil remaining in suspension, as given in 14.3, are based on the use of distilled or demineralized water. A dispersing agent is used in the water, however, and the specific gravity of the resulting liquid is appreciably greater than that of distilled or demineralized water.

7.1.1 Both soil hydrometers are calibrated at 68°F (20°C), and variations in temperature from this standard temperature produce inaccuracies in the actual hydrometer readings. The amount of the inaccuracy increases as the variation from the standard temperature increases.

7.1.2 Hydrometers are graduated by the manufacturer to be read at the bottom of the meniscus formed by the liquid on the stem. Since it is not possible to secure readings of soil suspensions at the bottom of the meniscus, readings must be taken at the top and a correction applied.

7.1.3 The net amount of the corrections for the three items enumerated is designated as the composite correction, and may be determined experimentally.

7.2 For convenience, a graph or table of composite corrections for a series of 1° temperature differences for the range of expected test temperatures may be prepared and used as needed. Measurement of the composite corrections may be made at two temperatures spanning the range of expected test temperatures, and corrections for the intermediate temperatures calculated assuming a straight-line relationship between the two observed values.

7.3 Prepare 1000 mL of liquid composed of distilled or demineralized water and dispersing agent in the same proportion as will prevail in the sedimentation (hydrometer) test. Place the liquid in a sedimentation cylinder and the cylinder in the constant-temperature water bath, set for one of the two temperatures to be used. When the temperature of the liquid becomes constant, insert the hydrometer, and, after a short interval to permit the hydrometer to come to the temperature of the liquid, read the hydrometer at the top of the meniscus formed on the stem. For hydrometer 151H the composite correction is the difference between this reading and one; for hydrometer 152H it is the difference between the reading and zero. Bring the liquid and the hydrometer to the other temperature to be used, and secure the composite correction as before.

8. Hygroscopic Moisture

8.1 When the sample is weighed for the hydrometer test, weigh out an auxiliary portion of from 10 to 15 g in a small metal or glass container, dry the sample to a constant mass in an oven at 230 ± 9°F (110 ± 5°C), and weigh again. Record the masses.

9. Dispersion of Soil Sample

9.1 When the soil is mostly of the clay and silt sizes, weigh out a sample of air-dry soil of approximately 50 g. When the soil is mostly sand the sample should be approximately 100 g.

9.2 Place the sample in the 250-mL beaker and cover with 125 mL of sodium hexametaphosphate solution (40 g/L). Stir until the soil is thoroughly wetted. Allow to soak for at least 16 h.

9.3 At the end of the soaking period, disperse the sample further, using either stirring apparatus A or B. If stirring apparatus A is used, transfer the soil - water slurry from the beaker into the special dispersion cup shown in Fig. 2, washing any residue from the beaker into the cup with distilled or demineralized water (Note 9). Add distilled or demineralized water, if necessary, so that the cup is more than half full. Stir for a period of 1 min.

NOTE 9—A large size syringe is a convenient device for handling the water in the washing operation. Other devices include the wash-water bottle and a hose with nozzle connected to a pressurized distilled water tank.

9.4 If stirring apparatus B (Fig. 3) is used, remove the cover cap and connect the cup to a compressed air supply by means of a rubber hose. A air gage must be on the line between the cup and the control valve. Open the control valve so that the gage indicates 1 psi (7 kPa) pressure (Note 10). Transfer the soil - water slurry from the beaker to the air-jet dispersion cup by washing with distilled or demineralized water. Add distilled or demineralized water, if necessary, so that the total volume in the cup is 250 mL, but no more.

NOTE 10—The initial air pressure of 1 psi is required to prevent the soil - water mixture from entering the air-jet chamber when the mixture is transferred to the dispersion cup.

9.5 Place the cover cap on the cup and open the air control valve until the gage pressure is 20 psi (140 kPa). Disperse the soil according to the following schedule:

Plasticity Index	Dispersion Period, min
Under 5	5
6 to 20	10
Over 20	15

Soils containing large percentages of mica need be dispersed for only 1 min. After the dispersion period, reduce the gage pressure to 1 psi preparatory to transfer of soil - water slurry to the sedimentation cylinder.

10. Hydrometer Test

10.1 Immediately after dispersion, transfer the soil - water slurry to the glass sedimentation cylinder, and add distilled or demineralized water until the total volume is 1000 mL.

10.2 Using the palm of the hand over the open end of the cylinder (or a rubber stopper in the open end), turn the cylinder upside down and back for a period of 1 min to complete the agitation of the slurry (Note 11). At the end of 1 min set the cylinder in a convenient location and take hydrometer readings at the following intervals of time (measured from the beginning of sedimentation), or as many as may be needed, depending on the sample or the specification for the material under test: 2, 5, 15, 30, 60, 250, and 1440 min. If the controlled water bath is used, the sedimentation cylinder should be placed in the bath between the 2- and 5-min readings.

NOTE 11—The number of turns during this minute should be approximately 60, counting the turn upside down and back as two turns. Any soil remaining in the bottom of the cylinder during the first few turns should be loosened by vigorous shaking of the cylinder while it is in the inverted position.

10.3 When it is desired to take a hydrometer reading, carefully insert the hydrometer about 20 to 25 s before the reading is due to approximately the depth it will have when the reading is taken. As soon as the reading is taken, carefully remove the hydrometer and place it with a spinning motion in a graduate of clean distilled or demineralized water.

NOTE 12—It is important to remove the hydrometer immediately after each reading. Readings shall be taken at the top of the meniscus formed by the suspension around the stem, since it is not possible to secure readings at the bottom of the meniscus.

10.4 After each reading, take the temperature of the suspension by inserting the thermometer into the suspension.

11. Sieve Analysis

11.1 After taking the final hydrometer reading, transfer the suspension to a No. 200 (75-μm) sieve and wash with tap water until the wash water is clear. Transfer the material on the No. 200 sieve to a suitable container, dry in an oven at 230 ± 9°F (110 ± 5°C) and make a sieve analysis of the portion retained, using as many sieves as desired, or required for the material, or upon the specification of the material under test.

CALCULATIONS AND REPORT

12. Sieve Analysis Values for the Portion Coarser than the No. 10 (2.00-mm) Sieve

12.1 Calculate the percentage passing the No. 10 sieve by dividing the mass passing the No. 10 sieve by the mass of soil originally split on the No. 10 sieve, and multiplying the result by 100. To obtain the mass passing the No. 10 sieve, subtract the mass retained on the No. 10 sieve from the original mass.

12.2 To secure the total mass of soil passing the No. 4 (4.75-mm) sieve, add to the mass of the material passing the No. 10 sieve the mass of the fraction passing the No. 4 sieve and retained on the No. 10 sieve. To secure the total mass of soil passing the 3/8-in. (9.5-mm) sieve, add to the total mass of soil passing the No. 4 sieve, the mass of the fraction passing the 3/8-in. sieve and retained on the No. 4 sieve. For the remaining sieves, continue the calculations in the same manner.

12.3 To determine the total percentage passing for each sieve, divide the total mass passing (see 12.2) by the total mass of sample and multiply the result by 100.

13. Hygroscopic Moisture Correction Factor

13.1 The hydroscopic moisture correction factor is the ratio between the mass of the oven-dried sample and the air-dry mass before drying. It is a number less than one, except when there is no hygroscopic moisture.

14. Percentages of Soil in Suspension

14.1 Calculate the oven-dry mass of soil used in the hydrometer analysis by multiplying the air-dry mass by the hygroscopic moisture correction factor.

14.2 Calculate the mass of a total sample represented by the mass of soil used in the hydrometer test, by dividing the oven-dry mass used by the percentage passing the No. 10 (2.00-mm) sieve, and multiplying the result by 100. This value is the weight W in the equation for percentage remaining in suspension.

14.3 The percentage of soil remaining in suspension at the level at which the hydrometer is measuring the density of the suspension may be calculated as follows (Note 13): For hydrometer 151H:

$$P = [(100\,000/W) \times G/(G - G_1)](R - G_1)$$

NOTE 13—The bracketed portion of the equation for hydrometer 151H is constant for a series of readings and may be calculated first and then multiplied by the portion in the parentheses.

For hydrometer 152H:

$$P = (Ra/W) \times 100$$

where:

a = correction faction to be applied to the reading of hydrometer 152H. (Values shown on the scale are computed using a specific gravity of 2.65. Correction factors are given in Table 1),
P = percentage of soil remaining in suspension at the level at which the hydrometer measures the density of the suspension,
R = hydrometer reading with composite correction applied (Section 7),
W = oven-dry mass of soil in a total test sample represented by mass of soil dispersed (see 14.2), g,
G = specific gravity of the soil particles, and
G_1 = specific gravity of the liquid in which soil particles are suspended. Use numerical value of one in both instances in the equation. In the first instance any possible variation produces no significant effect, and in the second instance, the composite correction for R is based on a value of one for G_1.

15. Diameter of Soil Particles

15.1 The diameter of a particle corresponding to the percentage indicated by a given hydrometer reading shall be calculated according to Stokes' law (Note 14), on the basis that a particle of this diameter was at the surface of the suspension at the beginning of sedimentation and had settled to the level at which the hydrometer is measuring the density of the suspension. According to Stokes' law:

$$D = \sqrt{[30n/980(G - G_1)] \times L/T}$$

where:

D = diameter of particle, mm,

n = coefficient of viscosity of the suspending medium (in this case water) in poises (varies with changes in temperature of the suspending medium),

L = distance from the surface of the suspension to the level at which the density of the suspension is being measured, cm. (For a given hydrometer and sedimentation cylinder, values vary according to the hydrometer readings. This distance is known as effective depth (Table 2)),

T = interval of time from beginning of sedimentation to the taking of the reading, min,

G = specific gravity of soil particles, and

G_1 = specific gravity (relative density) of suspending medium (value may be used as 1.000 for all practical purposes).

NOTE 14—Since Stokes' law considers the terminal velocity of a single sphere falling in an infinity of liquid, the sizes calculated represent the diameter of spheres that would fall at the same rate as the soil particles.

15.2 For convenience in calculations the above equation may be written as follows:

$$D = K\sqrt{L/T}$$

where:

K = constant depending on the temperature of the suspension and the specific gravity of the soil particles. Values of K for a range of temperatures and specific gravities are given in Table 3. The value of K does not change for a series of readings constituting a test, while values of L and T do vary.

15.3 Values of D may be computed with sufficient accuracy, using an ordinary 10-in. slide rule.

NOTE 15—The value of L is divided by T using the *A*- and *B*-scales, the square root being indicated on the *D*-scale. Without ascertaining the value of the square root it may be multiplied by K, using either the *C*- or *CI*-scale.

16. Sieve Analysis Values for Portion Finer than No. 10 (2.00-mm) Sieve

16.1 Calculation of percentages passing the various sieves used in sieving the portion of the sample from the hydrometer test involves several steps. The first step is to calculate the mass of the fraction that would have been retained on the No. 10 sieve had it not been removed. This mass is equal to the total percentage retained on the No. 10 sieve (100 minus total percentage passing) times the mass of the total sample represented by the mass of soil used (as calculated in 14.2), and the result divided by 100.

16.2 Calculate next the total mass passing the No. 200 sieve. Add together the fractional masses retained on all the sieves, including the No. 10 sieve, and subtract this sum from the mass of the total sample (as calculated in 14.2).

16.3 Calculate next the total masses passing each of the other sieves, in a manner similar to that given in 12.2.

16.4 Calculate last the total percentages passing by dividing the total mass passing (as calculated in 16.3) by the total mass of sample (as calculated in 14.2), and multiply the result by 100.

17. Graph

17.1 When the hydrometer analysis is performed, a graph of the test results shall be made, plotting the diameters of the particles on a logarithmic scale as the abscissa and the percentages smaller than the corresponding diameters to an arithmetic scale as the ordinate. When the hydrometer analysis is not made on a portion of the soil, the preparation of the graph is optional, since values may be secured directly from tabulated data.

18. Report

18.1 The report shall include the following:

18.1.1 Maximum size of particles,

18.1.2 Percentage passing (or retained on) each sieve, which may be tabulated or presented by plotting on a graph (Note 16),

18.1.3 Description of sand and gravel particles:

18.1.3.1 Shape—rounded or angular,

18.1.3.2 Hardness—hard and durable, soft, or weathered and friable,

18.1.4 Specific gravity, if unusually high or low,

18.1.5 Any difficulty in dispersing the fraction passing the No. 10 (2.00-mm) sieve, indicating any change in type and amount of dispersing agent, and

18.1.6 The dispersion device used and the length of the dispersion period.

NOTE 16—This tabulation of graph represents the gradation of the sample tested. If particles larger than those contained in the sample were removed before testing, the report shall so state giving the amount and maximum size.

18.2 For materials tested for compliance with definite specifications, the fractions called for in such specifications shall be reported. The fractions smaller than the No. 10 sieve shall be read from the graph.

18.3 For materials for which compliance with definite specifications is not indicated and when the soil is composed almost entirely of particles passing the No. 4 (4.75-mm) sieve, the results read from the graph may be reported as follows:

(*1*) Gravel, passing 3-in. and retained on No. 4 sieve ..... %

(*2*) Sand, passing No. 4 sieve and retained on No. 200 sieve ..... %

  (*a*) Coarse sand, passing No. 4 sieve and retained on No. 10 sieve ..... %

  (*b*) Medium sand, passing No. 10 sieve and retained on No. 40 sieve ..... %

  (*c*) Fine sand, passing No. 40 sieve and retained on No. 200 sieve ..... %

(*3*) Silt size, 0.074 to 0.005 mm ..... %

(*4*) Clay size, smaller than 0.005 mm ..... %

  Colloids, smaller than 0.001 mm ..... %

18.4 For materials for which compliance with definite specifications is not indicated and when the soil contains material retained on the No. 4 sieve sufficient to require a sieve analysis on that portion, the results may be reported as follows (Note 17):

SIEVE ANALYSIS

Sieve Size	Percentage Passing
3-in.	....
2-in.	....
1½-in.	....
1-in.	....
¾-in.	....
⅜-in.	....
No. 4 (4.75-mm)	....
No. 10 (2.00-mm)	....
No. 40 (425-μm)	....
No. 200 (75-μm)	....

HYDROMETER ANALYSIS

0.074 mm	....
0.005 mm	....
0.001 mm	....

NOTE 17—No. 8 (2.36-mm) and No. 50 (300-μm) sieves may be substituted for No. 10 and No. 40 sieves.

TABLE 1 Values of Correction Factor, *a*, for Different Specific Gravities of Soil Particles[A]

Specific Gravity	Correction Factor[A]
2.95	0.94
2.90	0.95
2.85	0.96
2.80	0.97
2.75	0.98
2.70	0.99
2.65	1.00
2.60	1.01
2.55	1.02
2.50	1.03
2.45	1.05

[A] For use in equation for percentage of soil remaining in suspension when using Hydrometer 152H.

TABLE 2 Values of Effective Depth Based on Hydrometer and Sedimentation Cylinder of Specified Sizes[A]

Hydrometer 151H		Hydrometer 152H			
Actual Hydrometer Reading	Effective Depth, *L*, cm	Actual Hydrometer Reading	Effective Depth, *L*, cm	Actual Hydrometer Reading	Effective Depth, *L*, cm
1.000	16.3	0	16.3	31	11.2
1.001	16.0	1	16.1	32	11.1
1.002	15.8	2	16.0	33	10.9
1.003	15.5	3	15.8	34	10.7
1.004	15.2	4	15.6	35	10.6
1.005	15.0	5	15.5		
1.006	14.7	6	15.3	36	10.4
1.007	14.4	7	15.2	37	10.2
1.008	14.2	8	15.0	38	10.1
1.009	13.9	9	14.8	39	9.9
1.010	13.7	10	14.7	40	9.7
1.011	13.4	11	14.5	41	9.6
1.012	13.1	12	14.3	42	9.4
1.013	12.9	13	14.2	43	9.2
1.014	12.6	14	14.0	44	9.1
1.015	12.3	15	13.8	45	8.9
1.016	12.1	16	13.7	46	8.8
1.017	11.8	17	13.5	47	8.6
1.018	11.5	18	13.3	48	8.4
1.019	11.3	19	13.2	49	8.3
1.020	11.0	20	13.0	50	8.1
1.021	10.7	21	12.9	51	7.9
1.022	10.5	22	12.7	52	7.8
1.023	10.2	23	12.5	53	7.6
1.024	10.0	24	12.4	54	7.4
1.025	9.7	25	12.2	55	7.3
1.026	9.4	26	12.0	56	7.1
1.027	9.2	27	11.9	57	7.0
1.028	8.9	28	11.7	58	6.8
1.029	8.6	29	11.5	59	6.6
1.030	8.4	30	11.4	60	6.5

TABLE 2 Continued

Hydrometer 151H		Hydrometer 152H			
Actual Hydrometer Reading	Effective Depth, *L*, cm	Actual Hydrometer Reading	Effective Depth, *L*, cm	Actual Hydrometer Reading	Effective Depth, *L*, cm
1.031	8.1				
1.032	7.8				
1.033	7.6				
1.034	7.3				
1.035	7.0				
1.036	6.8				
1.037	6.5				
1.038	6.2				

[A] Values of effective depth are calculated from the equation:

$$L = L_1 + \tfrac{1}{2}[L_2 - (V_B/A)]$$

where:

L = effective depth, cm,

L_1 = distance along the stem of the hydrometer from the top of the bulb to the mark for a hydrometer reading, cm,

L_2 = overall length of the hydrometer bulb, cm,

V_B = volume of hydrometer bulb, cm^3, and

A = cross-sectional area of sedimentation cylinder, cm^2

Values used in calculating the values in Table 2 are as follows:

For both hydrometers, 151H and 152H:

L_2 = 14.0 cm

V_B = 67.0 cm^3

A = 27.8 cm^2

For hydrometer 151H:

L_1 = 10.5 cm for a reading of 1.000

= 2.3 cm for a reading of 1.031

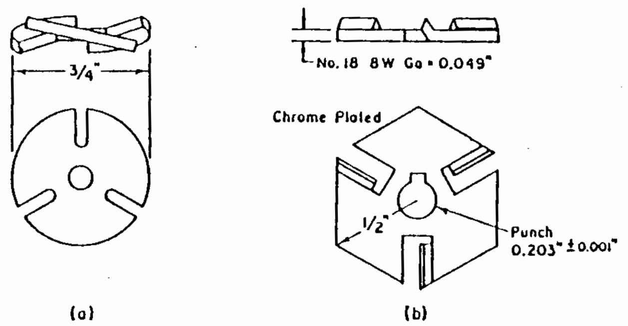
For hydrometer 152H:

L_1 = 10.5 cm for a reading of 0 g/litre

= 2.3 cm for a reading of 50 g/litre

TABLE 3 Values of *K* for Use in Equation for Computing Diameter of Particle in Hydrometer Analysis

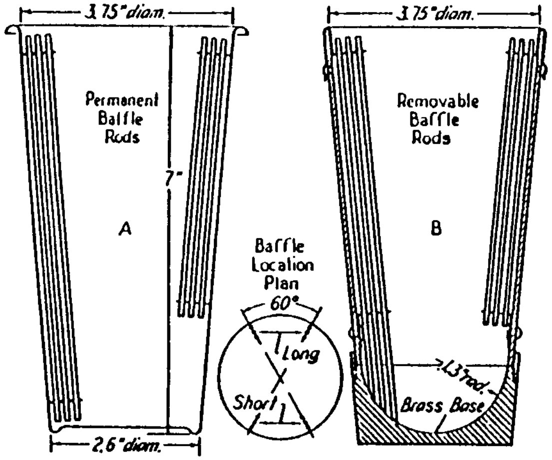
Temperature, °C	Specific Gravity of Soil Particles								
	2.45	2.50	2.55	2.60	2.65	2.70	2.75	2.80	2.85
16	0.01510	0.01505	0.01481	0.01457	0.01435	0.01414	0.01394	0.01374	0.01356
17	0.01511	0.01486	0.01462	0.01439	0.01417	0.01396	0.01376	0.01356	0.01338
18	0.01492	0.01467	0.01443	0.01421	0.01399	0.01378	0.01359	0.01339	0.01321
19	0.01474	0.01449	0.01425	0.01403	0.01382	0.01361	0.01342	0.1323	0.01305
20	0.01456	0.01431	0.01408	0.01386	0.01365	0.01344	0.01325	0.01307	0.01289
21	0.01438	0.01414	0.01391	0.01369	0.01348	0.01328	0.01309	0.01291	0.01273
22	0.01421	0.01397	0.01374	0.01353	0.01332	0.01312	0.01294	0.01276	0.01258
23	0.01404	0.01381	0.01358	0.01337	0.01317	0.01297	0.01279	0.01261	0.01243
24	0.01388	0.01365	0.01342	0.01321	0.01301	0.01282	0.01264	0.01246	0.01229
25	0.01372	0.01349	0.01327	0.01306	0.01286	0.01267	0.01249	0.01232	0.01215
26	0.01357	0.01334	0.01312	0.01291	0.01272	0.01253	0.01235	0.01218	0.01201
27	0.01342	0.01319	0.01297	0.01277	0.01258	0.01239	0.01221	0.01204	0.01188
28	0.01327	0.01304	0.01283	0.01264	0.01244	0.01255	0.01208	0.01191	0.01175
29	0.01312	0.01290	0.01269	0.01249	0.01230	0.01212	0.01195	0.01178	0.01162
30	0.01298	0.01276	0.01256	0.01236	0.01217	0.01199	0.01182	0.01165	0.01149



Metric Equivalents

in.	0.001	0.049	0.203	½	¾
mm	0.03	1.24	5.16	12.7	19.0

FIG. 1 Detail of Stirring Paddles



Metric Equivalents

in.	1.3	2.6	3.75
mm	33	66	95.2

FIG. 2 Dispersion Cups of Apparatus

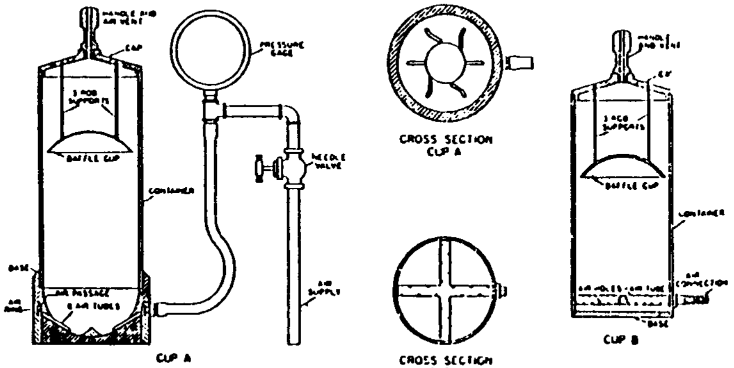
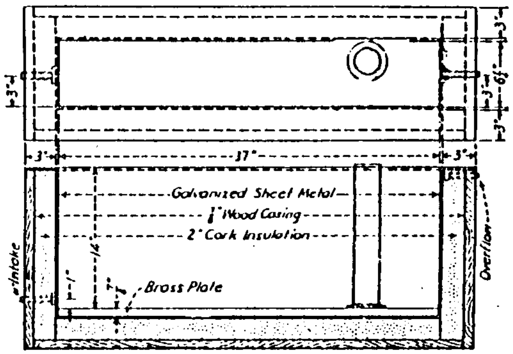


FIG. 3 Air-Jet Dispersion Cups of Apparatus B



Metric Equivalents

in.	⅞	1	3	6⅞	14	37
mm	22.2	25.4	76.2	158.2	356	940

FIG. 4 Insulated Water Bath

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Designation: D 698 – 78

An American National Standard

Standard Test Methods for
MOISTURE-DENSITY RELATIONS OF SOILS AND SOIL-AGGREGATE MIXTURES USING 5.5-lb (2.49-kg) RAMMER AND 12-in. (305-mm) DROP[1]

This standard is issued under the fixed designation D 698; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

These methods have been approved for use by agencies of the Department of Defense and for listing in the DoD Index of Specifications and Standards

1. Scope

1.1 These laboratory compaction methods cover the determination of the relationship between the moisture content and density of soils and soil-aggregate mixtures (Note 1) when compacted in a mold of a given size with a 5.5-lb (2.49-kg) rammer dropped from a height of 12 in. (305 mm) (Note 2). Four alternative procedures are provided as follows:

1.1.1 *Method A*—A 4-in. (101.6-mm) mold; material passing a No. 4 (4.75-mm) sieve;

1.1.2 *Method B*—A 6-in. (152.4-mm) mold; material passing a No. 4 (4.75-mm) sieve;

1.1.3 *Method C*—A 6-in. (152.4-mm) mold; material passing a $\frac{3}{4}$-in. (19.0-mm) sieve; and

1.1.4 *Method D*—A 6-in. (152.4-mm) mold; material passing a $\frac{3}{4}$-in. (19.0-mm) sieve, corrected by replacement for material retained on a $\frac{3}{4}$-in. sieve.

NOTE 1—Soils and soil-aggregate mixtures should be regarded as natural occurring fine- or coarse-grained soils or composites or mixtures of natural soils, or mixtures of natural and processed soils or aggregates such as silt, gravel, or crushed rock.

NOTE 2—These laboratory compaction test methods when used on soils and soil-aggregates which are not free-draining will, in most cases, establish a well-defined optimum moisture content and maximum density (see Section 7). However, for free-draining soils and soil-aggregate mixtures, these methods will not, in many cases, produce a well-defined moisture-density relationship and the maximum density obtained will generally be less than that obtained by vibratory methods.

1.2 The method to be used should be indicated in the specifications for the material being tested. If no method is specified, the provisions of Section 5 shall govern.

2. Applicable Documents

2.1 *ASTM Standards:*

C 127 Test Method for Specific Gravity and Absorption of Coarse Aggregate[2]
D 854 Test Method for Specific Gravity of Soils[3]
D 2168 Methods for Calibration of Laboratory Mechanical-Rammer Soil Compactors[3]
D 2216 Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures[3]
D 2487 Test Method for Classification of Soils for Engineering Purposes[3]
D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)[3]
E 11 Specification for Wire-Cloth Sieves for Testing Purposes[4]

3. Apparatus

3.1 *Molds*—The molds shall be cylindrical in shape, made of rigid metal and be within the capacity and dimensions indicated in 3.1.1 or 3.1.2. The molds may be the "split" type, consisting either of two half-round sections, or a section of pipe split along one element, which can be securely locked together to form a cylinder meeting the requirements of this section. The molds may also be the "taper" type, providing the internal diameter taper is uniform and is not more than 0.200 in./linear ft (16.7 mm/linear m) of mold height. Each mold shall have a base plate assembly and an extension collar assembly, both made of rigid metal and constructed so they can be securely attached to or detached from the mold. The extension collar assembly shall have a height extending above the top of the mold of at least 2 in. (50.8 mm), which may include an upper section that flares out to form a funnel provided there is at least a $\frac{3}{4}$-in. (19-mm) straight cylindrical section beneath it.

3.1.1 *Mold*, 4.0 in. (101.6 mm) in diameter, having a capacity of $\frac{1}{30} \pm 0.0004$ ft^3 (944 ± 11 cm^3) and conforming to Fig. 1.

3.1.2 *Mold*, 6.0 in. (152.4 mm) in diameter, having a capacity of $\frac{1}{13.333} \pm 0.0009$ ft^3 (2124 ± 25 cm^3) and conforming to Fig. 2.

3.1.3 The average internal diameter, height, and volume of each mold shall be determined before initial use and at intervals not exceeding 1000 times the mold is filled. The mold volume shall be calculated from the average of at least six internal diameter and three height measurements made to the nearest 0.001 in. (0.02 mm), or from the amount of water required to completely fill the mold, corrected for temperature variance in accordance with Table 1. If the average internal diameter and volume are not within the tolerances shown in Figs. 1 or 2, the mold shall not be used. The determined volume shall be used in computing the required densities.

3.2 *Rammer*—The rammer may be either manually operated (see 3.2.1) or mechanically operated (see 3.2.2). The rammer shall fall freely through a distance of $12.0 \pm \frac{1}{16}$ in. (304.8 ± 1.6 mm) from the surface of the specimen. The manufactured weight of the rammer shall be 5.5 ± 0.02 lb (2.49 ± 0.01 kg). The specimen contact face shall be flat.

3.2.1 *Manual Rammer*—The specimen contact face shall be circular with a diameter of 2.000 ± 0.005 in. (50.80 ± 0.13 mm). The rammer shall be equipped with a guidesleeve which shall provide sufficient clearance so that the free fall of the rammer shaft and head will not be restricted. The guidesleeve shall have four vent holes at each end (eight holes total) located with centers $\frac{3}{4} \pm \frac{1}{16}$ in. (19.0 ± 1.6 mm) from each end and spaced 90 deg apart. The minimum diameter of the vent holes shall be $\frac{3}{8}$ in. (9.5 mm).

3.2.2 *Mechanical Rammer*—The rammer shall operate mechanically in such a manner as to provide uniform and complete coverage of the specimen surface. There shall be 0.10 ± 0.03 in. (2.5 ± 0.8 mm) clearance between the rammer and the inside surface of the mold at its smallest diameter. When used with the 4.0-in. (101.6-mm) mold, the specimen contact face shall be circular with a diameter of 2.000 ± 0.005 in. (50.80 ± 0.13 mm). When used with the 6.0-in. (152.4-mm) mold, the specimen contact face shall have the shape of a section of a circle of a radius equal to 2.90 ± 0.02 in. (73.7 ± 0.5 mm). The sector face rammer shall operate in such a manner that the vertex of the sector is positioned at the center of the specimen. The mechanical rammer shall be calibrated and adjusted, as necessary, in accordance with 3.2.3.

3.2.3 *Calibration and Adjustment*—The mechanical rammer shall be calibrated, and adjusted as necessary, before initial use; near the end of each period during which the mold was filled 1000 times; before reuse after anything, including repairs, which may affect the test results significantly; and whenever the test results are questionable. Each calibration and adjustment shall be in accordance with Methods D 2168.

3.3 *Sample Extruder* (optional)—A jack, frame or other device adapted for the purpose of extruding compacted specimens from the mold.

3.4 *Balances*—A balance or scale of at least 20-kg capacity sensitive to ± 1 g and a balance of at least 1000-g capacity sensitive to ±0.01 g.

3.5 *Drying Oven*, thermostatically controlled, preferably of the forced-draft type, capable of maintaining a temperature of 230 ± 9°F (110 ± 5°C) for determining the moisture content of the compacted specimen.

3.6 *Straightedge*—A stiff metal straightedge of any convenient length but not less than 10 in. (254 mm). The scraping edge shall have a straightness tolerance of ±0.005 in. (±0.13 mm) and shall be beveled if it is thicker than $\frac{1}{8}$ in.

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[1] These methods are under the jurisdiction of ASTM Committee D-18 on Soil and Rock.

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[2] *Annual Book of ASTM Standards*, Vols 04.02 and 04.03.

[3] *Annual Book of ASTM Standards*, Vol 04.08.

[4] *Annual Book of ASTM Standards*, Vols 04.01, 04.02, 04.06, 05.05, and 14.02.

(3 mm).

3.7 *Sieves*, 3-in. (75-mm), $^{3}/_{4}$-in. (19.0-mm) and No. 4 (4.75-mm), conforming to the requirements of Specification E 11.

3.8 *Mixing Tools*—Miscellaneous tools such as mixing pan, spoon, trowel, spatula, etc., or a suitable mechanical device for thoroughly mixing the sample of soil with increments of water.

4. Procedure

4.1 *Specimen Preparation*—Select a representative portion of quantity adequate to provide, after sieving, an amount of material weighing as follows: Method A—25 lb (11 kg); Methods B, C, and D—50 lb (23 kg). Prepare specimens in accordance with either 4.1.1 through 4.1.3 or 4.1.4.

4.1.1 *Dry Preparation Procedure*—If the sample is too damp to be friable, reduce the moisture content by drying until the material is friable; see 4.1.2. Drying may be in air or by the use of a drying apparatus such that the temperature of the sample does not exceed 140°F (60°C). After drying (if required), thoroughly break up the aggregations in such a manner as to avoid reducing the natural size of the particles. Pass the material through the specified sieve as follows: Methods A and B—No. 4 (4.75-mm); Methods C and D—$^{3}/_{4}$-in. (19.0-mm). Correct for oversize material in accordance with Section 5, if Method D is specified.

4.1.2 Whenever practicable, soils classified as ML, CL, OL, GC, SC, MH, CH, OH and PT by Test Method D 2487 shall be prepared in accordance with 4.1.4.

4.1.3 Prepare a series of at least four specimens by adding increasing amounts of water to each sample so that the moisture contents vary by approximately 1½ %. The moisture contents selected shall bracket the optimum moisture content, thus providing specimens which, when compacted, will increase in mass to the maximum density and then decrease in density (see 7.2 and 7.3). Thoroughly mix each specimen to ensure even distribution of moisture throughout and then place in a separate covered container and allow to stand prior to compaction in accordance with Table 2. For the purpose of selecting a standing time [illegible] is not required to perform the actual classification procedures described in Test Method D 2487 (except in the case of referee testing), if previous data exist which provide a basis for classifying the sample.

4.1.4 *Moist Preparation Method*—The following alternate procedure is recommended for soils classified as ML, CL, OL, GC, SC, MH, CH, OH, and PT by Test Method D 2487. Without previously drying the sample, pass it through the $^{3}/_{4}$-in. (19.0-mm) and No. 4 (4.75-mm) sieves. Correct for oversize material in accordance with Section 5, if Method D is specified. Prepare a series of at least four specimens having moisture contents that vary by approximately 1½ %. The moisture contents selected shall bracket the optimum moisture content, thus providing specimens which, when compacted, will increase in mass to the maximum density and then decrease in density (see 7.2 and 7.3). To obtain the appropriate moisture content of each specimen, the addition of a predetermined amount of water (see 4.1.3) or the removal of a predetermined amount of moisture by drying may be necessary. Drying may be in air or by the use of a drying apparatus such that the temperature of the specimen does not exceed 140°F (60°C). The prepared specimens shall then be thoroughly mixed and stand, as specified in 4.1.3 and Table 2, prior to compaction.

NOTE 3—With practice, it is usually possible to visually judge the point of optimum moisture closely enough so that the prepared specimens will bracket the point of optimum moisture content.

4.2 *Specimen Compaction*—Select the proper compaction mold, in accordance with the method being used, and attach the mold extension collar. Compact each specimen in three layers of approximately equal height. Each layer shall receive 25 blows in the case of the 4-in. (101.6-mm) mold; each layer shall receive 56 blows in the case of the 6-in. (152.4-mm) mold. The total amount of material used shall be such that the third compacted layer is slightly above the top of the mold, but not exceeding $^{1}/_{4}$ in. (6 mm). During compaction the mold shall rest on a uniform rigid foundation, such as provided by a cylinder or cube of concrete weighing not less than 200 lb (91 kg).

4.2.1 In operating the manual rammer, care shall be taken to avoid rebound of the rammer from the top end of the guidesleeve. The guidesleeve shall be held steady and within 5 deg of the vertical. Apply the blows at a uniform rate not exceeding approximately 1.4 s per blow and in such a manner as to provide complete coverage of the specimen surface.

4.2.2 Following compaction, remove the extension collar; carefully trim the compacted specimen even with the top of the mold by means of the straightedge and determine the mass of the specimen. Divide the mass of the compacted specimen and mold, minus the mass of the mold, by the volume of the mold (see 3.1.3). Record the result as the wet density, γ_m, in pounds per cubic foot (or kilograms per cubic metre) of the compacted specimen.

4.2.3 Remove the material from the mold. Determine moisture content in accordance with Method D 2216, using either the whole specimen or alternatively a representative specimen of the whole specimen. The whole specimen must be used when the permeability of the compacted specimen is high enough so that the moisture content is not distributed uniformly throughout. If the whole specimen is used, break it up to facilitate drying. Obtain the representative specimen by slicing the compacted specimen axially through the center and removing 100 to 500 g of material from one of the cut faces.

4.2.4 Repeat 4.2 through 4.2.3 for each specimen prepared.

5. Oversize Corrections

5.1 If 30 % or more of the sample is retained on a $^{3}/_{4}$-in. (19.0-mm) sieve, then none of the methods described under these methods shall be used for the determination of either maximum density or optimum moisture content.

5.2 *Methods A and B*—The material retained on the No. 4 (4.75-mm) sieve is discarded and no oversize correction is made. However, it is recommended that if the amount of material retained is 7 % or greater, Method C be used instead.

5.3 *Method C*—The material retained on the $^{3}/_{4}$-in. (19.0-mm) sieve is discarded and no oversize correction is made. However, if the amount of material retained is 10 % or greater, it is recommended that Method D be used instead.

5.4 *Method D:*

5.4.1 This method shall not be used unless the amount of material retained on the $^{3}/_{4}$-in. (19.0-mm) sieve is 10 % or greater. When the amount of material retained on the $^{3}/_{4}$-in. sieve is less than 10 %, use Method C.

5.4.2 Pass the material retained on the $^{3}/_{4}$-in. (19.0-mm) sieve through a 3-in. or 75-mm sieve. Discard the material retained on the 3-in. sieve. The material passing the 3-in. sieve and retained on the $^{3}/_{4}$-in. sieve shall be replaced with an equal amount of material passing a $^{3}/_{4}$-in. sieve and retained on a No. 4 (4.75-mm) sieve. The material for replacement shall be taken from an unused portion of the sample.

6. Calculations

6.1 Calculate the moisture content and the dry density of each compacted specimen as follows:

$$w = [(A - B)/(B - C)] \times 100$$

and

$$\gamma_d = [\gamma_m/(w + 100)] \times 100$$

where:

w = moisture content in percent of the compacted specimens,
A = mass of container and moist specimen,
B = mass of container and oven-dried specimen,
C = mass of container,
γ_d = dry density, in pounds per cubic foot (or kilograms per cubic metre) of the compacted specimen, and
γ_m = wet density, in pounds per cubic foot (or kilograms per cubic metre) of the compacted specimen.

7. Moisture-Density Relationship

7.1 From the data obtained in 6.1, plot the dry density values as ordinates with corresponding moisture contents as abscissas. Draw a smooth curve connecting the plotted points. Also draw a curve termed the "curve of complete saturation" or "zero air voids curve" on this plot. This curve represents the relationship between dry density and corresponding moisture contents when the voids are completely filled with water. Values of dry density and corresponding moisture contents for plotting the curve of complete saturation can be computed using the following equation:

$$w_{sat} = [(62.4/\gamma_d) - (1/G_s)] \times 100$$

where:

w_{sat} = moisture content in percent for complete saturation,
γ_d = dry density in pounds per cubic foot (or kilograms per cubic metre),
G_s = specific gravity of the material being tested (see Note 4), and
62.4 = density of water in pounds per cubic foot (or kilograms per cubic metre).

NOTE 4—The specific gravity of the material can either be assumed or based on the weighted average values of: (*a*) the specific gravity of the material passing the No. 4 (4.75-mm) sieve in accordance with Test Method D 854; and (*b*) the apparent specific gravity of the material retained on the No. 4 sieve in accordance with Test Method C 127.

7.2 *Optimum Moisture Content*, w_o—The moisture content corresponding to the peak of the curve drawn as directed in 7.1 shall be termined the "optimum moisture content."

7.3 *Maximum Density*, γ_{max}—The dry density in pounds per cubic foot (or kilograms per cubic metre) of the sample at "optimum moisture content" shall be termed "maximum density."

8. Report

8.1 The report shall include the following.

8.1.1 Method used (Method A, B, C, or D).

8.1.2 Optimum moisture content.

8.1.3 Maximum density.

8.1.4 Description of rammer (whether manual or mechanical).

8.1.5 Description of appearance of material used in test, based on Practice D 2488 (Test Method D 2487 may be used as an alternative).

8.1.6 Origin of material used in test.

8.1.7 Preparation procedure used (moist or dry).

9. Precision

9.1 Criteria for judging the acceptability of the maximum density and optimum moisture content test results are given in Table 3. The standard deviation, s, is calculated from the equation:

$$s^2 = \frac{1}{n-1}\sum_{1}^{n}(x - \bar{x})^2$$

where:

n = number of determinations,
x = individual value of each determination, and
$\bar{x}$ = numerical average of the determinations.

9.2 Criteria for assigning standard deviation values for single-operator precision are not available at the present time.

TABLE 1 Volume of Water per Gram based on Temperature[A]

Temperature, °C (°F)	Volume of Water, ml/g
12 (53.6)	1.00048
14 (57.2)	1.00073
16 (60.8)	1.00103
18 (64.4)	1.00138
20 (68.0)	1.00177
22 (71.6)	1.00221
24 (75.2)	1.00268
26 (78.8)	1.00320
28 (82.4)	1.00375
30 (86.0)	1.00435
32 (89.6)	1.00497

[A] Values other than shown may be obtained by referring to the *Handbook of Chemistry and Physics*, Chemical Rubber Publishing Co., Cleveland, Ohio.

TABLE 2 Dry Preparation Method – Standing Times

Classification D 2487	Minimum Standing Time, h
GW, GP, SW, SP	no requirement
GM, SM	3
ML, CL, OL, GC, SC	18
MH, CH, OH, PT	36

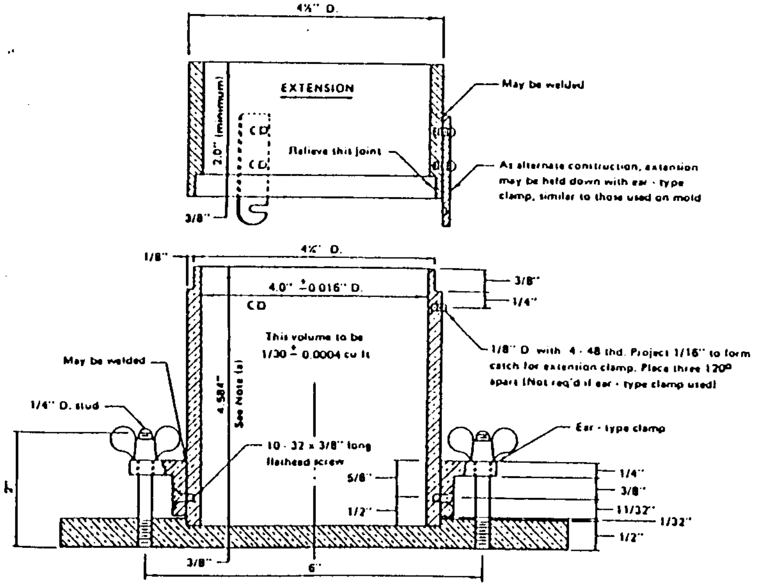
TABLE 3 Precision

	Standard Deviation, s	Acceptable Range of Two Results, Expressed as Percent of Mean Value[A]
Single operator precision:		
Maximum density	...	1.9
Optimum moisture content	...	9.5
Multilaboratory precision:		
Maximum density	±1.66	4.0
Optimum moisture content	±0.86	15.0

[A] This column indicates a limiting range of values which should not be exceeded by the difference between any two results, expressed as a percentage of the average value. In cooperative test programs it has been determined that 95 % of the tests do not exceed the limiting acceptable ranges shown below. All values shown in this table are based on average test results from a variety of different soils and are subject to future revision.

TABLE 4 Metric Equivalents for Figs. 1 and 2

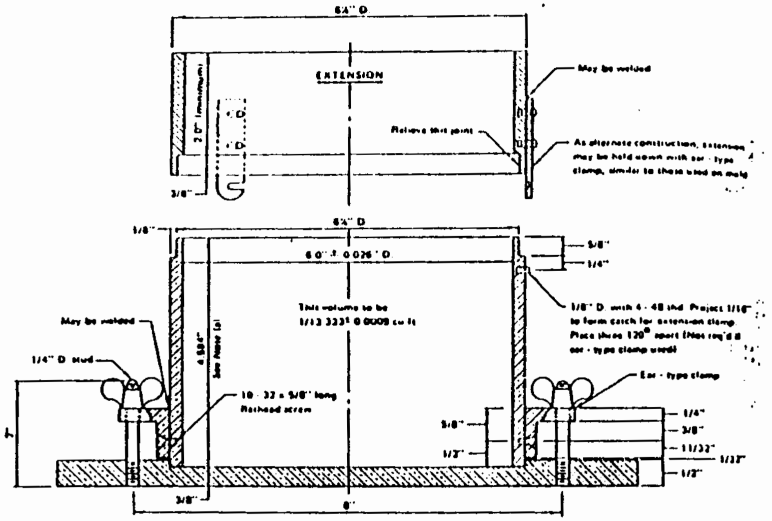
in.	mm
0.016	0.41
0.026	0.66
1/32	0.80
1/16	1.6
1/8	3.2
1/4	6.4
11/32	8.7
3/8	9.5
1/2	12.7
5/8	15.9
2	50.8
2 1/2	63.5
4	101.6
4 1/4	108.0
4 1/2	114.3
4.584	116.43
6	152.4
6 1/2	165.1
8	203.2
ft³	**cm³**
1/30	944
0.004	11
1/13.333	2124
0.0009	25



NOTE 1—The tolerance on the height is governed by the allowable volume and diameter tolerances.

NOTE 2—The methods shown for attaching the extension collar to the mold and the mold to the base plate are recommended. However, other methods are acceptable, providing the attachments are equally as rigid as those shown.

FIG. 1 Cylindrical Mold, 4.0-in. for Soil Tests (see Table 4 for metric equivalents).



NOTE 1 – The tolerance on the height is governed by the allowable volume and diameter tolerances.

NOTE 2 – The methods shown for attaching the extension collar to the mold and the mold to the base plate are recommended. However, other methods are acceptable, providing the attachments are equally as rigid as those shown.

FIG. 3 Cylindrical Mold, 6.0-in. for Soil Tests (see Table 4 for metric equivalents).

Designation: D 2434 – 68 (Reapproved 1974)$^{\epsilon 1}$

Standard Test Method for
PERMEABILITY OF GRANULAR SOILS (CONSTANT HEAD)[1]

This standard is issued under the fixed designation D 2434; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

$^{\epsilon 1}$ NOTE—Section 2 was added editorially and subsequent sections renumbered in July 1984.

1. Scope

1.1 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. In order to limit consolidation influences during testing, this procedure is limited to disturbed granular soils containing not more than 10 % soil passing the 75-μm (No. 200) sieve.

2. Applicable Documents

2.1 *ASTM Standards:*

D422 Method for Particle-Size Analysis of Soils[2]

D2049 Test Method for Relative Density of Cohesionless Soils[3]

3. Fundamental Test Conditions

3.1 The following ideal test conditions are prerequisites for the laminar flow of water through granular soils under constant-head conditions:

3.1.1 Continuity of flow with no soil volume change during a test,

3.1.2 Flow with the soil voids saturated with water and no air bubbles in the soil voids,

3.1.3 Flow in the steady state with no changes in hydraulic gradient, and

3.1.4 Direct proportionality of velocity of flow with hydraulic gradients below certain values, at which turbulent flow starts.

3.2. All other types of flow involving partial saturation of soil voids, turbulent flow, and unsteady state of flow are transient in character and yield variable and time-dependent coefficients of permeability; therefore, they require special test conditions and procedures.

4. Apparatus

4.1 *Permeameters*, as shown in Fig. 1, shall have specimen cylinders with minimum diameters approximately 8 or 12 times the maximum particle size in accordance with Table 1. The permeameter should be fitted with: (*1*) a porous disk or suitable reinforced screen at the bottom with a permeability greater than that of the soil specimen, but with openings sufficiently small (not larger than 10 % finer size) to prevent movement of particles; (*2*) manometer outlets for measuring the loss of head, *h*, over a length, *l*, equivalent to at least the diameter of the cylinder; (*3*) a porous disk or suitable reinforced screen with a spring attached to the top, or any other device, for applying a light spring pressure of 22 to 45-N (5 to 10-lbf) total load, when the top plate is attached in place. This will hold the placement density and volume of soil without significant change during the saturation of the specimen and the permeability testing to satisfy the requirement prescribed in 3.1.1.

4.2 *Constant-Head Filter Tank*, as shown in Fig. 1, to supply water and to remove most of

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[1] This test method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.04 on Hydrologic Properties of Soil and Rocks.

Current edition approved Sept. 13, 1968. Originally issued 1965. Replaces D 2434 – 65 T.

[2] *Annual Book of ASTM Standards*, Vol 04.08.

[3] Discontinued—See *1983 Annual Book of ASTM Standards*, Vol 04.08.

e air from tap water, fitted with suitable control lves to maintain conditions described in 3.1.2.

Note 1—De-aired water may be used if preferred.

4.3 *Large Funnels,* fitted with special cylin- cal spouts 25 mm (1 in.) in diameter for 9.5- n (⅜-in.) maximum size particles and 13 mm in.) in diameter for 2.00-mm (No. 10) maxi- um size particles. The length of the spout ould be greater than the full length of the rmeability chamber—at least 150 mm (6 in.).

4.4 *Specimen Compaction Equipment*[3]— mpaction equipment as deemed desirable may used. The following are suggested: a vibrating nper fitted with a tamping foot 51 mm (2 in.) diameter; a sliding tamper with a tamping foot mm (2 in.) in diameter, and a rod for sliding ights of 100 g (0.25 lb) (for sands) to 1 kg (2.25 (for soils with a large gravel content), having adjustable height of drop to 102 mm (4 in.) sands and 203 mm (8 in.) for soils with large vel contents.

4.5 *Vacuum Pump or Water-Faucet Aspirator,* evacuating and for saturating soil specimens der full vacuum (see Fig. 2).

4.6 *Manometer Tubes,* with metric scales for easuring head of water.

4.7 *Balance,* of 2-kg (4.4-lb) capacity, sensitive 1 g (0.002 lb).

4.8 *Scoop,* with a capacity of about 100 g (0.25 of soil.

4.9 *Miscellaneous Apparatus*—Thermome- s, clock with sweep second hand, 250-mL duate, quart jar, mixing pan, etc.

Sample

5.1 A representative sample of air-dried gran- r soil, containing less than 10 % of the mate- l passing the 75-μm (No. 200) sieve and equal an amount sufficient to satisfy the require- ents prescribed in 5.2 and 5.3, shall be selected the method of quartering.

5.2 A sieve analysis (See Method D 422) shall made on a representative sample of the com- te soil prior to the permeability test. Any rticles larger than 19 mm (¾ in.) shall be parated out by sieving (Method D 422). This ersize material shall not be used for the perme- ility test, but the percentage of the oversize aterial shall be recorded.

Note 2—In order to establish representative values coefficients of permeabilities for the range that may exist in the situation being investigated, samples of the finer, average, and coarser soils should be obtained for testing.

5.3 From the material from which the oversize has been removed (see 5.2), select by the method of quartering, a sample for testing equal to an amount approximately twice that required for filling the permeameter chamber.

6. Preparation of Specimens

6.1 The size of permeameter to be used shall be as prescribed in Table 1.

6.2 Make the following initial measurements in centimetres or square centimetres and record on the data sheet (Fig. 3); the inside diameter, D, of the permeameter; the length, L, between manometer outlets; the depth, H_1, measured at four symmetrically spaced points from the upper surface of the top plate of the permeability cylinder to the top of the upper porous stone or screen temporarily placed on the lower porous plate or screen. This automatically deducts the thickness of the upper porous plate or screen from the height measurements used to determine the volume of soil placed in the permeability cylinder. Use a duplicate top plate containing four large symmetrically spaced openings through which the necessary measurements can be made to determine the average value for H_1. Calculate the cross-sectional area, A, of the specimen.

6.3 Take a small portion of the sample selected as prescribed in 5.3 for water content determinations. Record the weight of the remaining air-dried sample (see 5.3), W'_1, for unit weight determinations.

6.4 Place the prepared soil by one of the following procedures in uniform thin layers approximately equal in thickness after compaction to the maximum size of particle, but not less than approximately 15 mm (0.60 in.).

6.4.1 For soils having a maximum size of 9.5 mm (⅜ in.) or less, place the appropriate size of funnel, as prescribed in 4.3, in the permeability device with the spout in contact with the lower porous plate or screen, or previously formed layer, and fill the funnel with sufficient soil to form a layer, taking soil from different areas of the sample in the pan. Lift the funnel by 15 mm (0.60 in.), or approximately the unconsolidated layer thickness to be formed, and spread the soil with a slow spiral motion, working from the perimeter of the device toward the center, so that

uniform layer is formed. Remix the soil in the pan for each successive layer to reduce segregation caused by taking soil from the pan.

6.4.2 For soils with a maximum size greater than 9.5 mm (⅜ in.), spread the soil from a scoop. Uniform spreading can be obtained by sliding a scoopful of soil in a nearly horizontal position down along the inside surface of the device to the bottom or to the formed layer, then tilting the scoop and drawing it toward the center with a single slow motion; this allows the soil to run smoothly from the scoop in a windrow without segregation. Turn the permeability cylinder sufficiently for the next scoopful, thus progressing around the inside perimeter to form a uniform compacted layer of a thickness equal to the maximum particle size.

6.5 Compact successive layers of soil to the desired relative density by appropriate procedures, as follows, to a height of about 2 cm (0.8 in.) above the upper manometer outlet.

6.5.1 *Minimum Density (0 % Relative Density)*—Continue placing layers of soil in succession by one of the procedures described in 6.4.1 or 6.4.2 until the device is filled to the proper level.

6.5.2 *Maximum Density (100 % Relative Density):*

6.5.2.1 *Compaction by Vibrating Tamper*—Compact each layer of soil thoroughly with the vibrating tamper, distributing the light tamping action uniformly over the surface of the layer in a regular pattern. The pressure of contact and the length of time of the vibrating action at each spot should not cause soil to escape from beneath the edges of the tamping foot, thus tending to loosen the layer. Make a sufficient number of coverages to produce maximum density, as evidenced by practically no visible motion of surface particles adjacent to the edges of the tamping foot.

6.5.2.2 *Compaction by Sliding Weight Tamper*—Compact each layer of soil thoroughly by tamping blows uniformly distributed over the surface of the layer. Adjust the height of drop and give sufficient coverages to produce maximum density, depending on the coarseness and gravel content of the soil.

6.5.2.3 *Compaction by Other Methods*—Compaction may be accomplished by other approved methods, such as by vibratory packer equipment, where care is taken to obtain a uniform specimen without segregation of particle sizes (See Test Method D 2049).

6.5.3 *Relative Density Intermediate Between 0 and 100 %*—By trial in a separate container of the same diameter as the permeability cylinder, adjust the compaction to obtain reproducible values of relative density. Compact the soil in the permeability cylinder by these procedures in thin layers to a height about 2.0 cm (0.80 in.) above the upper manometer outlet.

Note 3—In order to bracket, systematically and representatively, the relative density conditions that may govern in natural deposits or in compacted embankments, a series of permeability tests should be made to bracket the range of field relative densities.

6.6 *Preparation of Specimen for Permeability Test:*

6.6.1 Level the upper surface of the soil by placing the upper porous plate or screen in position and by rotating it gently back and forth.

6.6.2 Measure and record: the final height of specimen, $H_1 - H_2$, by measuring the depth, H_2, from the upper surface of the perforated top plate employed to measure H_1 to the top of the upper porous plate or screen at four symmetrically spaced points after compressing the spring lightly to seat the porous plate or screen during the measurements; the final weight of air-dried soil used in the test ($W_1 - W_2$) by weighing the remainder of soil, W_2, left in the pan. Compute and record the unit weights, void ratio, and relative density of the test specimen.

6.6.3 With its gasket in place, press down the top plate against the spring and attach it securely to the top of the permeameter cylinder, making an air-tight seal. This satisfies the condition described in 3.1.1 of holding the initial density without significant volume change during the test.

6.6.4 Using a vacuum pump or suitable aspirator, evacuate the specimen under 50 cm (20 in.) Hg minimum for 15 min to remove air adhering to soil particles and from the voids. Follow the evacuation by a slow saturation of the specimen from the bottom upward (Fig. 2) under full vacuum in order to free any remaining air in the specimen. Continued saturation of the specimen can be maintained more adequately by the use of (*1*) deaired water, or (*2*) water maintained in an in-flow temperature sufficiently high to cause a decreasing temperature gradient in the specimen during the test. Native water or water of low mineral content (Note 4) should be used for the test, but in any case the fluid should be described on the report form (Fig. 3). This satisfies the condition described in 3.1.2 for saturation of soil voids.

NOTE 4—Native water is the water occurring in the rock or soil *in situ*. It should be used if possible, but it (as well as de-aired water) may be a refinement not ordinarily feasible for large-scale production testing.

6.6.5 After the specimen has been saturated and the permeameter is full of water, close the bottom valve on the outlet tube (Fig. 2) and disconnect the vacuum. Care should be taken to ensure that the permeability flow system and the manometer system are free of air and are working satisfactorily. Fill the inlet tube with water from the constant-head tank by slightly opening the filter tank valve. Then connect the inlet tube to the top of the permeameter, open the inlet valve slightly and open the manometer outlet cocks slightly, to allow water to flow, thus freeing them of air. Connect the water manometer tubes to the manometer outlets and fill with water to remove the air. Close the inlet valve and open the outlet valve to allow the water in the manometer tubes to reach their stable water level under zero head.

7. Procedure

7.1 Open the inlet valve from the filter tank slightly for the first run to conditions described in 3.1.3, delay measurements of quantity of flow and heat until a stable head condition without appreciable drift in water manometer levels is attained. Measure and record the time, t, head, h (the difference in level in the manometers), quantity of flow, Q, and water temperature, T.

7.2 Repeat test runs at heads increasing by 0.5 cm in order to establish accurately the region of laminar flow with velocity, v, (where $v = Q/At$), directly proportional to hydraulic gradient, i (where $i = h/L$). When departures from the linear relation become apparent, indicating the initiation of turbulent flow conditions, 1-cm intervals of head may be used to carry the test run sufficiently along in the region of turbulent flow to define this region if it is significant for field conditions.

NOTE 5—Much lower values of hydraulic gradient, h/L, are required than generally recognized, in order to ensure laminar flow conditions. The following values are suggested: loose compactness ratings, h/L from 0.2 to 0.3, and dense compactness ratings, h/L from 0.3 to 0.5, the lower values of h/L applying to coarser soils and the higher values to finer soils.

7.3 At the completion of the permeability test, drain the specimen and inspect it to establish whether it was essentially homogeneous and isotropic in character. Any light and dark alternating horizontal streaks or layers are evidence of segregation of fines.

8. Calculations

8.1 Calculate the coefficient of permeability, k, as follows:

$$k = QL/Ath$$

where:

k = coefficient of permeability,
Q = quantity of water discharged,
L = distance between manometers,
A = cross-sectional area of specimen,
t = total time of discharge,
h = difference in head on manometers.

8.2 Correct the permeability to that for 20°C (68°F) by multiplying k (see 8.1) by the ratio of the viscosity of water at test temperature to the viscosity of water at 20°C (68°F).

9. Report

9.1 The report of permeability test shall include the following information:

9.1.1 Project, dates, sample number, location, depth, and any other pertinent information,

9.1.2 Grain size analysis, classification, maximum particle size, and percentage of any oversize material not used,

9.1.3 Dry unit weight, void ratio, relative density as placed, and maximum and minimum densities,

9.1.4 A statement of any departures from these test conditions, so the results can be evaluated and used,

9.1.5 Complete test data, as indicated in the laboratory form for test data (see Fig. 3), and

9.1.6 Test curves plotting velocity, Q/At, versus hydraulic gradient, h/L, covering the ranges of soil identifications and of relative densities.

TABLE 1 Cylinder Diameter

Maximum Particle Size Lies Between Sieve Openings	Minimum Cylinder Diameter			
	Less than 35 % of Total Soil Retained on Sieve Opening		More than 35 % of Total Soil Retained on Sieve Opening	
	2.00-mm (No. 10)	9.5-mm (⅜-in.)	2.00-mm (No. 10)	9.5-mm (⅜-in.)
2.00-mm (No. 10) and 9.5-mm (⅜-in.)	76 mm (3 in.)	. . .	114 mm (4.5 in.)	. . .
9.5-mm (⅜-in.) and 19.0-mm (¾-in.)	. . .	152 mm (6 in.)	. . .	229 mm (9 in.)

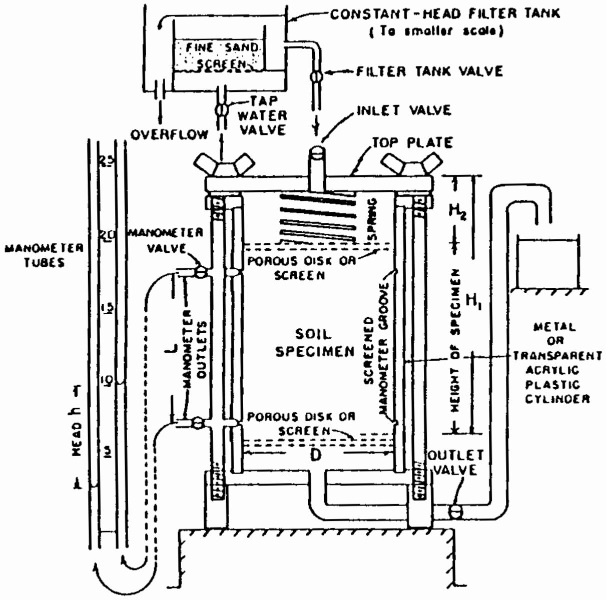

FIG. 1 Constant-Head Permeameter

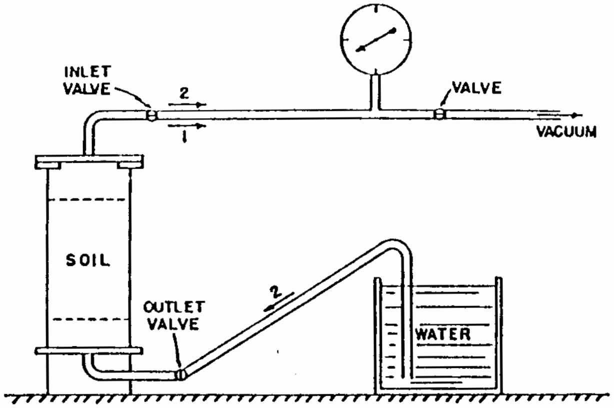

FIG. 2 Device for Evacuating and Saturating Specimen

PERMEABILITY TEST ON GRANULAR SOIL

Test No. Date of Test

Location of Sample Date Sampled Report

Boring — Sample — Depth —

(a) Description of Soil ______

Materials Used: ______

(b) Unit Weight Determination:

Diameter, D, cm Height Before, H_1 Weight Before, W_1

Area, A, cm^2 Height After, H_2 Weight After, W_2

Length, L, cm Height Net, cm Weight Net, g

Moisture Content (air-dried) ______

W(max) Dry Unit Weight, lb/ft^3 W ______

V(min) Void Ratio, e, ______

Relative Density, RD ______

(c) Permeability Test (Degree of Compactness)

Test No.	Manometers		Head, h cm	Q cm^3	t s	Q/At	h/L	Temperature, °C	k cm/s
	H_1	H_2							
1									
2									
3									
4									
5									
6									

FIG. 3 Permeability Test Data Sheet

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Designation: D 2435 – 80

An American National Stan

Standard Test Method for
ONE-DIMENSIONAL CONSOLIDATION PROPERTIES OF SOILS[1]

This standard is issued under the fixed designation D 2435; the number immediately following the designation indicates t year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of la reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This method covers a procedure for determining the rate and magnitude of consolidation of soil when it is restrained laterally and loaded and drained axially.

1.2 The values stated in SI units are to be regarded as the standard. The values stated in inch-pound units are approximate.

2. Applicable Documents

2.1 *ASTM Standards:*

D422 Method for Particle-Size Analysis of Soils[2]

D423 Test Method for Liquid Limit of Soils[3]

D424 Test Method for Plastic Limit and Plasticity Index of Soils[3]

D854 Test Method for Specific Gravity of Soils[2]

D1587 Method for Thin-Walled Tube Sampling of Soils[2]

D2216 Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures[2]

D3550 Practice for Ring-Lined Barrel Sampling of Soils[2]

3. Summary of Method

3.1 The method requires that an element of soil be restrained laterally and axially loaded in increments with a constant stress being applied until all of the excess pore water pressures have dissipated for each increment. During the compression process measurements of decrease in the sample height are made and these data are used to compute the parameters that describe the relationship between the effective stress and void ratio or strain and describe the rate at which compression can occur.

4. Significance and Use

4.1 The compressibility of soils as determined from this test is one of the most usel properties that can be obtained from laborato testing. The data from the consolidation te can be used to develop an estimate of both tl rate and the amount of both differential ar total settlement of a structure or a landfi Estimates of this type are often of key impo tance in first selecting a foundation type an secondly in evaluating its adequacy.

5. Apparatus

5.1 *Load Device*—A suitable device for a plying vertical loads to the specimen. The de vice should be capable of maintaining specific loads for long periods of time with an accurac of ± 0.5 % of the applied load and shoul permit application of a given load incremen within a period of 2 s. without significant im pact.

5.2 *Consolidometer*—A device to hold th specimen in a ring which is either fixed to th base or floating (supported by friction on periphery of specimen) with porous stones on each face of the specimen. The consolidomete shall also provide means for submerging the specimen, for applying a vertical load, and fo measuring the change in height of specimen. The consolidometer ring shall conform to the following requirements:

5.2.1 *Minimum Specimen (Ring) Diameter*—The minimum specimen diameter shall be 50 mm (2.00 in.), and shall be at least 5 mm (¼

.) less than the inside diameter of the sample be if samples are extruded and trimmed.

5.2.2 *Minimum Specimen Height*—The minnum specimen height shall be 13 mm (0.5 in.) ut shall be not less than 10 times the maximum rticle diameter.

5.2.3 *Minimum Specimen Diameter-to-eight Ratio*—The minimum specimen diamer-to-height ratio shall be 2.5.

5.2.4 *Rigidity*—The rigidity of the ring shall such that, under hydrostatic stress conditions the specimen, the change in diameter of the g will not exceed 0.03 % of the diameter der the greatest load applied.

5.2.5 The ring shall be made of a material t is noncorrosive in relation to the soil tested. e inner surface shall be highly polished or ll be coated with a low-friction material. icon grease is recommended or polytetraroethylene for nonsandy soils.

.3 *Porous Stones*—The porous stones shall of silicon carbide, aluminum oxide, or metal is not attacked by the soil or soil moisture. grade of the stones shall be fine enough to ent intrusion of soil into the pores of the e. If necessary, a filter paper[3] may be used revent intrusion of the soil into the stones. vever, the permeability of the stones, and r paper, if used, must be sufficiently high revent retardation of the drainage of the imen. The stones shall be clean and free of ks, chips, and nonuniformities.

3.1 The diameter of the top stone shall be o 0.5 mm (0.01 to 0.02 in.) less than that of inside diameter of the ring. If a floating is used, the bottom stone shall have the diameter as the top stone. The use of red stones is recommended, with the larger eter in contact with the soil.

.2 The stone thickness shall be sufficient revent breaking. The top stone shall be d through a corrosion-resistant plate of ient rigidity to prevent breakage of the .

. *Storage*—Storage of sealed samples ld be such that no moisture is lost during ge, that is, no evidence of partial drying of nds of the samples or shrinkage. Time of e should be minimized, particularly when oil or soil moisture is expected to react the sample tubes.

.1 *Sample Preparation Environment*—Test specimens shall be prepared in an environment where soil moisture change during preparation does not exceed 0.2 %. (A high humidity moisture room is usually used for this purpose.)

5.5 *Temperature*—Tests should be performed in an environment where temperature fluctuations are less than ± 4°C (7.2°F) and there is not any direct contact with sunlight.

5.6 *Trimmer*, or cylindrical cutter, for trimming the sample down to the inside diameter of the consolidometer ring with a minimum of disturbance. The cutter shall have a highly polished surface and be coated with a low-friction material.

5.7 *Balance*, sensitive to 0.1 g or to 0.1 % of the total mass of the test specimen.

5.8 *Drying Oven*, that can be maintained uniformly at 110 ± 5°C (230 ± 9°F). A forced-draft oven is recommended.

5.9 *Extensometer*, to measure change in height of the specimen with a sensitivity of 0.0025 mm (0.0001 in.).

5.10 *Miscellaneous Equipment*, including spatulas, knives, wire saws, used in preparing the specimen.

5.11 *Moisture Content Containers*, shall be in accordance with Method D 2216.

6. Sampling

6.1 Relatively undisturbed samples should be obtained and used for consolidation testing because the meaningfulness of the results diminishes greatly with sample disturbance. Method D 1587 and Practice D 3550 cover procedures and apparatus that may be used to obtain satisfactory samples for testing.

7. Specimen Preparation (Note 2)

7.1 Prepare the sample in an environment in accordance with 5.4.1. Trim the specimen to the inside diameter of the consolidometer, forcing it directly into the ring during trimming. Trim it flush with the plane surface of the ring. For soft to medium soils, a wire saw should be used for trimming the top and bottom of the specimen to minimize smearing. A straightedge with a sharp cutting edge may be used for the final trim after the excess soil has first been removed with a wire saw. For stiff soils, a sharpened straightedge alone may be used for

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[1] This method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.05 on Structural Properties of Soils.

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[2] *Annual Book of ASTM Standards*, Vol 04.08.

[3] Discontinued, see *1983 Annual Book of ASTM Standards*, Vol 04.08.

[3] Use a hardened, fast filter paper.

trimming the top and bottom. If desired, the specimen height may be made less than the ring height by partial extrusion and trimming, provided the minimum specimen thickness requirements in 5.2.2 and 5.2.3 are met. A specimen ring with the cutting edge attached provides the most accurate fit in moist soils.

NOTE—Precautions should be taken to minimize disturbance of the soil or changes in moisture and density during sample transportation and preparation. Vibration, distortion, and compression must be avoided.

7.2 Fibrous soils, such as peat, and those soils that are easily damaged by trimming, may be transferred directly from the sampling tube to the ring provided that the ring has the same diameter as the sample tube.

7.3 Specimens obtained using a ring-lined sampler may be used without prior trimming, provided they comply with the requirements of Practice D 3550 and this method.

7.4 Determine the mass of the specimen in the consolidation ring.

8. Calibration

8.1 Assemble the consolidometer with a copper or hard steel disk of approximately the same height as the test specimen and 1 mm (0.04 in.) smaller diameter than the ring in place of the sample. Moisten the porous stones. If filter papers are to be used (see 5.3), they should be moistened and sufficient time for the moisture to be squeezed from them should be allowed during the calibration process.

8.2 Load and unload the consolidometer as in the test and measure the deformation for each load applied.

8.3 Plot or tabulate the corrections to be applied to the deformation of the test specimen at each load applied. Note that the metal disk will deform also. However, the correction due to this deformation will be negligible for all but extremely stiff soils. If necessary, the compression of the metal disk can be computed and applied to the corrections.

9. Natural Moisture Content, Weight, Volume, Specific Gravity, Liquid and Plastic Limits, and Particle Size Distribution Determinations

9.1 Use the material trimmed adjacent to the specimen (see Section 7) to determine the natural moisture content in accordance with Method D 2216 and the specific gravity with Test Method D 854. Determine the initial wet mass of the specimen by subtracting the mass of the specimen ring from the combined mass of the specimen ring and the specimen. Determine the initial volume of the specimen from the diameter and height of the specimen. The value of moisture content determined from the trimmings is approximate but permits determination of the void ratio before the test is complete. The most accurate determination of the specimen dry mass and moisture content is found by drying the entire specimen at the end of the test. This procedure should be used unless a portion of the specimen is needed for index tests (see 10.9). The specific gravity can be estimated where an accurate void ratio is not needed.

9.2 The liquid limit, as determined in accordance with Test Method D 423, the plastic limit, as determined in accordance with Test Method D 424, and the particle size distribution, for soils with substantial granular material, as determined in accordance with Method D 422, are useful in identifying the soil and in correlating the results of tests on different soils. It is recommended that liquid and plastic limits be determined on the trimmings or on representative portions of the test specimen if the soil exhibits significant heterogeneity.

10. Procedure

10.1 The objective of the preparation of the stones and other apparatus prior to their contact with the specimen is to prevent change in moisture content of the specimen. Thus, very dry, highly expansive soils should be placed on dry stones but most partially saturated soils may be placed on stones that have simply been dampened. If the specimen is saturated and is believed not to exhibit a high affinity for water, the porous stones should be boiled after cleaning with a nonabrasive brush and kept saturated until the time of their contact with the specimen. Assemble the ring, specimen and porous stones. With the consolidometer assembled, enclose the specimen, ring, filter paper (when used), and porous stones with a loose-fitting plastic or rubber membrane to prevent change in specimen volume due to evaporation. This step may be omitted if the specimen is to be inundated after the first load increment is applied as provided in 10.8.

10.2 Place the consolidometer in the loading device and apply a seating pressure of 5 kPa (100 lbf/ft^2). Within 5 min after application of the seating load, adjust the extensometer dial gage for the initial or zero reading. (For very soft soils a seating pressure of 2 or 3 kPa (about 50 lbf/ft^2) or less is desirable.)

10.3 Place loads on the consolidometer to obtain pressures on the soil of approximately 5, 10, 20, 40, 80, etc., kPa (100, 200, 400, 800, 1600, etc., lbf/ft^2), with each pressure maintained constant as required in 10.4. (Smaller increments may be desirable on very soft specimens or when it is desirable to determine the preconsolidation pressure with more precision.) Loading of the specimen should continue into the virgin compression region so that the slope and shape of the virgin compression curve may be assessed. Typically, a final pressure that is equal to or greater than four times the preconsolidation pressure of the sample is required for this assessment. In the case of overconsolidated clays in particular, it may be desirable to use an unloading-reloading cycle to better evaluate recompression parameters, but such a procedure is optional.

10.4 For at least two load increments (including at least one load increment after the preconsolidation pressure has been exceeded), record the height or change in height of the specimen before each pressure increment is applied and at time intervals of approximately 0.1, 0.25, 0.5, 1, 2, 4, 8, 15, and 30 min, 1, 2, 4, 8, etc., h, measured from the time of each incremental pressure application. These time-rate readings need be obtained only for saturated specimens. Readings should continue at least until the slope of the characteristic linear secondary compression portion of the thickness versus log of time plot is apparent (see 11.1), unless the method 11.6 is used, in which case the next loading may proceed as soon as 100 % consolidation is completed. (For soils that have slow primary consolidation, pressures should be applied for at least 24 h. In extreme cases, or where secondary compression must be evaluated, they should be applied much longer.) Then apply the next pressure increment. For pressure increments where time versus deformation data are not required, the load should be left on the sample for essentially the same length of time as when time versus deformation readings are taken. Sufficient readings should be taken near the end of the pressure-increment period to allow for any needed extrapolation of the time-deformation curve.

10.5 If thickness versus square root of time plots are to be made, the time intervals may be adjusted to those that have easily obtained square roots, for example, 0.09, 0.25, 0.49, 1 min, 4 min, 9 min, etc.

10.6 *Rebound*—Where rebound or unloading characteristics are desired, unload soil by pressure decrements in reverse order. However, if desired, each successive load can be only one fourth as large as the preceding load. Record at time intervals as suggested in 10.4. Note, however, that for most soils the rebound will be complete in less time than would be required for an increment of load during primary consolidation, but sufficient readings should be taken to verify that rebound is essentially complete.

10.7 An alternative loading, unloading, or reloading schedule may be employed that reproduces the construction stress changes, or obtains better definition of some part of the stress-deformation curve, or aids in interpreting the field behavior of the soil. This should be clearly indicated on the test results.

10.8 If the test is performed on an undisturbed sample that was either saturated under field conditions or obtained from below the water table, it should be inundated after the first load increment is applied. As inundation and specimen wetting occur, the load should be increased if required, to prevent the specimen from swelling, unless it tends to swell under the estimated in situ vertical stress. If the specimen compresses after inundation, simply record the amount of compression. Specimens also may be inundated at pressures that simulate future inundation under field conditions. In such cases, the pressure at inundation and any resulting effects, such as expansion or increased compression, should be noted in the test results.

10.9 To minimize swell during disassembly, the specimen should be rebounded back to a very small stress and dismantled quickly after releasing the final load on the specimen. Remove the specimen and the ring from the consolidometer and wipe the free water from the ring and specimen. Remove the specimen from the ring and determine its mass, oven dry it, and reweigh it to obtain the dry mass of solids and the final water content. If the original soil sample is very heterogeneous, any index tests should be performed on a portion of the test specimen and the remainder can be used for a final water content measurement. Porous stones should be boiled clean after the test to prevent clay from drying on them and reducing their permeability.

11. Calculation

11.1 From those increments of load where time-rate readings are obtained, plot the deformation readings versus the log of time (in minutes) for each increment of load or pressure as the test progresses, and for any increments of rebound where time versus deformation data have been obtained.

11.2 Find the deformation representing 100 % primary consolidation for each load increment. First draw a straight line through the points representing the final readings and that exhibit a straight line trend and a flat slope. Draw a second straight line tangent to the steepest part of the deformation-log time curve. The intersection represents the deformation corresponding to 100 % primary consolidation. Correct the deformation at 100 % consolidation in accordance with the results of the calibration (see Section 8). Compression that occurs subsequent to 100 % primary consolidation is defined as secondary compression.

11.3 Find the deformation representing 0 % primary consolidation by selecting the deformations at any 2 times that have a ratio of 1 to 4. The deformation corresponding to the larger of the two times should be greater than ¼ but less than ½ of the total change in deformation for the load increment. The deformation corresponding to 0 % primary consolidation is equal to the deformation corresponding to the smaller time interval less the difference in the deformations for the two selected times.

11.4 The deformation corresponding to 50 % primary consolidation for each load increment is equal to the average of the uncorrected deformations corresponding to the 0 and 100 % deformations. The time required for 50 % consolidation under any load increment may be found graphically from the deformation-log time curve for that load increment by observing the time that corresponds to 50 % of the primary consolidation of the curve.

11.5 For each load increment for which time-rate readings were obtained, compute the coefficient of consolidation, c_v, as follows:

$$c_v = \frac{0.05H^2}{t_{50}}$$

where:

H = sample height in metres (feet) for a doubly drained sample at 50 % consolidation,

t_{50} = time for 50 % consolidation in years, and

c_v = coefficient of consolidation in m²/year (ft²/year).

If H is in millimetres and t in seconds or minutes, c_v will be expressed in mm²/s or mm²/min, respectively, and conversion to more convenient units is desirable.

11.6 An alternative procedure requiring a plot of deformation versus the square root of time in minutes may be used to determine the points of 0 and 100 % consolidation as well as the coefficient of consolidation for each load increment. The initial part of the curve is approximated by a straight line. The line is extrapolated back to $t = 0$. The corresponding deformation ordinate represents 0 % primary consolidation. A second straight line is drawn through this point so that the abscissa of this line is 1.15 times the abscissa of the straight line approximation of the initial part of the curve. The intersection of the new line with the deformation-square root of time curve corresponds to 90 % primary consolidation. The deformation at 100 % primary consolidation is 1/9 more than the difference in deformations between 0 and 90 % consolidation. Similarly the deformation at 50 % consolidation is 5/9 of the difference between that at 0 and 90 %. The coefficient of consolidation can be found from the time of 90 % consolidation by the formula:

$$c_v = \frac{0.21H^2}{t_{90}}$$

where:

H = sample height for a doubly drained sample at 90 % consolidation, m (or ft),

t_{90} = time for 90 % consolidation, years, and

c_v = coefficient of consolidation, m²/year (ft²/year).

If H is in millimetres and t in seconds or minutes, the units of c_v will be mm²/s or mm²/min, respectively, and conversion to more convenient units is desirable. The square root

time method may also be used to obtain a lue of t_{90}, if desired.

11.7 Compute initial void ratio, water con- it, unit weight, and degree of saturation, sed on the dry weight of the total specimen. ecimen volume is computed from measure- nts of the container ring height and diame- . Volume of solids is computed by dividing e dry weight of specimen by the specific avity of the solids times the unit weight of ater. Volume of voids is assumed to be the fference between the specimen volume and e volume of the solids.

11.8 Compute void ratio corresponding to 0 % primary consolidation (using corrected formation readings) for each load. As an ternative, compute percent compression at 0 % primary consolidation for each load from e initial sample height. As a second alterna- ve, compute void ratios (or values of percent ompression) using the deformation values obained after a selected time interval that shall nclude some portion of secondary compres- on, and such time interval shall be the same r each load increment. However, if the "equi- ibrium" value chosen is other than the 100 % rimary consolidation point, a note to this efect should be included with the test results. It hould be noted that the second alternative ited above will result in somewhat lower val- es of the preconsolidation pressure than are btained when the 100 % primary consolidation points are used.

12. Report

12.1 The report shall include the following information:

12.1.1 Identification and description of the test sample, including whether soil is undisturbed, remolded, compacted, or otherwise prepared,

12.1.2 Initial and final moisture content,

12.1.3 Dry mass and initial and final wet unit weight,

12.1.4 Initial percentage saturation,

12.1.5 Specific gravity of solids or Atterberg Limit gradation data if obtained,

12.1.6 Specimen dimensions,

12.1.7 Condition of test (natural moisture or inundated, pressure at inundation),

12.1.8 Preparation procedure used relative to trimming; state whether specimen was trimmed, extruded directly into the ring, or tested directly in a ring from a ring-lined sampler,

12.1.9 Plot of log of time or square root of time versus deformation, for those load increments where time-rate readings were taken. For organic or highly micaceous soils, or other soils with appreciable secondary compression, it is highly desirable that log of time plots extending into the secondary compression region be included,

12.1.10 Plot of void ratio versus log of pressure curve or percent compression versus log of pressure curve,

12.1.11 In cases where time rate of consolidation readings have been taken for several load increments, a plot of coefficient of consolidation versus log of average pressure. As an alternative, a plot of log of coefficient of consolidation versus log of average pressure curve may be used. The method used for computing c_v should be noted. If time-rate readings were obtained for only two load increments, simply tabulate the values of c_v versus the average pressure for the increment,

12.1.12 All departures from the procedure outlined, including special loading sequences. For example, it may be desirable to inundate and load the specimen precisely in accordance with the wetting or loading pattern expected in the field in order to best simulate the response. Smaller than standard load increment ratios may be desirable for soils that are highly sensitive or whose response is highly dependent on strain rate.

13. Precision and Accuracy

13.1 Section 5 of this method specifies the sensitivity of the load and deformation measurements. The corresponding accuracy of the applied stress and resultant strain in the specimen can be computed from the specimen dimensions. The accuracy with which the test results can be applied to the field varies from case to case and depends on:

13.1.1 The quality of samples used,

13.1.2 The number of samples tested,

13.1.3 The vertical and horizontal distribution of the samples tested, and

13.1.4 The heterogeneity of the soil profile in the field.

13.2 A statistical analysis that includes both the sampling program and the laboratory test results is required to assess, in any meaningful way, the accuracy with which the test results apply to the field. In the absence of such an analysis, most engineers assess the applicability of the test results to the field qualitatively by looking at the variation in the test results and the variations in the boring logs. In general, it can be noted that the accuracy of settlement predictions based on consolidation tests increase (on a percentage basis) with the compressibility of the soil.

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Designation: D 1452 - 80

An American National Standard

Standard Practice for
SOIL INVESTIGATION AND SAMPLING BY AUGER BORINGS[1]

This standard is issued under the fixed designation D 1452; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice covers equipment and procedures for the use of earth augers in shallow geotechnical exploration. This practice does not apply to sectional continuous flight augers.

2. Significance and Use

2.1 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 level determination and indication of changes in strata and advancement of hole for spoon and tube sampling. Equipment required is simple and readily available. Depths of auger investigations are, however, limited by ground water conditions, soil characteristics, and the equipment used.

3. Apparatus

3.1 *Hand-Operated Augers:*

3.1.1 *Helical Augers*—Small lightweight augers generally available in sizes from 1 through 3 in. (25.4 through 76.2 mm).

3.1.1.1 *Spiral-Type Auger*, consisting of a flat thin metal strip, machine twisted to a spiral configuration of uniform pitch; having at one end, a sharpened or hardened point, with a means of attaching a shaft or extension at the opposite end.

3.1.1.2 *Ship-Type Auger*—Similar to a carpenter's wood bit. It is generally forged from steel and machined to the desired size and configuration. It is normally provided with sharpened and hardened nibs at the point end and with an integral shaft extending through its length for attachment of a handle or extension at the opposite end.

3.1.2 *Open Tubular Augers*, ranging in size from 1.5 through 8 in. (38.1 through 203.2 mm) and having the common characteristic of appearing essentially tubular when viewed from the digging end.

3.1.2.1 *Orchard-Barrel Type*, consisting essentially of a tube having cutting lips or nibs hardened and sharpened to penetrate the formation on one end and an adaptor fitting for an extension or handle on the opposite end.

3.1.2.2 *Open-Spiral Type*, consisting of a flat thin metal strip that has been helically wound around a circular mandrel to form a spiral in which the flat faces of the strip are parallel to the axis of the augered hole. The lower helix edges are hard-faced to improve wear characteristics. The opposite end is fitted with an adaptor for extension.

3.1.2.3 *Closed-Spiral Type*—Nearly identical to the open-spiral type except, the pitch of the helically wound spiral is much less than that of the open-spiral type.

3.1.3 *Post-Hole Augers*, generally 2 through 8 in. (50.8 through 203.2 mm), and having in common a means of blocking the escape of soil from the auger.

3.1.3.1 *Clam-Shell Type*, consisting of two

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[1] This practice is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D 18.02 on Sampling and Related Field Testing for Soil Investigations.

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ves, hinged to allow opening and closing for ernately digging and retrieving. It is not able deeper than about 3.5 ft (1.07 m).

3.1.3.2 *Iwan Type*, consisting of two tubular el segments, connected at the top to a com- on member to form a nearly complete tube, with diametrically opposed openings. It is connected at the bottom by two radial blades ched to serve as cutters which also block the cape of contained soil. Attachment of handle extension is at the top connector.

3.2 *Machine-Operated Augers:*

3.2.1 *Helical Augers*, generally 8 through 48 (203.2 through 1219 mm), consisting essen- ally of a center shaft fitted with a shank or cket for application of power, and having one three complete 360° (6.28-rad) spirals for veyance and storage of cut soil. Cutter bits pilot bits are available in moderate and rd formation types and normally replaceable the field. They are normally operated by avy-duty, high-torque machines, designed heavy construction work.

3.2.2 *Stinger Augers*, generally 6 through 30 (152.4 through 762 mm), are similar to the cal auger in 3.2.1, but lighter and generally aller. They are commonly operated by light- y machines for post and power pole holes.

3.2.3 *Disk Augers*, generally 10 through 30 (254 through 762 mm), consisting essentially a flat, steel disk with diametrically opposed ments removed and having a shank or cket located centrally for application of wer. Replaceable cutter bits, located down- ard from the leading edges of the remaining dig and load soil that is held on the disk valves or shutters hinged at the disk in order close the removed segments. The disk auger pecifically designed to be operated by ma- nes having limited vertical clearance be- een spindle and ground surface.

3.2.4 *Bucket Auger*, generally 12 through 48 (304.8 through 1219 mm), consisting essen- ly of a disk auger, without shank or socket, hinge-mounted to the bottom of a steel e or bucket of approximately the same di- eter as the disk auger. A socket or shank for er application is located in the top center the bucket diametral cross piece provided the purpose.

3.3 *Casing* (when needed), consisting of pipe htly larger diameter than the auger used.

3.4 *Accessory Equipment*—Labels, field log sheets, sample jars, sealing wax, sample bags, and other necessary tools and supplies.

4. Procedure

4.1 Make the auger boring by rotating and advancing the desired distance into the soil. Withdraw the auger from the hole and remove the soil for examination and test. Return the empty auger to the hole and repeat the procedure. Continue the sequence until the required depth is reached.

4.2 Casing is required in unstable soil in which the bore hole fails to stay open and especially when the boring is extended below the ground-water level. The inside diameter of the casing must be slightly larger than the diameter of the auger used. The casing shall be driven to a depth not greater than the top of the next sample and shall be cleaned out by means of the auger. The auger can then be inserted into the bore hole and turned below the bottom of the casing to obtain a sample.

4.3 The soil auger can be used both for boring the hole and for bringing up disturbed samples of the soil encountered. The structure of a cohesive soil is completely destroyed and the moisture may be changed by the auger. Seal all samples in a jar or other airtight container and label appropriately. If more than one type of soil is picked up in the sample, prepare a separate container for each type of soil.

4.4 *Field Observations*—Record complete ground water information in the field logs. Where casing is used, measure ground water levels, both before and after the casing is pulled. In sands, determine the water level at least 30 min after the boring is completed; in silts, at least 24 h. In clays, no accurate water level determination is possible unless pervious seams are present. As a precaution, however, water levels in clays shall be taken after at least 24 h.

5. Report

5.1 The data obtained in boring shall be recorded in the field logs and shall include the following:

5.1.1 Date of start and completion of boring,

5.1.2 Identifying number of boring,

5.1.3 Reference datum including direction and distance of boring relative to reference line of project or other suitable reference points,

5.1.4 Type and size of auger used in boring,

5.1.5 Depth of changes in strata,

5.1.6 Description of soil in each major stratum,

5.1.7 Ground water elevation and location of seepage zones, when found, and

5.1.8 Condition of augered hole upon removal of auger, that is, whether the hole remains open or the sides cave, when such can be observed.

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This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, 1916 Race St., Philadelphia, Pa. 19103.

Designation: D 1587 - 83

Standard Practice for
THIN-WALLED TUBE SAMPLING OF SOILS[1]

This standard is issued under the fixed designation D 1587; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This practice has been approved for use by agencies of the Department of Defense and for listing in the DOD Index of Specifications and Standards.

1. Scope

1.1 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. Thin-walled tubes used in piston, plug, or rotary-type samplers, such as the Denison or Pitcher, must comply with the portions of this practice which describe the thin-walled tubes (5.3).

Note 1—This practice does not apply to liners used within the above samplers.

2. Applicable Documents

2.1 *ASTM Standards:*

D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)[2]

D 3550 Practice for Ring-Lined Barrel Sampling of Soils[2]

D 4220 Practices for Preserving and Transporting Soil Samples[2]

3. Summary of Practice

3.1 A relatively undisturbed sample is obtained by pressing a thin-walled metal tube into the in-situ soil, removing the soil-filled tube, and sealing the ends to prevent the soil from being disturbed or losing moisture.

4. Significance and Use

4.1 This practice, or Practice D 3550, is used when it is necessary to obtain a relatively undisturbed specimen suitable for laboratory tests of structural properties or other tests that might be influenced by soil disturbance.

5. Apparatus

5.1 *Drilling Equipment*—Any drilling equipment may be used that provides a reasonably clean hole; that does not disturb the soil to be sampled; and that does not hinder the penetration of the thin-walled sampler. Open borehole diameter and the inside diameter of driven casing or hollow stem auger shall not exceed 3.5 times the outside diameter of the thin-walled tube.

5.2 *Sampler Insertion Equipment*, shall be adequate to provide a relatively rapid continuous penetration force. For hard formations it may be necessary, although not recommended, to drive the thin-walled tube sampler.

5.3 *Thin-Walled Tubes*, should be manufactured as shown in Fig. 1. They should have an outside diameter of 2 to 5 in. and be made of metal having adequate strength for use in the soil and formation intended. Tubes shall be clean and free of all surface irregularities including projecting weld seams.

5.3.1 *Length of Tubes*—See Table 1 and 6.4.

5.3.2 *Tolerances*, shall be within the limits shown in Table 2.

5.3.3 *Inside Clearance Ratio*, should be 1 % or as specified by the engineer or geologist for the soil and formation to be sampled. Generally, the inside clearance ratio used should increase with the increase in plasticity of the soil being sampled. See Fig. 1 for definition of inside clearance ratio.

5.3.4 *Corrosion Protection*—Corrosion, whether from galvanic or chemical reaction, can damage or destroy both the thin-walled tube and the sample. Severity of damage is a function of

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[1] This practice is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.02 on Sampling and Related Field Testing for Soil Investigations.

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[2] *Annual Book of ASTM Standards*, Vol 04.08.

ell as interaction between the sample
ube. Thin-walled tubes should have
a of protective coating. Tubes which
n samples for more than 72 h shall be
e type of coating to be used may vary
upon the material to be sampled.
ay include a light coat of lubricating
, epoxy, Teflon, and others. Type of
ist be specified by the engineer or
storage will exceed 72 h. Plating of
r alternate base metals may be speci-
engineer or geologist.

pler Head, serves to couple the thin-
to the insertion equipment and, to-
the thin-walled tube, comprises the
tube sampler. The sampler head shall
itable check valve and a venting area
de equal to or greater than the area
check valve. Attachment of the head
shall be concentric and coaxial to
rm application of force to the tube
ler insertion equipment.

e

out the borehole to sampling ele-
. whatever method is preferred that
the material to be sampled is not
groundwater is encountered, main-
id level in the borehole at or above
r level during the sampling opera-

n discharge bits are not permitted.
ge bits may be used, with caution.
gh an open-tube sampler to clean
hole to sampling elevation is not
emove loose material from the cen-
g or hollow stem auger as carefully
avoid disturbance of the material
d.

oller bits are available in downward-
used-jet configurations. Downward-jet-
on rock bits are not acceptable. Diffuse-
ns are generally acceptable.

he sample tube so that its bottom
bottom of the hole. Advance the
out rotation by a continuous rela-
notion.

ine the length of advance by the
l condition of the formation, but
ll never exceed 5 to 10 diameters
sands and 10 to 15 diameters of
ys.

eight of sample, laboratory handling capabilities, transportation problems, and commercial availability of tubes will generally limit maximum practical lengths to those shown in Table 1.

6.5 When the formation is too hard for push-type insertion, the tube may be driven or Practice D 3550 may be used. Other methods, as directed by the engineer or geologist, may be used. If driving methods are used, the data regarding weight and fall of the hammer and penetration achieved must be shown in the report. Additionally, that tube must be prominently labeled a "driven sample."

6.6 In no case shall a length of advance be greater than the sample-tube length minus an allowance for the sampler head and a minimum of 3 in. for sludge-end cuttings.

Note 4—The tube may be rotated to shear bottom of the sample after pressing is complete.

6.7 Withdraw the sampler from the formation as carefully as possible in order to minimize disturbance of the sample.

7. Preparation for Shipment

7.1 Upon removal of the tube, measure the length of sample in the tube. Remove the disturbed material in the upper end of the tube and measure the length again. Seal the upper end of the tube. Remove at least 1 in. of material from the lower end of the tube. Use this material for soil description in accordance with Practice D 2488. Measure the overall sample length. Seal the lower end of the tube. Alternatively, after measurement, the tube may be sealed without removal of soil from the ends of the tube if so directed by the engineer or geologist.

Note 5—Field extrusion and packaging of extruded samples under the specific direction of a geotechnical engineer or geologist is permitted.

Note 6—Tubes sealed over the ends as opposed to those sealed with expanding packers should contain end padding in end voids in order to prevent drainage or movement of the sample within the tube.

7.2 Prepare and immediately affix labels or apply markings as necessary to identify the sample. Assure that the markings or labels are adequate to survive transportation and storage.

8. Report

8.1 The appropriate information is required as follows:

8.1.1 Name and location of the project,

8.1.2 Boring number and precise location on project, 8.1.3 Surface elevation or reference to a datum,

8.1.4 Date and time of boring—start and finish,

8.1.5 Depth to top of sample and number of sample,

8.1.6 Description of sampler: size, type of metal, type of coating,

8.1.7 Method of sampler insertion: push or drive,

8.1.8 Method of drilling, size of hole, casing, and drilling fluid used,

8.1.9 Depth to groundwater level: date and time measured;

8.1.10 Any possible current or tidal effect on water level,

8.1.11 Soil description in accordance with Practice D 2488,

8.1.12 Length of sampler advance, and

8.1.13 Recovery: length of sample obtained.

9. Precision and Bias

9.1 This practice does not produce numerical data; therefore, a precision and bias statement is not applicable.

TABLE 1 Suitable Thin-Walled Steel Sample Tubes[A]

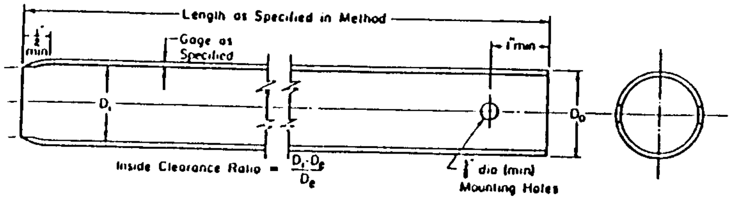
Outside diameter:			
in.	2	3	5
mm	50.8	76.2	127
Wall thickness:			
Bwg	18	16	11
in.	0.049	0.065	0.120
mm	1.24	1.65	3.05
Tube length:			
in.	36	36	54
m	0.91	0.91	1.45
Clearance ratio, %	1	1	1

[A] The three diameters recommended in Table 1 are indicated for purposes of standardization, and are not intended to indicate that sampling tubes of intermediate or larger diameters are not acceptable. Lengths of tubes shown are illustrative. Proper lengths to be determined as suited to field conditions.

TABLE 2 Dimensional Tolerances for Thin-Walled Tubes

	Nominal Tube Diameters from Table 1[A] Tolerances, in.		
Size Outside Diameter	2	3	5
Outside diameter	+0.007 −0.000	+0.010 −0.000	+0.015 −0.000
Inside diameter	+0.000 −0.007	+0.000 −0.010	+0.000 −0.015
Wall thickness	±0.007	±0.010	±0.015
Ovality	0.015	0.020	0.030
Straightness	0.030/ft	0.030/ft	0.030/ft

[A] Intermediate or larger diameters should be proportional. Tolerances shown are essentially standard commercial manufacturing tolerances for seamless steel mechanical tubing. Specify only two of the first three tolerances; that is, O.D. and I.D., or O.D. and Wall, or I.D. and Wall.



TE 1—Minimum of two mounting holes on opposite sides for 2 to 3½ in. sampler.

TE 2—Minimum of four mounting holes spaced at 90° for samplers 4 in. and larger.

TE 3—Tube held with hardened screws.

TE 4—Two-inch outside-diameter tubes are specified with an 18 gage wall thickness to comply with area ratio criteria accepted ndisturbed samples." Users are advised that such tubing is difficult to locate and can be extremely expensive in small ies. Sixteen-gage tubes are generally readily available.

Metric Equivalents

in.	mm
¼	6.77
½	12.7
1	25.4
2	50.8
3½	88.9
4	101.6

FIG. 1 Thin-Walled Tube for Sampling

APPENDIX VII:

PERMEABILITY TESTS

1. DARCY'S LAW FOR FLOW OF WATER THROUGH SOIL. The flow of water through a soil medium is assumed to follow Darcy's law:

$$q = k\,i\,A$$

where q = rate of discharge through a soil of cross-sectional area A
k = coefficient of permeability
i = hydraulic gradient: the loss of hydraulic head per unit distance of flow

The application of Darcy's law to a specimen of soil in the laboratory is illustrated in Figure 1. The coefficient of permeability, k (often termed

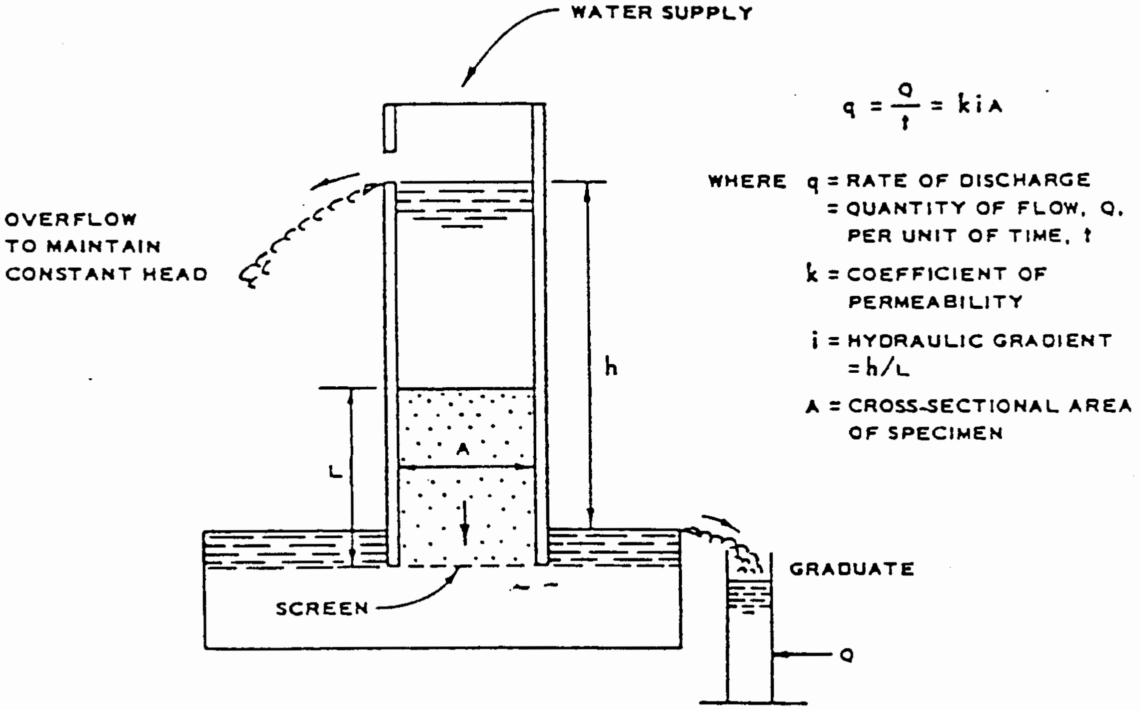


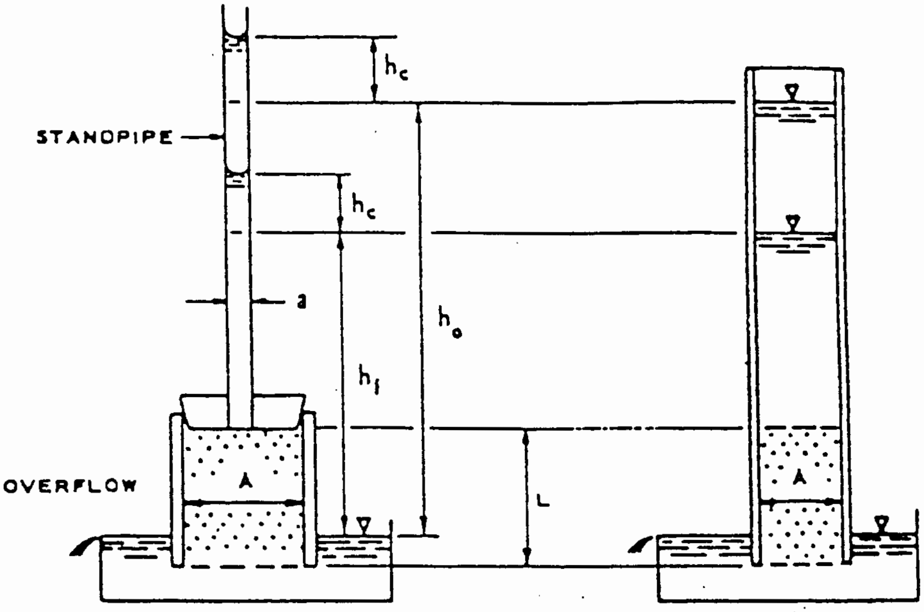
Figure 1. Flow of water through soil

''permeability''), is defined as the rate of discharge of water at a temperature of 20 C under conditions of laminar flow through a unit cross-sectional area of a soil medium under a unit hydraulic gradient. The coefficient of permeability has the dimensions of a velocity and is usually expressed in centimeters per second. The permeability of a soil depends primarily on the size and shape of the soil grains, the void ratio of the soil, the shape and arrangement of the voids, and the degree of saturation.

Permeability computed on the basis of Darcy's law is limited to the conditions of laminar flow and complete saturation of the voids. In turbulent flow, the flow is no longer proportional to the first power of the hydraulic gradient. Under conditions of incomplete saturation, the flow is in a transient state and is time-dependent. The laboratory procedures presented herein for determining the coefficient of permeability are based on the Darcy conditions of flow. Unless otherwise required, the coefficient of permeability shall be determined for a condition of complete saturation of the specimen. Departure from the Darcy flow conditions to simulate natural conditions is sometimes necessary; however, the effects of turbulent flow and incomplete saturation on the permeability should be recognized and taken into consideration.

2. TYPES OF TESTS AND EQUIPMENT. a. Types of Tests. (1) Constant-head test. The simplest of all methods for determining the coefficient of permeability is the constant-head type of test illustrated in Figure 1. This test is performed by measuring the quantity of water, Q, flowing through the soil specimen, the length of the soil specimen, L, the head of water, h, and the elapsed time, t. The head of water is kept constant throughout the test. For fine-grained soils, Q is small and may be difficult to measure accurately. Therefore, the constant-head test is used principally for coarse-grained soils (clean sands and gravels) with k values greater than about 10×10^{-4} cm per sec.

(2) Falling-head test. The principle of the falling-head test is illustrated in Figure 2. This test is conducted in the same manner as



(a) (b)

USING SETUP SHOWN IN (a), THE COEFFICIENT OF PERMEABILITY IS DETERMINED AS FOLLOWS:

$$k = \frac{La}{At} \ln \frac{h_o}{h_f} = 2.303 \frac{La}{At} \log_{10} \frac{h_o}{h_f}$$

USING SETUP SHOWN IN (b), THE COEFFICIENT OF PERMEABILITY IS DETERMINED AS FOLLOWS:

$$k = \frac{L}{t} \ln \frac{h_o}{h_f} = 2.303 \frac{L}{t} \log_{10} \frac{h_o}{h_f}$$

WHERE: h_c = HEIGHT OF CAPILLARY RISE

a = INSIDE AREA OF STANDPIPE

A = CROSS-SECTIONAL AREA OF SPECIMEN

L = LENGTH OF SPECIMEN

h_o = HEIGHT OF WATER IN STANDPIPE ABOVE DISCHARGE LEVEL MINUS h_c AT TIME, t_o

h_f = HEIGHT OF WATER IN STANDPIPE ABOVE DISCHARGE LEVEL MINUS h_c AT TIME, t_f

t = ELAPSED TIME, $t_f - t_o$

Figure 2. Principle of falling-head test

the constant-head test, except that the head of water is not maintained constant but is permitted to fall within the upper part of the specimen container or in a standpipe directly connected to the specimen. The quantity of water flowing through the specimen is determined indirectly by computation. The falling-head test is generally used for less pervicus soils (fine sands to fat clays) with k values less than 10×10^{-4} cm per sec.

b. Equipment. The apparatus used for permeability testing may vary considerably in detail depending primarily on the condition and character of the sample to be tested. Whether the sample is fine-grained or coarse-grained, undisturbed, remolded, or compacted, saturated or nonsaturated will influence the type of apparatus to be employed. The basic types of apparatus, grouped according to the type of specimen container (permeameter), are as follows:

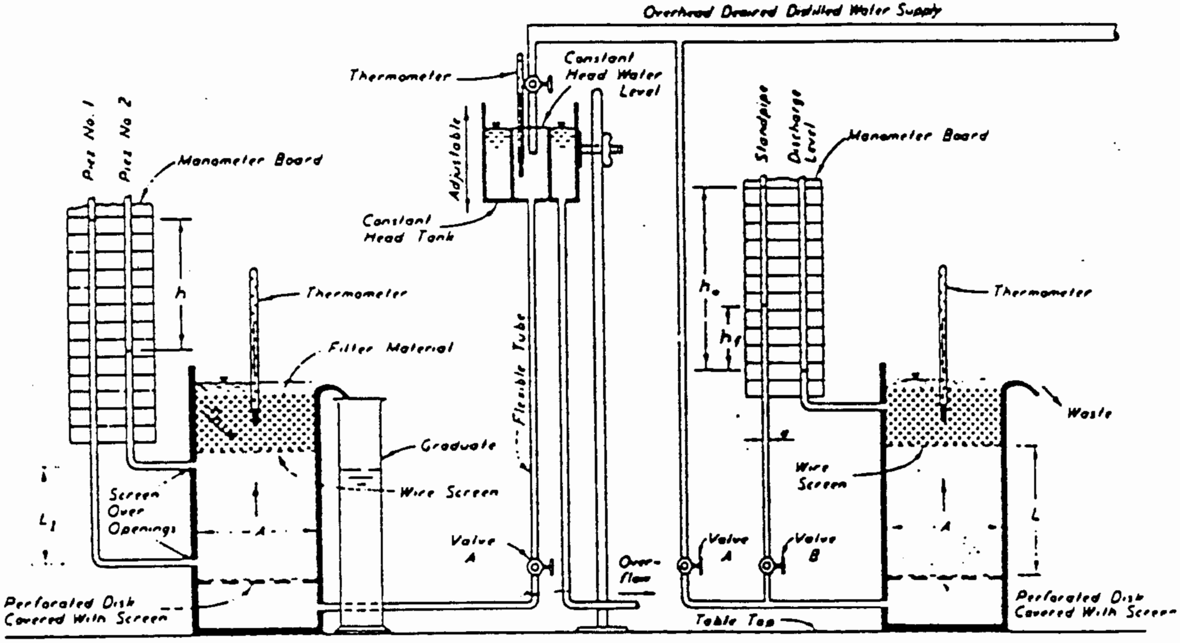
(1) Permeameter cylinders
(2) Sampling tubes
(3) Pressure cylinders
(4) Consolidometers

The permeability of remolded cohesionless soils is determined in permeameter cylinders, while the permeability of undisturbed cohesionless soils in a vertical direction can be determined using the sampling tube as a permeameter. The permeability of remolded cohesionless soils is generally used to approximate the permeability of undisturbed cohesionless soils in a horizontal direction. Pressure cylinders and consolidometers are used for fine-grained soils in the remolded, undisturbed, or compacted state. Fine-grained soils can be tested with the specimen oriented to obtain the permeability in either the vertical or horizontal direction. The above-listed devices are described in detail under the individual test procedures. Permeability tests utilizing the different types of apparatus, together with recommendations regarding their use, are discussed in the following paragraphs.

3. CONSTANT-HEAD PERMEABILITY TEST WITH PERMEAMETER CYLINDER. a. Use. The constant-head permeability test with the permeameter cylinder shall in general be used for determining the permeability of remolded samples of coarse-grained soils such as clean sands and gravels having a permeability greater than about 10×10^{-4} cm per sec.

b. Apparatus. The apparatus and accessory equipment should consist of the following:

(1) A permeameter cylinder similar to that shown schematically in Figure 3a. The permeameter cylinder should be constructed of a transparent plastic material. The inside diameter of the cylinder should be not less than about 10 times the diameter of the largest soil particles, except when the specimen is encased in a rubber membrane as in the permeability test with pressure chamber, in which case the diameter of the cylinder should be at least six times the diameter of the largest soil particles.



(a) CONSTANT-HEAD APPARATUS

(b) FALLING-HEAD APPARATUS

Figure 3. Schematic diagram of constant-head and falling-head permeability apparatus

Piezometer taps along the side of the permeameter within limits to be occupied by the sample are advantageous in that the head loss within the sample is always measured across a fixed distance and rapid determination of hydraulic gradient can be made.

(2) Perforated metal or plastic disks and circular wire screens, 35 to 100 mesh, cut for a close fit inside the permeameter.

(3) Glass tubing, rubber or plastic tubing, stoppers, screw clamps, etc., necessary to make connections as shown in Figure 3a.

(4) Filter materials such as Ottawa sand, coarse sand, and gravel of various gradations.

(5) A device for maintaining a constant-head water supply.

(6) Deaired distilled† water. Tapwater contains dissolved air and gases which separate from solution in the initial layers of a test specimen of soil in the form of small bubbles. These bubbles reduce the permeability of the soil by decreasing the void space available for the flow of water. The most common method for removing dissolved air from water is by boiling the water and then cooling it at reduced pressures. This method is applicable only with small quantities of water. Freshly distilled water also has a very negligible amount of air. Large quantities of deaired distilled water may be prepared and retained for subsequent use by spraying distilled water in a fine stream into a container from which the air has been evacuated (see Fig. 4). Permeability tests on saturated specimens should show no significant decrease in permeability with time if properly deaired distilled water is used. However, if such a decrease in permeability occurs during a test, then a prefilter, consisting of a layer of the same material as the test specimen, should be used between the deaired distilled water reservoir and the test specimen to remove the air remaining in solution.‡

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† Demineralized water or tapwater when it is known to be relatively free of minerals may be used in place of distilled water.

‡ G. E. Bertram, An Experimental Investigation of Protective Filters, Soil Mechanics Series No. 7, Harvard University (Cambridge, Mass., January 1940, reprinted May 1959).

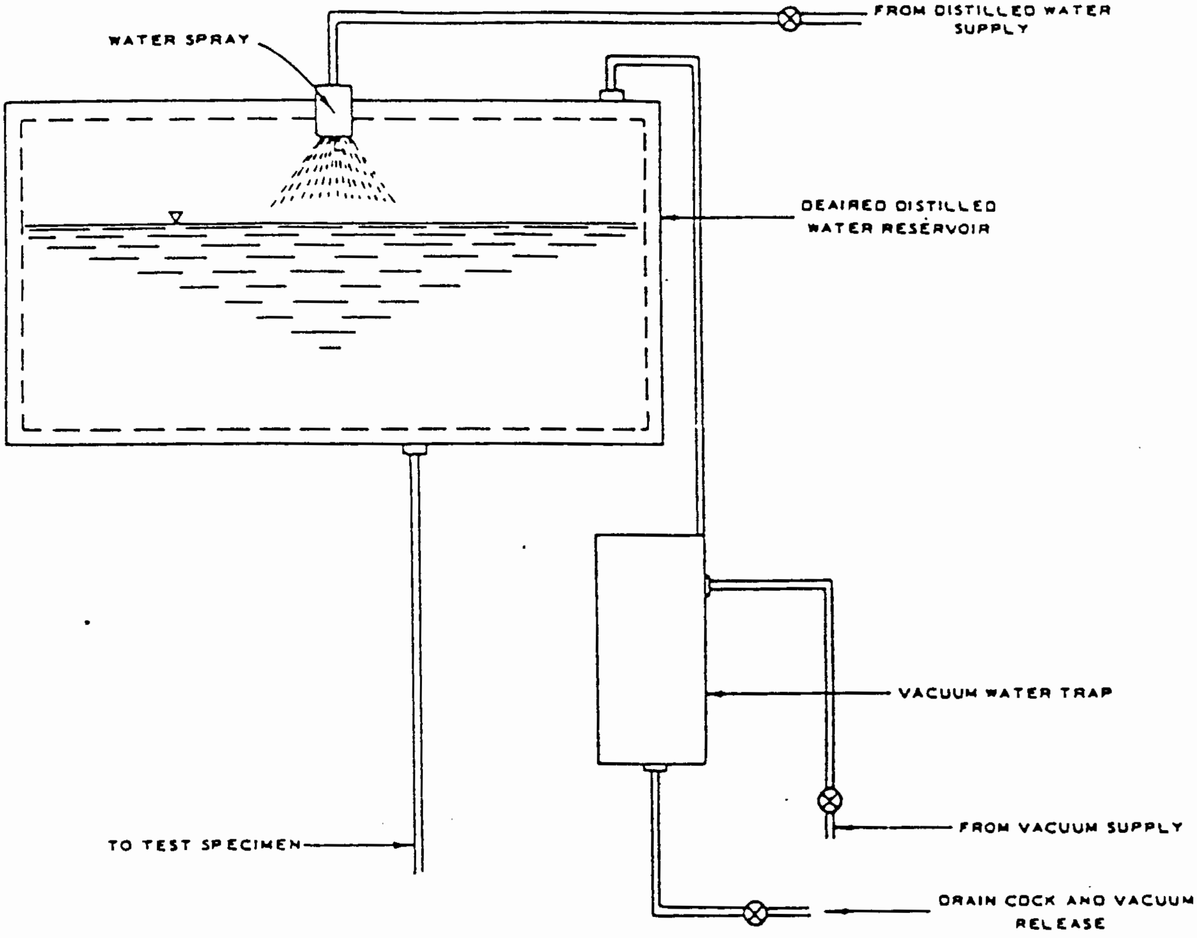

Figure 4. Schematic diagram of apparatus for preparing deaired distilled water

(7) Manometer board with tubing leading from the piezometer taps. If piezometer taps are not provided, equipment to measure the distance between the constant-head source and tailwater is required.

(8) Timing device, a watch or clock with second hand.

(9) Graduated cylinder, 100-ml capacity.

(10) Centigrade thermometer, range 0 to 50 C, accurate to 0.1 C.

(11) Balance, sensitive to 0.1 g.

(12) Oven (see Appendix I, WATER CONTENT - GENERAL).

(13) Scale, graduated in centimeters.

c. Placement and Saturation of Specimen. Placement and saturation of the specimen shall be done in the following steps:

(1) Record all identifying information for the specimen, such as project, boring number, sample number, or other pertinent data, on a data sheet (Plate VII-1 is a suggested form).

(2) Oven-dry the specimen. Allow it to cool and weigh to the nearest 0.1 g. Record the oven-dry weight of material on the data sheet opposite W_s. The amount of material should be sufficient to provide a specimen in the permeameter having a minimum length of about one to two times the diameter of the specimen.

(3) Place a wire screen, with openings small enough to retain the specimen, over a perforated disk near the bottom of the permeameter above the inlet. The screen openings should be approximately equal to the 10 percent size of the specimen.

(4) Allow deaired distilled water to enter the water inlet of the permeameter to a height of about 1/2 in. above the bottom of the screen, taking care that no air bubbles are trapped under the screen.

(5) Mix the material thoroughly and place in the permeameter to avoid segregation. The material should be dropped just at the water surface, keeping the water surface about 1/2 in. above the top of the soil during placement. A funnel or a special spoon as shown in Figure 5 is convenient for this purpose.

(6) The placement procedure outlined above will result in a saturated specimen of uniform density although in a relatively loose condition. To produce a higher density in the specimen, the sides of the permeameter containing the soil sample are tapped uniformly along its circumference and length with a rubber mallet to produce an increase in density; however, extreme caution should be exercised so that fines are not put into suspension and segregated within the sample. As an alternative to this procedure, the specimen may be placed in the in the dry using a funnel or

spoon which permits the material to fall a constant height. The desired density may be achieved by vibrating the specimen to obtain a specimen of predetermined height. Compacting the specimen in layers is not recommended as a film of dust may be formed at the surface of the compacted layer which might affect the permeability results. After placement, apply a vacuum to the top of the specimen and permit water to enter the evacuated specimen through the base of the permeameter.

(7) After the specimen has been placed, weigh the excess material, if any, and the container. The specimen weight is the difference between the original weight of sample and the weight of the excess material. Care must be taken so that no material is lost during placement of the specimen. If there is evidence that material has been lost, oven-dry the specimen and weigh after the test as a check.

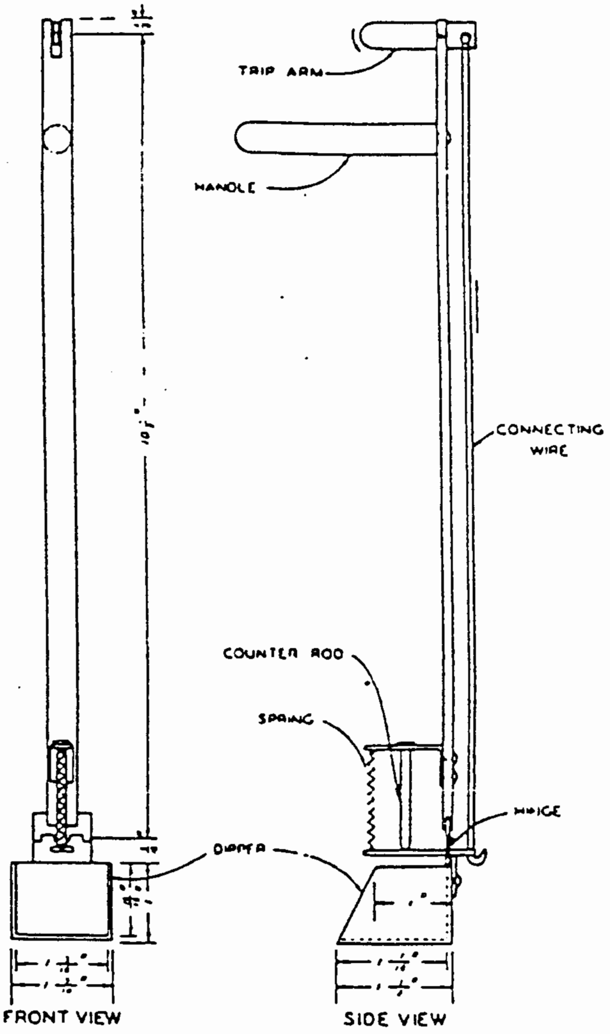

Figure 5. Spoon for placing cohesionless soils

(8) Level the top of the specimen, cover with a wire screen similar to that used at the base, and fill the remainder of the permeameter with a filter material.

(9) Measure the length of the specimen and inside diameter of the permeameter to the nearest 0.1 cm and record on the data sheet as initial height and diameter of specimen.

(10) Test the specimen at the estimated natural void ratio or

at a series of different void ratios, produced by increasing the amount of vibration after each permeability determination. Measure and record the length (height) of specimen in the permeameter prior to each determination. Permeability determinations at three different void ratios are usually sufficient to establish the relation of void ratio to permeability.

d. Procedure. The procedure shall consist of the following steps:

(1) Measure the distance, L_1, between the centers of the piezometer taps to the nearest 0.01 cm and record on the data sheet.

(2) Adjust the height of the constant-head tank to obtain the desired hydraulic gradient. The hydraulic gradient should be selected so that the flow through the specimen is laminar. The range of laminar flow conditions can be determined by plotting discharge versus hydraulic gradient. A straight-line relation indicates laminar flow, while deviations from the straight-line at high gradients indicate turbulent flow. Laminar flow for fine sands is limited to hydraulic gradients less than approximately 0.3. It is usually not practicable to achieve laminar flow for coarser soils, and the tests generally should be run at the hydraulic gradient anticipated in the field.

(3) Open valve A (see Fig. 3a) and record the initial piezometer readings after the flow has become stable. Exercise care in building up heads in the permeameter so that the specimen is not disturbed.

(4) After allowing a few minutes for equilibrium conditions to be reached, measure by means of a graduate the quantity of discharge corresponding to a given time interval. Measure the piezometric heads and the water temperature in the permeameter.

(5) Record the quantity of flow, piezometer readings, water temperature, and the time interval during which the quantity of flow was measured on the data sheet, Plate VII-1.

(6) Repeat steps (4) and (5) several times over a period of about 1 hr, and compute the coefficient of permeability corresponding to each set of measured data. If there is no substantial change in the

permeability, then the computed permeability is probably reliable. If there is a slight decrease in the permeability, then the permeability computed from the initial measurements, rather than the average, should be reported, so long as a plot of permeability versus time shows that the initial measurements are consistent with the subsequent measurements; a difference in permeability may result from a change in density caused by inadvertent jarring of the specimen in the permeameter. If there is any substantial decrease of the permeability with time, a prefilter should be used between the water reservoir and the permeameter (see paragraph 3b(6)). The criterion for judging whether a change in the computed permeability is "substantial" depends on the desired accuracy of the coefficient of permeability.

(7) If desired, reduce the void ratio as previously described and repeat the constant-head test.

e. Computations. The computations consist of the following steps:

(1) Compute the test void ratios in accordance with Appendix II, UNIT WEIGHTS, VOID RATIO, POROSITY, AND DEGREE OF SATURATION. The specific gravity shall be estimated or determined in accordance with Appendix IV, SPECIFIC GRAVITY.

(2) Compute the coefficient of permeability, k, by means of the following equation:

$$k_{20} = \frac{Q \times L \times R_T}{h \times A \times t}$$

where k_{20} = coefficient of permeability, cm per sec at 20 C

Q = quantity of flow, cc

L = length of specimen over which head loss is measured, cm. If piezometer taps are used, $L = L_1$ = distance between piezometer taps, cm

R_T = temperature correction factor for viscosity of water obtained from Table VII-1

h = loss of head in length, L, or difference in piezometer readings = $h_1 - h_2$, cm

A = cross-sectional area of specimen, sq cm

t = elapsed time, sec

Table VII-1

Correction Factor, R_T, for Viscosity of Water at Various Temperatures

Temperature Degrees C	Tenths of Degrees									
	0	1	2	3	4	5	6	7	8	9
0.0	1.783	1.777	1.771	1.765	1.759	1.753	1.747	1.741	1.735	1.729
1.0	1.723	1.717	1.711	1.705	1.699	1.694	1.688	1.682	1.676	1.670
2.0	1.664	1.659	1.654	1.648	1.643	1.638	1.632	1.627	1.622	1.616
3.0	1.611	1.606	1.601	1.596	1.590	1.585	1.580	1.575	1.570	1.565
4.0	1.560	1.555	1.550	1.545	1.540	1.535	1.531	1.526	1.521	1.516
5.0	1.511	1.507	1.502	1.498	1.493	1.488	1.484	1.479	1.475	1.470
6.0	1.465	1.461	1.457	1.452	1.448	1.443	1.439	1.435	1.430	1.426
7.0	1.421	1.417	1.413	1.409	1.404	1.400	1.396	1.392	1.388	1.383
8.0	1.379	1.375	1.371	1.367	1.363	1.359	1.355	1.351	1.347	1.343
9.0	1.339	1.336	1.332	1.328	1.324	1.320	1.317	1.313	1.309	1.305
10.0	1.301	1.298	1.294	1.290	1.287	1.283	1.279	1.276	1.272	1.269
11.0	1.265	1.262	1.258	1.255	1.251	1.248	1.244	1.241	1.237	1.234
12.0	1.230	1.227	1.223	1.220	1.217	1.213	1.210	1.207	1.203	1.200
13.0	1.197	1.194	1.190	1.187	1.184	1.181	1.178	1.175	1.171	1.168
14.0	1.165	1.162	1.159	1.156	1.153	1.150	1.147	1.144	1.141	1.138
15.0	1.135	1.132	1.129	1.126	1.123	1.120	1.117	1.114	1.111	1.108
16.0	1.106	1.103	1.100	1.097	1.094	1.091	1.089	1.086	1.083	1.080
17.0	1.077	1.075	1.072	1.069	1.067	1.064	1.061	1.059	1.056	1.053
18.0	1.051	1.048	1.045	1.043	1.040	1.038	1.035	1.033	1.030	1.027
19.0	1.025	1.022	1.020	1.017	1.015	1.012	1.010	1.007	1.005	1.002
20.0	1.000	0.998	0.995	0.993	0.990	0.988	0.986	0.983	0.981	0.979
21.0	0.976	0.974	0.972	0.969	0.967	0.965	0.962	0.960	0.958	0.955
22.0	0.953	0.951	0.949	0.947	0.944	0.942	0.940	0.938	0.936	0.933
23.0	0.931	0.929	0.927	0.925	0.923	0.920	0.918	0.916	0.914	0.912
24.0	0.910	0.908	0.906	0.904	0.901	0.899	0.897	0.895	0.893	0.891
25.0	0.889	0.887	0.885	0.883	0.881	0.879	0.877	0.875	0.873	0.871
26.0	0.869	0.867	0.866	0.864	0.862	0.860	0.858	0.856	0.854	0.852
27.0	0.850	0.848	0.847	0.845	0.843	0.841	0.839	0.837	0.836	0.834
28.0	0.832	0.830	0.828	0.826	0.825	0.823	0.821	0.819	0.818	0.816
29.0	0.814	0.812	0.810	0.809	0.807	0.805	0.804	0.802	0.800	0.798
30.0	0.797	0.795	0.793	0.792	0.790	0.788	0.787	0.785	0.783	0.782
31.0	0.780	0.778	0.777	0.775	0.774	0.772	0.770	0.769	0.767	0.766
32.0	0.764	0.763	0.761	0.759	0.758	0.756	0.755	0.753	0.752	0.750
33.0	0.749	0.747	0.746	0.744	0.743	0.741	0.739	0.738	0.736	0.735
34.0	0.733	0.732	0.731	0.729	0.728	0.726	0.725	0.723	0.722	0.720
35.0	0.719	0.718	0.716	0.715	0.713	0.712	0.711	0.709	0.708	0.706
36.0	0.705	0.704	0.702	0.701	0.699	0.698	0.697	0.695	0.694	0.693
37.0	0.691	0.690	0.689	0.687	0.686	0.685	0.683	0.682	0.681	0.679
38.0	0.678	0.677	0.675	0.674	0.673	0.672	0.670	0.669	0.668	0.666
39.0	0.665	0.664	0.663	0.661	0.660	0.659	0.658	0.656	0.655	0.654
40.0	0.653	0.652	0.650	0.649	0.648	0.647	0.646	0.644	0.643	0.642
41.0	0.641	0.639	0.638	0.637	0.636	0.635	0.634	0.632	0.631	0.630
42.0	0.629	0.628	0.627	0.626	0.624	0.623	0.622	0.621	0.620	0.619
43.0	0.618	0.616	0.615	0.614	0.613	0.612	0.611	0.610	0.609	0.608
44.0	0.607	0.606	0.604	0.603	0.602	0.601	0.600	0.599	0.598	0.597
45.0	0.596	0.595	0.594	0.593	0.592	0.591	0.590	0.588	0.587	0.586
46.0	0.585	0.584	0.583	0.582	0.581	0.580	0.579	0.578	0.577	0.576
47.0	0.575	0.574	0.573	0.572	0.571	0.570	0.569	0.568	0.567	0.566
48.0	0.565	0.564	0.564	0.563	0.562	0.561	0.560	0.559	0.558	0.557
49.0	0.556	0.555	0.554	0.553	0.552	0.551	0.550	0.549	0.548	0.548

Computed from Table 170 - Smithsonian Physical Tables - 8th Edition
Correction factor, R_T, is found by dividing the viscosity of water at the test temperature by the viscosity of water at 20 C.

f. Presentation of Results. The coefficient of permeability shall be reported in units with coefficients of 1.0, 1×10^{-4}, and 1×10^{-9} cm per sec. The void ratio of the specimen shall be reported with all values of k. The coefficient of permeability, k, is logarithmically dependent upon the void ratio of the soil. Where k is determined at several void ratios, the test results shall be presented on a semilogarithmic chart as shown in Figure 6 in which k is plotted on the abscissa (logarithmic scale) and the void ratio is plotted on the ordinate (arithmetic scale).

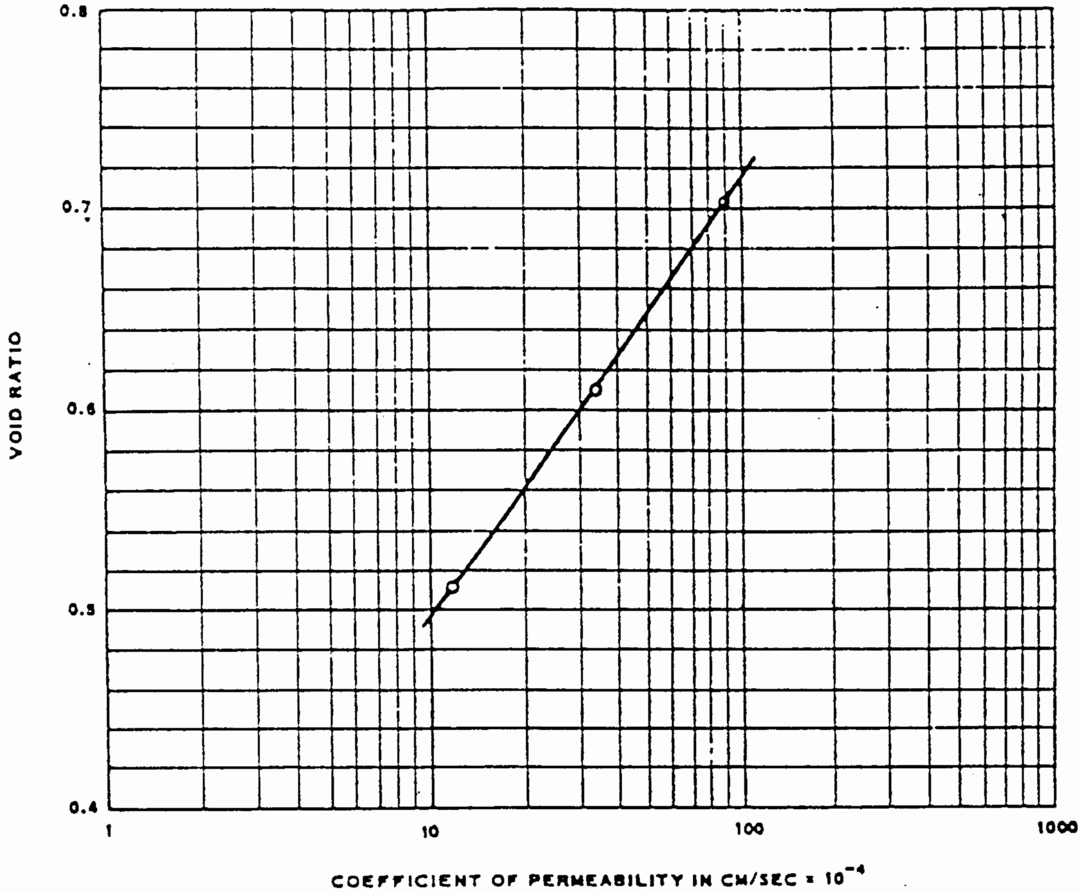

Figure 6. Relation between permeability and void ratio for cohesionless soils

4. FALLING-HEAD PERMEABILITY TEST WITH PERMEAMETER CYLINDER. a. Use. The falling-head test with the permeameter cylinder should in general be used for determining the permeability of remolded samples of cohesionless soils having a permeability less than about 10×10^{-4} cm per sec.

b. Apparatus. The apparatus and accessory equipment should consist of the following:

(1) A permeameter cylinder similar to that shown schematically in Figure 3b, or modified versions thereof. The permeameter cylinder should be constructed of a transparent plastic material. The inside diameter of the cylinder should be not less than about 10 times the diameter of the largest soil particles. The use of two piezometer taps, as shown by Figure 3b, connected to a standpipe and discharge level tube eliminates the necessity for taking into account the height of capillary rise which would be necessary in the case of a single standpipe of small size. The height of capillary rise for a given tube and condition can be measured simply by standing the tube upright in a beaker full of water. The size of standpipe to be used is generally based on experience with the equipment used and soils tested. In order to accelerate testing, air pressure may be applied to the standpipe to increase the hydraulic gradient.

(2) Perforated metal or plastic disks and circular wire screens, 35 to 100 mesh, cut for a close fit inside the permeameter.

(3) Glass tubing, rubber or plastic tubing, stoppers, screw clamps, etc., necessary to make connections as shown in Figure 3b.

(4) Filter materials such as Ottawa sand, coarse sand, and gravel of various gradations.

(5) Deaired distilled water, prepared according to paragraph 3b(6).

(6) Manometer board or suitable scales for measuring levels in piezometers or standpipe.

(7) Timing device, a watch or clock with second hand.

(8) Centigrade thermometer, range 0 to 50 C, accurate to 0.1 C.

(9) Balance, sensitive to 0.1 g.

(10) Oven (see Appendix I, WATER CONTENT - GENERAL).

(11) Scale, graduated in centimeters.

c. Placement and Saturation of Specimen. Placement and saturation of the specimen shall be done as described in paragraph 3c. Identifying information for the sample and test data shall be entered on a data sheet similar to Plate VII-2.

d. Procedure. The procedure shall consist of the following steps:

(1) Measure and record the height of the specimen, L, and the cross-sectional area of the specimen, A.

(2) With valve B open (see Fig. 3b), crack valve A and slowly bring the water level up to the discharge level of the permeameter.

(3) Raise the head of water in the standpipe above the discharge level of the permeameter. The difference in head should not result in an excessively high hydraulic gradient during the test. Close valves A and B.

(4) Begin the test by opening valve B. Start the timer. As the water flows through the specimen, measure and record the height of water in the standpipe above the discharge level, h_o, in centimeters, at time t_o, and the height of water above the discharge level, h_f, in centimeters, at time t_f.

(5) Observe and record the temperature of the water in the permeameter.

(6) Repeat the determination of permeability, and if the computed values differ by an appreciable amount, repeat the test until consistent values of permeability are obtained.

e. Computations. The computations consist of the following steps:

(1) Compute the test void ratios as outlined in paragraph 3e(1).

(2) Compute the coefficient of permeability, k, by means of the following equation:

$$k = 2.303 \frac{a}{A} \frac{L}{t} \left(\log \frac{h_o}{h_f} \right) R_T$$

where a = inside area of standpipe, sq cm

A = cross-sectional area of specimen, sq cm

L = length of specimen, cm

t = elapsed time $(t_f - t_o)$, sec

h_o = height of water in standpipe above discharge level at time t_o, cm

h_f = height of water in standpipe above discharge level at time t_f, cm

R_T = temperature correction factor for viscosity of water obtained from Table VII-1, degrees C

If a single standpipe of small diameter is used as shown in Figure 2, the height of capillary rise, h_c, should be subtracted from the standpipe readings to obtain h_o and h_f.

f. Presentation of Results. The results of the falling-head permeability test shall be reported as described in paragraph 3f.

5. PERMEABILITY TESTS WITH SAMPLING TUBES. Permeability tests may be performed directly on undisturbed samples without removing them from the sampling tubes. The sampling tube serves as the permeameter cylinder. The method is applicable primarily to cohesionless soils which cannot be removed from the sampling tube without excessive disturbance. The permeability obtained is in the direction in which the sample was taken, i.e. generally vertical. The permeability obtained in a vertical direction may be substantially less than that obtained in a horizontal direction.

Permeability tests with sampling tubes may be performed under constant-head or falling-head conditions of flow, depending on the estimated permeability of the sample (see paragraph 2a). The equipment should be capable of reproducing the conditions of flow in the constant-head or falling-head tests. It is important that all disturbed material or material containing drilling mud be removed from the top and bottom of the sample. The ends of the sample should be protected by screens held in place by perforated packers. The test procedure and computations are the same as those described previously for each test.

6. PERMEABILITY TEST WITH PRESSURE CHAMBER. In the permeability test with a pressure chamber, see Figure 7, a cylindrical specimen is confined in a rubber membrane and subjected to an external hydrostatic pressure during the permeability test. The advantages of this type of test are: (a) leakage along the sides of the specimen, which would occur if the specimen were tested in a permeameter, is prevented, and (b) the specimen can be tested under conditions of loading expected in the field. The test is applicable primarily to cohesive soils in the undisturbed, remolded, or compacted state. Complete saturation of the specimen, if it is not fully saturated initially, is practically impossible. Consequently, this test should be used only for soils that are fully saturated, unless values of permeability are purposely desired for soils in an unsaturated condition. The permeability test with the pressure chamber is usually performed as a falling-head test.

The permeability specimens for use in the pressure chamber generally should be 2.8 in. in diameter, as rubber membranes and equipment for cutting and trimming specimens of this size are available for triaxial testing apparatus (see Appendix X, TRIAXIAL COMPRESSION TESTS). A specimen length of about 4 in. is adequate. (The dimensions of a test specimen may be varied if equipment and supplies are available to make a suitable test setup.) The pressure in the chamber should not be less than the maximum head on the specimen during the test. The other test procedure and computations are the same as those described for the falling-head test. The linear relation between permeability and void ratio on a semilogarithmic plot as shown in Figure 6 is usually not applicable to fine-grained soils, particularly when compacted. Other methods of presenting permeability-void ratio data may be desirable.

7. PERMEABILITY TESTS WITH BACK PRESSURE.

a. Description. Gas bubbles in the pores of a compacted or undisturbed specimen of fine-grained soil will invalidate the results of the

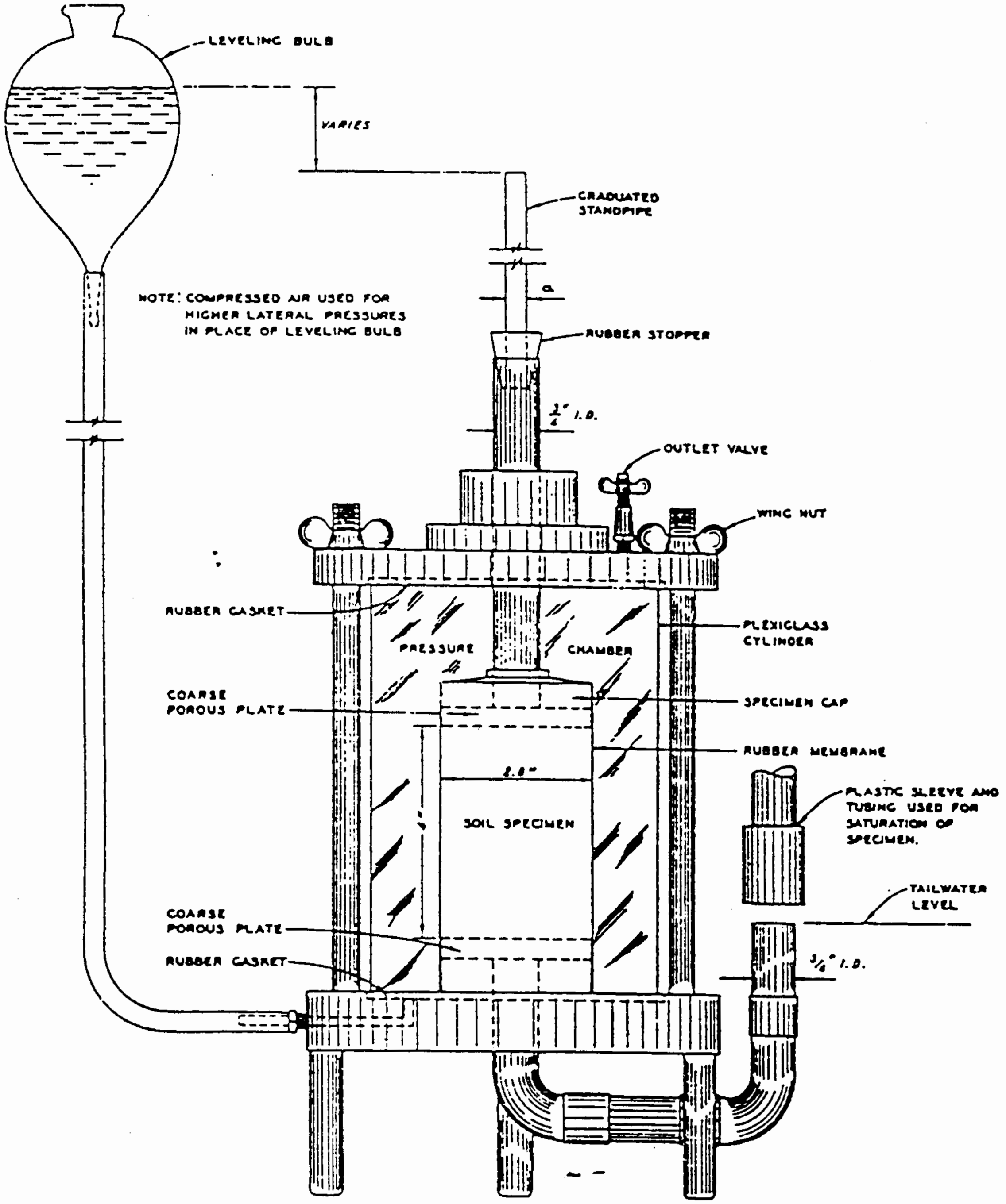

Figure 7. Pressure chamber for permeability test

permeability tests described in the preceding paragraphs. It is known that an increase in pressure will cause a reduction in volume of gas bubbles and also an increased weight of gas dissolved in water. To each degree of saturation there corresponds a certain additional pressure (back pressure) which, if applied to the pore fluid of the specimen, will cause complete saturation. The permeability test with back pressure is performed in a pressure chamber such as that shown in Figure 8, utilizing equipment that permits increasing the chamber pressure and pore pressure simultaneously, maintaining their difference constant. The method is generally applicable to fine-grained soils that are not fully saturated. Apparatus and procedures have been described by A. Casagrande† and L. Bjerrum and J. Huder.‡

<u>b</u>. <u>Procedure (see Fig. 8).</u> The procedure shall consist of the following steps:

(1) After having determined the dimensions and wet weight of the test specimen, place it in the triaxial apparatus, using the same procedure as for setting up a specimen for an R triaxial test with pore pressure measurements except that filter strips should not be used (see para 7, APPENDIX X, TRIAXIAL COMPRESSION TESTS).

(2) Saturate the specimen and verify 100 percent saturation using the procedure described in paragraph 7<u>b</u>, APPENDIX X, TRIAXIAL COMPRESSION TESTS. Burette "A" is utilized during this operation.

(3) With the drainage valves closed, increase the chamber

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† Casagrande, A., "Third Progress Report on Investigation of Stress Deformation and Strength Characteristics of Compacted Clays," Soil Mechanics Series No. 70, Nov 1963, Harvard University, Cambridge, Mass., pp 30 and 31.

‡ Bjerrum, L. and Huder, J., "Measurement of the Permeability of Compacted Clays," <u>Proceedings, Fourth International Conference on Soil Mechanics and Foundation Engineering</u>, London, Vol 1, Aug 1957, pp 6-8.

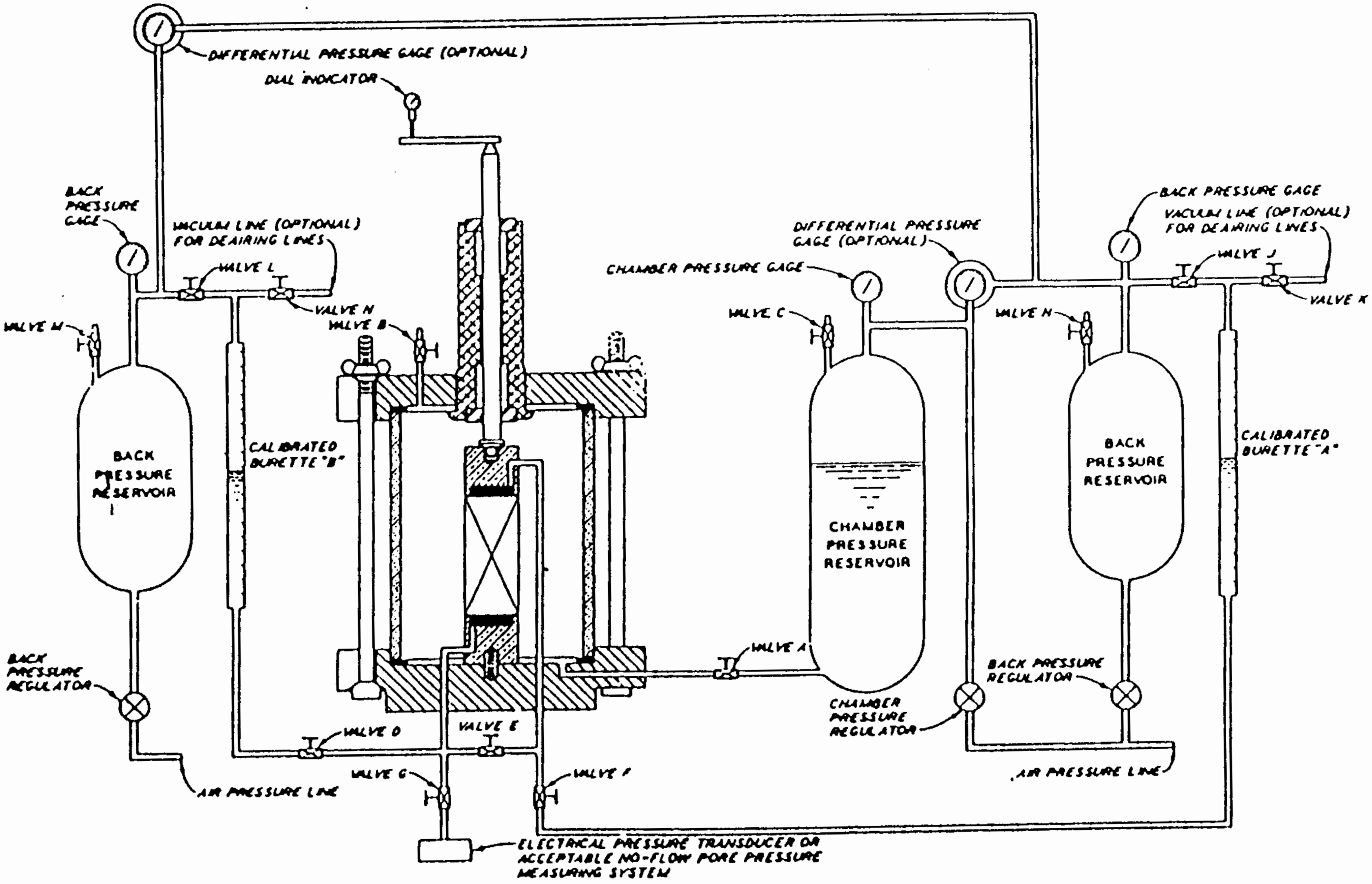


Figure 8. Schematic diagram of typical triaxial compression apparatus for permeability tests with back pressure

pressure to attain the desired effective consolidation pressure (chamber pressure minus back pressure). At zero elapsed time, open valves E and F.

(4) Record time, dial indicator reading, and burette reading at elapsed times of 0, 15, and 30 sec, 1, 2, 4, 8, and 15 min, and 1, 2, 4, and 8 hr, etc. Plot the dial indicator readings and burette readings on an arithmetic scale versus elapsed time on a log scale. When the consolidation curves indicate that primary consolidation is complete, close valves E and F.

(5) Apply a pressure to burette B greater than that in burette A. The difference between the pressures in burettes B and A is equal to the head loss h; h divided by the height of the specimen after consolidation, L, is the hydraulic gradient. The difference between the two pressures should be kept as small as practicable, consistent with the requirement that the rate of flow be large enough to make accurate measurements of the quantity of flow within a reasonable period of time. Because the difference in the two pressures may be very small in comparison to the pressures at the ends of the specimen, and because the head loss must be maintained constant throughout the test, the difference between the pressures within the burettes must be measured accurately; a differential pressure gage is very useful for this purpose. The difference between the elevations of the water within the burettes should also be considered (1 in. of water = 0.036 psi of pressure).

(6) Open valves D and F. Record the burette readings at any zero elapsed time. Make readings of burettes A and B and of temperature at various elapsed times (the interval between successive readings depends upon the permeability of the soil and the dimensions of the specimen). Plot arithmetically the change in readings of both burettes versus time. Continue making readings until the two curves become parallel and straight over a sufficient length of time to accurately determine the rate of flow (slope of the curves).

(7) If it is desired to determine the permeability at several void ratios, steps 3 through 6 can be repeated, using different consolidation pressures in step 3.

(8) At the end of the permeability determinations, close all drainage valves and reduce the chamber pressure to zero; disassemble the apparatus.

(9) Determine the wet and dry weights of the specimen.

c. Computations. The computations consist of the following steps.

(1) Compute the test void ratios as outlined in paragraph 3e(1).

(2) Computations of coefficients of permeability are the same as those described for the constant-head permeability test.

8. PERMEABILITY TESTS WITH CONSOLIDOMETER. A permeability test in a consolidometer (see Appendix VIII, CONSOLIDATION TEST) is essentially similar to that conducted in a pressure chamber, except that the specimen is placed within a relatively rigid ring and is loaded vertically. The test can be used as an alternate to the permeability test in the pressure chamber. The test is applicable primarily to cohesive soils in a fully saturated condition. Testing is usually performed under falling-head conditions.

A schematic diagram of the consolidation apparatus set up for a falling-head permeability test is shown in Figure 9. Identifying information for the specimen and subsequent test data are entered on a data sheet (Plate VII-3 is a suggested form). The specimen should be placed in the specimen ring and the apparatus assembled as outlined under Appendix VIII, CONSOLIDATION TEST. The specimen is consolidated under the desired load and the falling-head test is performed as previously described. The

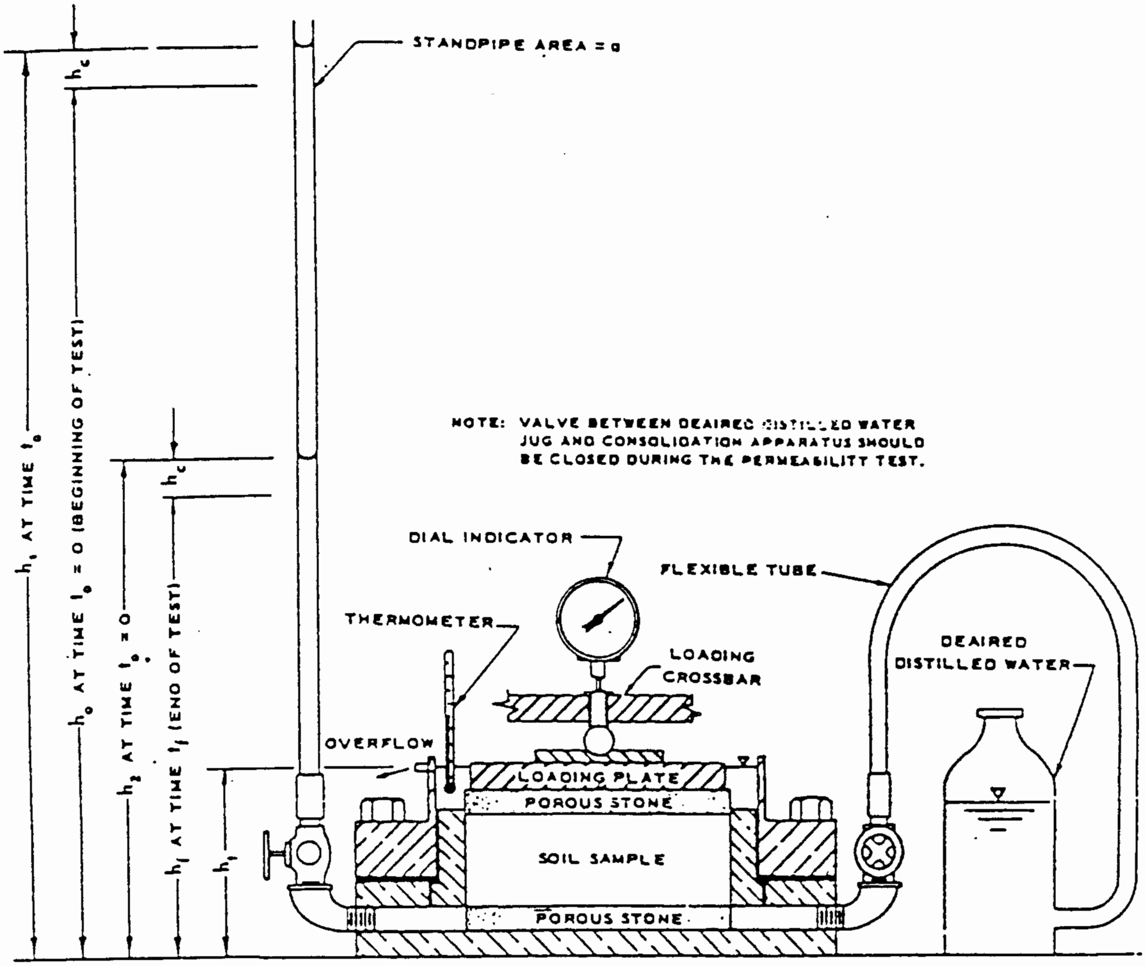


Figure 9. Schematic diagram of falling-head device for permeability test in consolidometer

net head on the specimen may be increased by use of air pressure; however, the pressure on the pore water should not exceed 25 to 30 percent of the vertical pressure under which the specimen has consolidated. Dial indicator readings are observed before and after consolidation to permit computation of void ratios. The determination of the coefficient of permeability may be made in conjunction with the consolidation test, in which case the test is performed at the end of the consolidation phase under each load increment. Computations are similar to those described for the falling-head test with the permeameter cylinder.

The permeability may also be determined indirectly from computations using data obtained during the consolidation test; however the assumptions on which the method is based are seldom satisfied, and consequently, the direct determination of permeability should be employed where reliable values of permeability are required.

9. POSSIBLE ERRORS. Following are possible errors that would cause inaccurate determinations of the coefficient of permeability:

a. Stratification or nonuniform compaction of cohesionless soils. If the specimen is compacted in layers, any accumulation of fines at the surface of the layers will reduce the measured coefficient of permeability.

b. Incomplete initial saturation of specimen.

c. Excessive hydraulic gradient. Darcy's law is applicable only to conditions of laminar flow.

d. Air dissolved in water. No other source of error is as troublesome as the accumulation of air in the specimen from the flowing water. As water enters the specimen, small quantities of air dissolved in the water will tend to collect as fine bubbles at the soil-water interface and reduce the permeability at this interface with increasing time. The method for detecting and avoiding this problem is described in paragraph 3d(6). (It should be noted that air accumulation will not affect the coefficient of permeability determined by the constant-head test if piezometer taps along the side of the specimen are used to measure the head loss.)

e. Leakage along side of specimen in permeameter. One major advantage to the use of the triaxial compression chamber for permeability tests (see paragraphs 6 and 7) is that the specimen is confined by a flexible membrane which is pressed tightly against the specimen by the chamber pressure.

APPENDIX C

Test Methods for Evaluating Solid Waste (EPA SW-846)

CHAPTER NINE

SAMPLING PLAN

9.1 DESIGN AND DEVELOPMENT

The initial -- and perhaps most critical -- element in a program designed to evaluate the physical and chemical properties of a solid waste is the plan for sampling the waste. It is understandable that analytical studies, with their sophisticated instrumentation and high cost, are often perceived as the dominant element in a waste characterization program. Yet, despite that sophistication and high cost, analytical data generated by a scientifically defective sampling plan have limited utility, particularly in the case of regulatory proceedings.

This section of the manual addresses the development and implementation of a scientifically credible sampling plan for a solid waste and the documentation of the chain of custody for such a plan. The information presented in this section is relevant to the sampling of any solid waste, which has been defined by the EPA in its regulations for the identification and listing of hazardous wastes to include solid, semisolid, liquid, and contained gaseous materials. However, the physical and chemical diversity of those materials, as well as the dissimilarity of storage facilities (lagoons, open piles, tanks, drums, etc.) and sampling equipment associated with them, preclude a detailed consideration of any specific sampling plan. Consequently, because the burden of responsibility for developing a technically sound sampling plan rests with the waste producer, it is advisable that he/she seek competent advice before designing a plan. This is particularly true in the early developmental stages of a sampling plan, at which time at least a basic understanding of applied statistics is required. Applied statistics is the science of employing techniques that allow the uncertainty of inductive inferences (general conclusions based on partial knowledge) to be evaluated.

9.1.1 Development of Appropriate Sampling Plans

An appropriate sampling plan for a solid waste must be responsive to both regulatory and scientific objectives. Once those objectives have been clearly identified, a suitable sampling strategy, predicated upon fundamental statistical concepts, can be developed. The statistical terminology associated with those concepts is reviewed in Table 9-1; Student's "t" values for use in the statistics of Table 9-1 appear in Table 9-2.

9.1.1.1 Regulatory and Scientific Objectives

The EPA, in its hazardous waste management system, has required that certain solid wastes be analyzed for physical and chemical properties. It is mostly chemical properties that are of concern, and, in the case of a number of chemical contaminants, the EPA has promulgated levels (regulatory thresholds) that cannot be equaled or exceeded. The regulations pertaining to the management of hazardous wastes contain three references regarding the

TABLE 9-1. BASIC STATISTICAL TERMINOLOGY APPLICABLE TO SAMPLING PLANS FOR SOLID WASTES

Terminology	Symbol	Mathematical equation	(Equation)
• Variable (e.g., barium or endrin)	x	—	
• Individual measurement of variable	x_i	—	
• Mean of all possible measurements of variable (population mean)	μ	$\mu = \frac{\sum_{i=1}^{N} x_i}{N}$, with N = number of possible measurements	(1)
• Mean of measurements generated by sample (sample mean)	$\bar{x}$	Simple random sampling and systematic random sampling $\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$, with n = number of sample measurements	(2a)
		Stratified random sampling $\bar{x} = \sum_{k=1}^{r} W_k \bar{x}_k$, with $\bar{x}_k$ = stratum mean and W_k = fraction of population represented by Stratum k (number of strata [k] range from 1 to r)	(2b)
• Variance of sample	s^2	Simple random sampling and systematic random sampling $s^2 = \frac{\sum_{i=1}^{n} x_i^2 - (\sum_{i=1}^{n} x_i)^2/n}{n - 1}$	(3a)
		Stratified random sampling $s^2 = \sum_{k=1}^{r} W_k s_k^2$, with s_k^2 = stratum variance and W_k = fraction of population represent by Stratum k (number of strata [k] ranges from 1 to r)	(3b)

TABLE 9-1. (Continued)

Terminology	Symbol	Mathematical equation	(Equation)
• Standard deviation of sample	s	$s = \sqrt{s^2}$	(4)
• Standard error (also standard error of mean and standard deviation of mean) of sample	$s_{\bar{x}}$	$s_{\bar{x}} = \frac{s}{\sqrt{n}}$	(5)
• Confidence interval for μ[a]	CI	$CI = \bar{x} \pm t_{.20}\, s_{\bar{x}}$, with $t_{.20}$ obtained from Table 2 for appropriate degrees of freedom	(6)
• Regulatory threshold[a]	RT	Defined by EPA (e.g., 100 ppm for barium in elutriate of EP toxicity)	(7)
• Appropriate number of samples to collect from a solid waste (financial constraints not considered)	n	$n = \frac{t^2_{.20}s^2}{\Delta^2}$, with $\Delta = RT - \bar{x}$	(8)
• Degrees of freedom	df	$df = n - 1$	(9)
• Square root transformation	---	$X_i + 1/2$	(10)
• Arcsin transformation	---	Arcsin p; if necessary, refer to any text on basic statistics; measurements must be converted to percentages (p)	(11)

---

[a] The upper limit of the CI for μ is compared with the applicable regulatory threshold (RT) to determine if a solid waste contains the variable (chemical contaminant) of concern at a hazardous level. The contaminant of concern is not considered to be present in the waste at a hazardous level if the upper limit of the CI is less than the applicable RT. Otherwise, the opposite conclusion is reached.

TABLE 9-2. TABULATED VALUES OF STUDENT'S "t" FOR EVALUATING SOLID WASTES

Degrees of freedom (n-1)[a]	Tabulated "t" value[b]
1	3.078
2	1.886
3	1.638
4	1.533
5	1.476
6	1.440
7	1.415
8	1.397
9	1.393
10	1.372
11	1.363
12	1.356
13	1.350
14	1.345
15	1.341
16	1.337
17	1.333
18	1.330
19	1.328
20	1.325
21	1.323
22	1.321
23	1.319
24	1.318
25	1.316
26	1.315
27	1.314
28	1.313
29	1.311
30	1.310
40	1.303
60	1.296
120	1.289
	1.282

---

[a] Degrees of freedom (df) are equal to the number of samples (n) collected from a solid waste less one.

[b] Tabulated "t" values are for a two-tailed confidence interval and a probability of 0.20 (the same values are applicable to a one-tailed confidence interval and a probability of 0.10).

sampling of solid wastes for analytical properties. The first reference, which occurs throughout the regulations, requires that representative samples of waste be collected and defines representative samples as exhibiting average properties of the whole waste. The second reference, which pertains just to petitions to exclude wastes from being listed as hazardous wastes, specifies that enough samples (but in no case less than four samples) be collected over a period of time sufficient to represent the variability of the wastes. The third reference, which applies only to ground water monitoring systems, mandates that four replicates (subsamples) be taken from each ground water sample intended for chemical analysis and that the mean concentration and variance for each chemical constituent be calculated from those four subsamples and compared with background levels for ground water. Even the statistical test to be employed in that comparison is specified (Student's t-test).

The first of the above-described references addresses the issue of sampling accuracy, and the second and third references focus on sampling variability or, conversely, sampling precision (actually the third reference relates to analytical variability, which, in many statistical tests, is indistinguishable from true sampling variability). Sampling accuracy (the closeness of a sample value to its true value) and sampling precision (the closeness of repeated sample values) are also the issues of overriding importance in any scientific assessment of sampling practices. Thus, from both regulatory and scientific perspectives, the primary objectives of a sampling plan for a solid waste are twofold: namely, to collect samples that will allow measurements of the chemical properties of the waste that are both accurate and precise. If the chemical measurements are sufficiently accurate and precise, they will be considered reliable estimates of the chemical properties of the waste.

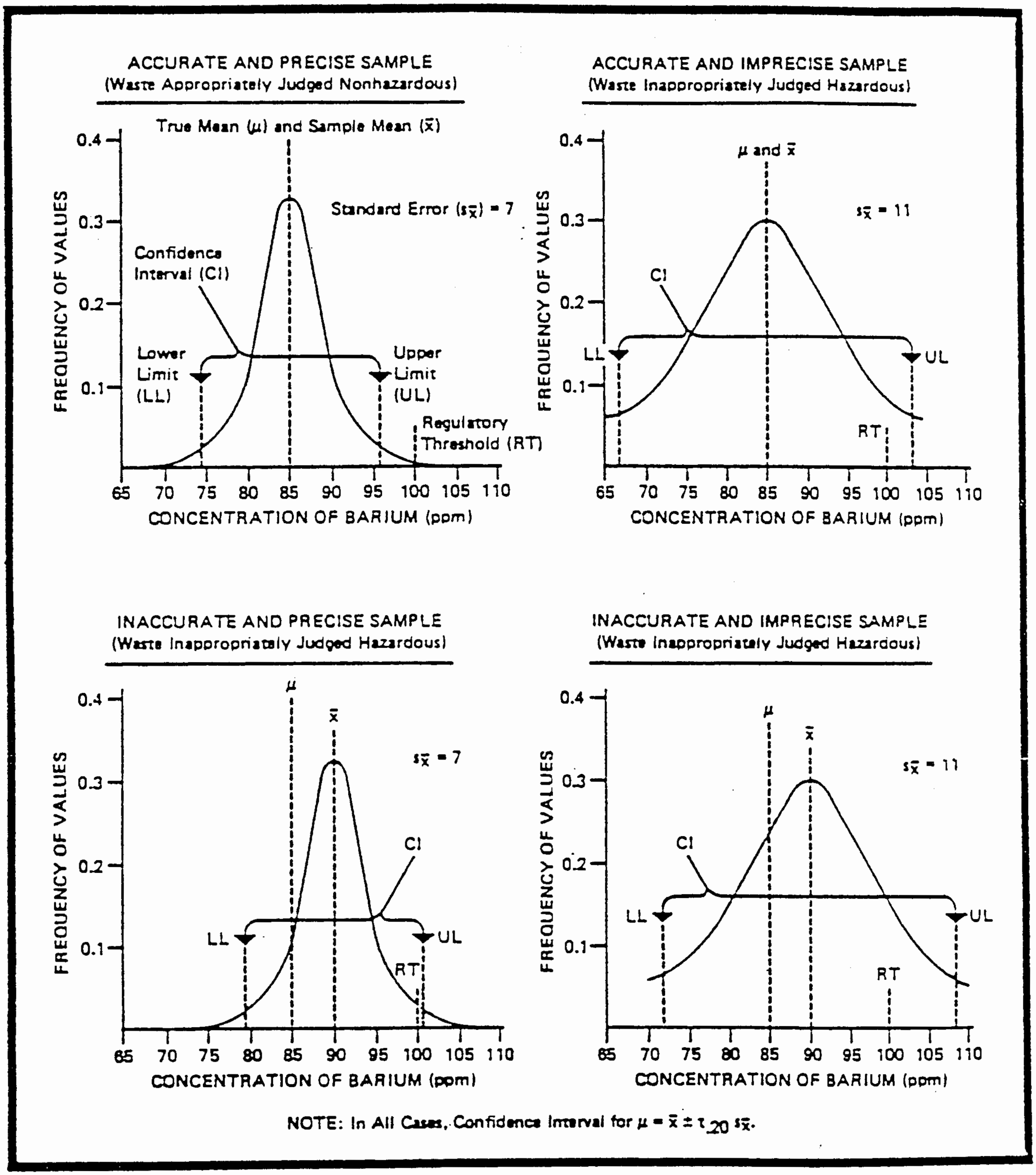
It is now apparent that a judgment must be made as to the degree of sampling accuracy and precision that is required to estimate reliably the chemical characteristics of a solid waste for the purpose of comparing those characteristics with applicable regulatory thresholds. Generally, high accuracy and high precision are required if one or more chemical contaminants of a solid waste are present at a concentration that is close to the applicable regulatory threshold. Alternatively, relatively low accuracy and low precision can be tolerated if the contaminants of concern occur at levels far below or far above their applicable thresholds. However, a word of caution is in order. Low sampling precision is often associated with considerable savings in analytical, as well as sampling, costs and is clearly recognizable even in the simplest of statistical tests. On the other hand, low sampling accuracy may not entail cost savings and is always obscured in statistical tests (i.e., it cannot be evaluated). Therefore, although it is desirable to design sampling plans for solid wastes to achieve only the minimally required precision (at least two samples of a material are required for any estimate of precision), it is prudent to design the plans to attain the greatest possible accuracy.

The roles that inaccurate and imprecise sampling can play in causing a solid waste to be inappropriately judged hazardous are illustrated in Figure 9-1. When evaluating Figure 9-1, several points are worthy of consideration. Although a sampling plan for a solid waste generates a mean concentration ($\bar{x}$) and standard deviation (s, a measure of the extent to which individual sample concentrations are dispersed around $\bar{x}$) for each chemical contaminant of concern, it is not the variation of individual sample concentrations that is of ultimate concern, but rather the variation that characterizes $\bar{x}$ itself. That measure of dispersion is termed the standard deviation of the mean (also, the standard error of the mean or standard error) and is designated as $s_{\bar{x}}$. Those two sample values, $\bar{x}$ and $s_{\bar{x}}$, are used to estimate the interval (range) within which the true mean (μ) of the chemical concentration probably occurs, under the assumption that the individual concentrations exhibit a normal (bell-shaped) distribution. For the purposes of evaluating solid wastes, the probability level (confidence interval) of 80% has been selected. That is, for each chemical contaminant of concern, a confidence interval (CI) is described within which μ occurs if the sample is representative, which is expected of about 80 out of 100 samples. The upper limit of the 80% CI is then compared with the appropriate regulatory threshold. If the upper limit is less than the threshold, the chemical contaminant is not considered to be present in the waste at a hazardous level; otherwise, the opposite conclusion is drawn. One last point merits explanation. Even if the upper limit of an estimated 80% CI is only slightly less than the regulatory threshold (the worst case of chemical contamination that would be judged acceptable), there is only a 10% (not 20%) chance that the threshold is equaled or exceeded. That is because values of a normally distributed contaminant that are outside the limits of an 80% CI are equally distributed between the left (lower) and right (upper) tails of the normal curve. Consequently, the CI employed to evaluate solid wastes is, for all practical purposes, a 90% interval.

9.1.1.2 Fundamental Statistical Concepts

The concepts of sampling accuracy and precision have already been introduced, along with some measurements of central tendency ($\bar{x}$) and dispersion (standard deviation [s] and $s_{\bar{x}}$) for concentrations of a chemical contaminant of a solid waste. The utility of $\bar{x}$ and $s_{\bar{x}}$ in estimating a confidence interval that probably contains the true mean (μ) concentration of a contaminant has also been described. However, it was noted that the validity of that estimate is predicated upon the assumption that individual concentrations of the contaminant exhibit a normal distribution.

Statistical techniques for obtaining accurate and precise samples are relatively simple and easy to implement. Sampling accuracy is usually achieved by some form of random sampling. In random sampling, every unit in the population (e.g., every location in a lagoon used to store a solid waste) has a theoretically equal chance of being sampled and measured. Consequently, statistics generated by the sample (e.g., $\bar{x}$ and, to a lesser degree, $s_{\bar{x}}$) are unbiased (accurate) estimators of true population parameters (e.g., the CI for μ). In other words, the sample is representative of the population. One of the commonest methods of selecting a random sample is to divide the



NOTE: In All Cases, Confidence Interval for $\mu = \bar{x} \pm t_{.20}\, s_{\bar{x}}$.

Figure 9-1.—Important theoretical relationships between sampling accuracy and precision and regulatory objectives for a chemical contaminant of a solid waste that occurs at a concentration marginally less than its regulatory threshold. In this example, barium is the chemical contaminant. The true mean concentration of barium in the elutriate of the EP toxicity test is 85 ppm, as compared to a regulatory threshold of 100 ppm. The upper limit of the confidence interval for the true mean concentration, which is estimated from the sample mean and standard error, must be less than the regulatory threshold if barium is judged to be present in the waste at a nonhazardous level.

population by an imaginary grid, assign a series of consecutive numbers to the units of the grid, and select the numbers (units) to be sampled through the use of a random-numbers table (such a table can be found in any text on basic statistics). It is important to emphasize that a haphazardly selected sample is not a suitable substitute for a randomly selected sample. That is because there is no assurance that a person performing undisciplined sampling will not consciously or subconsciously favor the selection of certain units of the population, thus causing the sample to be unrepresentative of the population.

Sampling precision is most commonly achieved by taking an appropriate number of samples from the population. As can be observed from the equation for calculating $s_{\bar{x}}$, precision increases ($s_{\bar{x}}$ and the CI for μ decrease) as the number of samples (n) increases, although not in a 1:1 ratio. For example, a 100% increase in the number of samples from two to four causes the CI to decrease by approximately 62% (about 31% of that decrease is associated with the critical upper tail of the normal curve). However, another 100% increase in sampling effort from four to eight samples results in only an additional 39% decrease in the CI. Another technique for increasing sampling precision is to maximize the physical size (weight or volume) of the samples that are collected. That has the effect of minimizing between-sample variation and, consequently, decreasing $s_{\bar{x}}$. Increasing the number or size of samples taken from a population, in addition to increasing sampling precision, has the secondary effect of increasing sampling accuracy.

In summary, reliable information concerning the chemical properties of a solid waste is needed for the purpose of comparing those properties with applicable regulatory thresholds. If chemical information is to be considered reliable, it must be accurate and sufficiently precise. Accuracy is usually achieved by incorporating some form of randomness into the selection process for the samples that generate the chemical information. Sufficient precision is most often obtained by selecting an appropriate number of samples.

There are a few ramifications of the above-described concepts that merit elaboration. If, for example, as in the case of semiconductor etching solutions, each batch of a waste is completely homogeneous with regard to the chemical properties of concern and that chemical homogeneity is constant (uniform) over time (from batch to batch), a single sample collected from the waste at an arbitrary location and time would theoretically generate an accurate and precise estimate of the chemical properties. However, most wastes are heterogeneous in terms of their chemical properties. If a batch of waste is randomly heterogeneous with regard to its chemical characteristics and that random chemical heterogeneity remains constant from batch to batch, accuracy and appropriate precision can usually be achieved by simple random sampling. In that type of sampling, all units in the population (essentially all locations or points in all batches of waste from which a sample could be collected) are identified, and a suitable number of samples is randomly selected from the population. More complex stratified random sampling is appropriate if a batch of waste is known to be nonrandomly heterogeneous in terms of its chemical properties and/or nonrandom chemical heterogeneity is known to exist from batch to batch. In such cases, the population is stratified to isolate the known sources of nonrandom chemical heterogeneity.

After stratification, which may occur over space (locations or points in a batch of waste) and/or time (each batch of waste), the units in each stratum are numerically identified, and a simple random sample is taken from each stratum. As previously intimated, both simple and stratified random sampling generate accurate estimates of the chemical properties of a solid waste. The advantage of stratified random sampling over simple random sampling is that, for a given number of samples and a given sample size, the former technique often results in a more precise estimate of chemical properties of a waste (a lower value of $s_{\bar{x}}$) than the latter technique. However, greater precision is likely to be realized only if a waste exhibits substantial nonrandom chemical heterogeneity and stratification efficiently "divides" the waste into strata that exhibit maximum between-strata variability and minimum within-strata variability. If that does not occur, stratified random sampling can produce results that are less precise than in the case of simple random sampling. Therefore, it is reasonable to select stratified random sampling over simple random sampling only if the distribution of chemical contaminants in a waste is sufficiently known to allow an intelligent identification of strata and at least two or three samples can be collected in each stratum. If a strategy employing stratified random sampling is selected, a decision must be made regarding the allocation of sampling effort among strata. When chemical variation within each stratum can be estimated with a great degree of detail, samples should be optimally allocated among strata, i.e., the number of samples collected from each stratum should be directly proportional to the chemical variation encountered in the stratum. When detailed information concerning chemical variability within strata is not available, samples should be proportionally allocated among strata, i.e., sampling effort in each stratum should be directly proportional to the size of the stratum.

Simple random sampling and stratified random sampling are types of probability sampling, which, because of a reliance upon mathematical and statistical theories, allows an evaluation of the effectiveness of sampling procedures. Another type of probability sampling is systematic random sampling, in which the first unit to be collected from a population is randomly selected, but all subsequent units are taken at fixed space or time intervals. An example of systematic random sampling is the sampling of a waste lagoon along a transect in which the first sampling point on the transect is 1 m from a randomly selected location on the shore and subsequent sampling points are located at 2-m intervals along the transect. The advantages of systematic random sampling over simple random sampling and stratified random sampling are the ease with which samples are identified and collected (the selection of the first sampling unit determines the remainder of the units) and, sometimes, an increase in precision. In certain cases, for example, systematic random sampling might be expected to be a little more precise than stratified random sampling with one unit per stratum because samples are distributed more evenly over the population. As will be demonstrated shortly, disadvantages of systematic random sampling are the poor accuracy and precision that can occur when unrecognized trends or cycles occur in the population. For those reasons, systematic random sampling is recommended only when a population is essentially random or contains at most a modest stratification. In such cases, systematic random sampling would be employed for the sake of convenience, with little expectation of an increase in precision over other random sampling techniques.

Probability sampling is contrasted with authoritative sampling, in which an individual who is well acquainted with the solid waste to be sampled selects a sample without regard to randomization. The validity of data gathered in that manner is totally dependent on the knowledge of the sampler and, although valid data can sometimes be obtained, authoritative sampling is not recommended for the chemical characterization of most wastes.

It may now be useful to offer a generalization regarding the four sampling strategies that have been identified for solid wastes. If little or no information is available concerning the distribution of chemical contaminants of a waste, simple random sampling is the most appropriate sampling strategy. As more information is accumulated for the contaminants of concern, greater consideration can be given (in order of the additional information required) to stratified random sampling, systematic random sampling, and, perhaps, authoritative sampling.

The validity of a CI for the true mean (μ) concentration of a chemical contaminant of a solid waste is, as previously noted, based on the assumption that individual concentrations of the contaminant exhibit a normal distribution. This is true regardless of the strategy that is employed to sample the waste. Although there are computational procedures for evaluating the correctness of the assumption of normality, those procedures are meaningful only if a large number of samples are collected from a waste. Because sampling plans for most solid wastes entail just a few samples, one can do little more than superficially examine resulting data for obvious departures from normality (this can be done by simple graphical methods), keeping in mind that even if individual measurements of a chemical contaminant of a waste exhibit a considerably abnormal distribution, such abnormality is not likely to be the case for sample means, which are our primary concern. One can also compare the mean of the sample ($\bar{x}$) with the variance of the sample (s^2). In a normally distributed population, $\bar{x}$ would be expected to be greater than s^2 (assuming that the number of samples [n] is reasonably large). If that is not the case, the chemical contaminant of concern may be characterized by a Poisson distribution ($\bar{x}$ is approximately equal to s^2) or a negative binomial distribution ($\bar{x}$ is less than s^2). In the former circumstance, normality can often be achieved by transforming data according to the square root transformation. In the latter circumstance, normality may be realized through use of the arcsine transformation. If either transformation is required, all subsequent statistical evaluations must be performed on the transformed scale.

Finally, it is necessary to address the appropriate number of samples to be employed in the chemical characterization of a solid waste. As has already been emphasized, the appropriate number of samples is the least number of samples required to generate a sufficiently precise estimate of the true mean (μ) concentration of a chemical contaminant of a waste. From the perspective of most waste producers, that means the minimal number of samples needed to demonstrate that the upper limit of the CI for μ is less than the applicable regulatory threshold (RT). The formula for estimating appropriate sampling effort (Table 9-1, Equation 8) indicates that increased sampling effort is generally justified as s^2 or the "$t_{.20}$" value (probable error rate) increases and as $\Delta(RT - \bar{x})$ decreases. In a well-designed sampling plan for a solid waste, an effort is made to estimate the values of $\bar{x}$ and s^2 before sampling is initiated. Such preliminary estimates, which may be derived from information pertaining to similar wastes, process engineering data, or limited analytical studies, are used to identify the approximate number of samples that must be collected from the waste. It is always prudent to collect a somewhat greater number of samples than indicated by preliminary estimates of $\bar{x}$ and s^2 since poor preliminary estimates of those statistics can result in an underestimate of the appropriate number of samples to collect. It is usually possible to process and store the extra samples appropriately until analysis of the initially identified samples is completed and it can be determined if analysis of the additional samples is warranted.

9.1.1.3 Basic Sampling Strategies

It is now appropriate to present general procedures for implementing the three previously introduced sampling strategies (simple random sampling, stratified random sampling, and systematic random sampling) and a hypothetical example of each sampling strategy. The hypothetical examples illustrate the statistical calculations that must be performed in most situations likely to be encountered by a waste producer and, also, provide some insight into the efficiency of the three sampling strategies in meeting regulatory objectives.

The following hypothetical conditions are assumed to exist for all three sampling strategies. First, barium, which has an RT of 100 ppm as measured in the EP elutriate test, is the only chemical contaminant of concern. Second, barium is discharged in particulate form to a waste lagoon and accumulates in the lagoon in the form of a sludge, which has built up to approximately the same thickness throughout the lagoon. Third, concentrations of barium are relatively homogeneous along the vertical gradient (from the water-sludge interface to the sludge-lagoon interface), suggesting a highly controlled manufacturing process (little between-batch variation in barium concentrations). Fourth, the physical size of sludge samples collected from the lagoon is as large as practical, and barium concentrations derived from those samples are normally distributed (note that we do not refer to barium levels in the samples of sludge because barium measurements are actually made on the elutriate from EP toxicity tests performed with the samples). Last, a preliminary study of barium levels in the elutriate of four EP toxicity tests conducted with sludge collected from the lagoon several years ago identified values of 86 and 90 ppm for material collected near the outfall (in the upper third) of the lagoon and values of 98 and 104 ppm for material obtained from the far end (the lower two-thirds) of the lagoon.

For all sampling strategies, it is important to remember that barium will be determined to be present in the sludge at a hazardous level if the upper limit of the CI for μ is equal to or greater than the RT of 100 ppm (Table 9-1, Equations 6 and 7).

9.1.1.3.1 Simple Random Sampling

Simple random sampling (Box 1) is performed by general procedures in which preliminary estimates of $\bar{x}$ and s^2, as well as a knowledge of the RT, for each chemical contaminant of a solid waste that is of concern are employed to estimate the appropriate number of samples (n) to be collected from the waste. That number of samples is subsequently analyzed for each chemical contaminant of concern. The resulting analytical data are then used to conclude definitively that each contaminant is or is not present in the waste at a hazardous concentration or, alternatively, to suggest a reiterative process, involving increased sampling effort, through which the presence or absence of hazard can be definitively determined.

In the hypothetical example for simple random sampling (Box 1), preliminary estimates of $\bar{x}$ and s^2 indicated a sampling effort consisting of six samples. That number of samples was collected and initially analyzed, generating analytical data somewhat different from the preliminary data (s^2 was substantially greater than was preliminarily estimated). Consequently, the upper limit of the CI was unexpectedly greater than the applicable RT, resulting in a tentative conclusion of hazard. However, a reestimation of appropriate sampling effort, based on statistics derived from the six samples, suggested that such a conclusion might be reversed through the collection and analysis of just one more sample. Fortunately, a resampling effort was not required because of the foresight of the waste producer in obtaining three extra samples during the initial sampling effort, which, because of their influence in decreasing the final values of $\bar{x}$, $s_{\bar{x}}$, $t_{.20}$, and, consequently, the upper limit of the CI -- values obtained from all nine samples -- resulted in a definitive conclusion of nonhazard.

9.1.1.3.2 Stratified Random Sampling

Stratified random sampling (Box 2) is conducted by general procedures that are similar to the procedures described for simple random sampling. The only difference is that, in stratified random sampling, values of $\bar{x}$ and s^2 are calculated for each stratum in the population and then integrated into overall estimates of those statistics, the standard deviation (s), $s_{\bar{x}}$, and the appropriate number of samples (n) for all strata.

The hypothetical example for stratified random sampling (Box 2) is based on the same nine sludge samples previously identified in the example of simple random sampling (Box 1) so that the relative efficiencies of the two sampling strategies can be fully compared. The efficiency generated through the process of stratification is first evident in the preliminary estimate of n (Step 2 in Boxes 1 and 2), which is six for simple random sampling and four for stratified random sampling. (The lesser value for stratified sampling is the consequence of a dramatic decrease in s^2, which more than compensated for a modest increase in Δ.) The most relevant indication of sampling efficiency is the value of $s_{\bar{x}}$, which is directly employed to calculate the CI. In the case of simple random sampling, $s_{\bar{x}}$ is calculated as 2.58 (Step 9 in Box 1), and, for stratified random sampling, $s_{\bar{x}}$ is determined to be 2.35 (Steps 5 and 7 in Box 2). Consequently, the gain in efficiency attributable to stratification is approximately 9% (0.23/2.58).

APPENDIX D

Cyanide Destruction Systems, Inc. Information

ORTECH
INTERNATIONAL
2395 Speakman Drive
Mississauga, Ontario L5K 1B3
(416) 822-4111 (800) 268-5390
Telefax (416) 823-1446

January 4, 1989.

Mr. Jose Bou,
Martin Marietta Corpoation,
Aluminum Properties,
6801 Rockledge,
Bethesda, Maryland 20817
U.S.A.

Dear Mr. Bou:

Enclosed please find the results of the hydrolysis experiments on the supplied wastes. The results look very encouraging for using hydrolysis, with excellent destruction during all the runs. If you have any questions regarding this report or further testing, please do not hesitate to contact me.

Our invoice for $2,000 is enclosed.

Yours truly,

Peter Top

Peter Top
Waste Treatment Technology
Energy & Environmental Engineering Division

PT/id
enc.

JAN 4 1989

January 4, 1989.

Martin Marietta Corporation,
Aluminum Properties,
6801 Rockledge,
Bethesda, Maryland 20817
U.S.A.

Report No.	48-25078 (88-48-WTS-036)
Identification	Acceptance Letter
Specifications of Order	Cyanide Hydrolysis Experiments

Two cyanide waste samples were received from Martin Marietta Corporation, labelled "Hard Pitch Sample" (HP), and "Waste Pitch Sample" (WP). A 1,000 mL aliquot of WP sample was placed in the 2 litre hydrolysis unit. The temperature was set for 475°F and the unit was stirred at 400 rpm. After approximately 30 minutes, the set temperature was reached, and the first sample was taken (i.e. t = 0 mins). Samples were also taken at 3, 6, 10 and 30 minutes. The feed and samples were tested for total cyanide and the 0, 3 and 6 minute samples were analyzed for free cyanide.

The HP sample was hydrolyzed according to the above procedure, and the results are given in Table 1.

Insufficient sample was available to specifically determine some of the free cyanide levels and, for these, "less than" values are given.

Significant destruction of the cyanide was achieved during the first sample period (i.e. t = 0 mins); 99.9% for the WP sample and 92.3% for the HP sample. Therefore, rather than perform two runs at 450°F and 425°F, as specified in the original quotation, the second experiment was

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ORTECH Corporation

performed at a much lower temperature (350°F) and for a longer time (120 mins). To evaluate the hydrolysis of the mixed wastes, the HP and WP samples were mixed 50/50 by volume. Samples were taken at 0, 20, 60 and 120 minutes and analyzed for Total and Free Cyanide. The results are given in Table 2.

The free cyanide concentrations for the 60 minute sample was not analyzed because of insufficient sample.

Peter Top
Waste Treatment Technology
Energy & Environmental Engineering Division

Approved by:

Glenn Vicevic
Manager, Waste Treatment Technology
Energy & Environmental Engineering Division

PT/id

TABLE 1 – Run 1 Cyanide Concentrations

Time (mins)	Total CN^- (mg/L)	Free CN^- (mg/L)
WP Feed	755	n.a.
0	1.0	0.04
3	0.57	n.a.
6	0.14	<0.2
10	0.13	n.a.
30	0.09	<0.2
HP Feed	19.4	n.a.
0	1.5	<0.01
3	0.19	n.a.
6	0.16	<0.05
10	0.16	n.a.
30	0.15	<0.05

TABLE 2 – Run 2 Cyanide Concentration

Time (mins)	Total CN^- (mg/L)	Free CN^- (mg/L)
Feed	387*	n.a.
0	0.178	0.152
20	0.0125	0.0108
60	0.045	i.s.
120	0.038	<0.00006

n.a. – not analyzed
i.s. – insufficient sample
* – calculated average feed concentration

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January 12, 1989.

Ms. Loretta Gabrowski,
Martin Marietta Corporation,
3313 West Second,
The Dalles, Oregon 97058
U.S.A.

Dear Ms. Gabrowski:

Enclosed please find the cyanide analytical procedures you requested. These are the methods used for the cyanide analysis; the results of which were reported to you in Report No. 48-25078 (88-48-WTS-036).

For determination of Total Cyanides, Method A (Sections 12 to 18) is used, and Method C (Sections 26 to 32) is used for determination of Free Cyanide.

The reference for these procedures is the 1988 Annual Book of ASTM Standards, Volume 11.02, ASTM, Philadelphia, PA, U.S.A..

I hope this information is of help to you. If you have any further questions, please do not hesitate to call me.

Yours truly,

Peter Top
Waste Treatment Technology
Energy & Environmental Engineering Division

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enc.

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JAN 27 1989

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ORTECH Corporation

JAN 17 1989

Designation: D 2036 – 87

Test Methods for Cyanides in Water[1]

This standard is issued under the fixed designation D 2036; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 These test methods cover the determination of cyanides in water. The following test methods are included:

	Sections
Test Method A—Total Cyanides after Distillation	12 to 18
Test Method B—Cyanides Amenable to Chlorination[2] by Difference	19 to 25
Test Method C—Weak Acid Dissociable Cyanides	26 to 32
Test Method D—Cyanides Amenable to Chlorination without Distillation (Short-cut method)	33 to 39

1.2 Cyanogen halides may be determined separately.

NOTE 1—Cyanogen chloride is the most common of the cyanogen halide complexes as it is a reaction product and is usually present when chlorinating cyanide-containing industrial waste water. For the presence or absence of CNCl the spot test method given in Annex A1 can be used.

1.3 These test methods do not distinguish between cyanide ions and metallocyanide compounds and complexes. Furthermore, they do not detect the cyanates.

NOTE 2—The cyanate complexes are decomposed when the sample is acidified in the distillation procedure.

1.4 The cyanide in cyanocomplexes of gold, platinum, cobalt and some other transition metals is not completely recovered by these test methods.

1.5 Only a few organo-cyanide complexes are recovered, and those only to a minor extent.

1.6 Part or all of these test methods have been used successfully with reagent water and various waste waters. It is the user's responsibility to assure the validity of the test method for the water matrix being tested.

1.7 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* Specific hazard statements are given in 8.8, Note 4, 8.20, Section 9, and 11.2.

2. Referenced Documents

2.1 *ASTM Standards:*

D 1129 Definitions of Terms Relating to Water[3]

D 1193 Specification for Reagent Water[3]

D 3370 Practice for Sampling Water[3]

D 4210 Practice for Intralaboratory Quality Control Procedures and a Discussion on Reporting Low-Level Data[3]

E 60 Practice for Photometric Spectrophotometric Methods for Chemical Analysis of Metals[4]

E 275 Practice for Describing and Measuring Performance of Ultraviolet, Visible, and Near Infrared Spectrophotometers[5]

3. Definitions

3.1 For definitions of terms used in these test methods, refer to Definitions D 1129.

4. Summary of Test Methods

4.1 The cyanide as hydrocyanic acid (HCN) is released from compounds by means of reflux distillation and absorbed in sodium hydroxide solution. The conditions used for the distillation distinguish the type of cyanide. The sodium cyanide in the absorbing solution can be determined colorimetrically, by titration or by selective ion electrode.

4.2 Test Method A, Total Cyanide, is based on the decomposition of nearly all cyanides in the presence of strong acid, magnesium chloride catalyst, and heat during a 1-h reflux distillation.

4.3 Test Method B, Cyanide Amenable to Chlorination, is based on chlorinating a portion of the sample under controlled conditions followed by the determination of total cyanide in both the original and chlorinated samples. Cyanides amenable to chlorination are calculated by difference.

4.3.1 This test method can be affected by compounds that are converted during chlorination to color-producing compounds or react with the reagents used, and cause interference in the procedure employed to determine cyanide in the absorption solution.

4.4 Test Method C, Weak Acid Dissociable Cyanides, is based on the decomposition of cyanides in the presence of weak acid, zinc acetate and heat during a 1-h reflux distillation.

4.5 Test Method D, Cyanide Amenable to Chlorination without Distillation, is a direct colorimetric procedure.

4.6 The minimum concentration of cyanide in the absorption solution that can be accurately determined colorimetrically is 0.005 mg/L, by titration 0.4 mg/L and by selective ion electrode 0.05 mg/L. Pretreatment including distillation tends to increase these concentrations to a degree

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[1] These test methods are under the jurisdiction of ASTM Committee D-19 on Water and are the direct responsibility of Subcommittee D 19.06 on Methods for Analysis for Organic Substances in Water.

Current edition approved May 29, 1987. Published July 1987. Originally published as D 2036 – 64 T. Last previous edition D 2036 – $82^{\epsilon 1}$.

[2] For an explanation of the term cyanides amenable to alkaline chlorination, see Lancy, L. E. and Zabban, W., "Analytical Methods and Instrumentation for Determining Cyanogen Compounds," *Papers on Industrial Water and Industrial Waste Water, ASTM STP 337*, 1962, pp. 32–45.

[3] *Annual Book of ASTM Standards*, Vol 11.01.

[4] *Annual Book of ASTM Standards*, Vol 03.05.

[5] *Annual Book of ASTM Standards*, Vol 14.01.

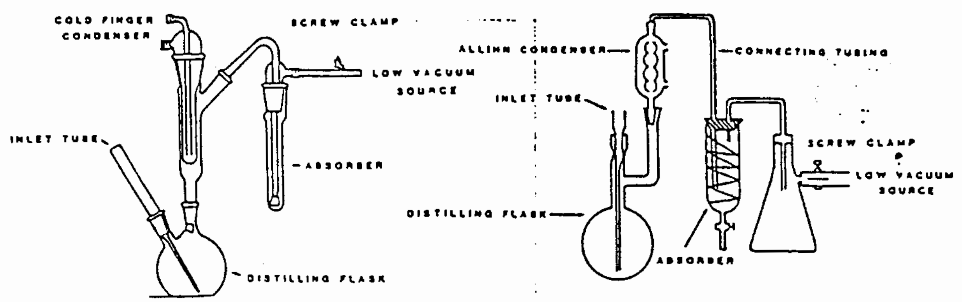

FIG. 1 Cyanide Distillation Apparatus

determined by the amount of manipulation required and the type of sample.

4.7 Round-robin data indicate the following minimum concentrations: colorimetric 0.03 mg/L; titration 1.0 mg/L; and selective ion electrode 0.03 mg/L.

5. Significance and Use

5.1 Cyanide is highly toxic. Regulations have been established to require the monitoring of cyanide in industrial and domestic wastes and in surface waters (Appendix X1).

5.2 Test Method D is applicable for natural water and clean metal finishing or heat treatment effluents. It may be used for process control in wastewater treatment facilities providing its applicability has been validated by Test Method B or C.

5.2 The spot test outlined in Annex A1 can be used to ct cyanide and thiocyanate in water or wastewater, and pproximate its concentration.

6. Interferences

6.1 Common interferences in the analysis for cyanide include oxidizing agents, sulfides, aldehydes, glucose, and other sugars, high concentration of carbonate, fatty acids, thiocyanate, and other sulfur containing compounds.

6.2 It is beyond the scope of these test methods to describe procedures for overcoming all of the possible interferences that may be encountered.

6.3 When the procedures must be revised to meet specific requirements, recovery data must be obtained by the addition of known amounts of cyanide to the sample.

7. Apparatus

7.1 *Distillation Apparatus*—The reaction vessel shall be a 1-L round bottom flask, with provision for an inlet tube and a condenser. The inlet tube shall be a funnel with an 8-mm diameter stem that extends to within 6 mm of the bottom of the flask. The condenser, which is recommended, shall be a reflux-type, cold finger or Allihn. The condenser shall be connected to a vacuum-type absorber which shall be in turn connected to a vacuum line which has provision for fine control. The flask shall be heated with an electric heater. Examples of the apparatus are shown in Fig. 1. Equivalent apparatus is acceptable provided cyanide recoveries of 100 ± are documented.

.2 *Spectrophotometer or Filter Photometer*, suitable for measurement in the region of 578 nm, using 1.0-, 2.0-, 5.0-, and 10.0-cm absorption cells. Filter photometers and photometric practices used in these test methods shall conform to Practice E 60. Spectrophotometers shall conform to Practice E 275.

7.3 *Selective Ion Meter*, or a pH meter with expanded millivolt scale equipped with a cyanide activity electrode and a reference electrode.

7.4 *Mixer*, magnetic, with a TFE-fluorocarbon-coated stirring bar.

7.5 *Buret*, Koch, micro, 2- or 5-mL, calibrated in 0.01 mL.

8. Reagents and Materials

8.1 *Purity of Reagents*—Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the American Chemical Society, where such specifications are available.[6] Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

8.2 *Purity of Water*—Unless otherwise indicated, references to water shall be understood to mean reagent water conforming to Type II grade of Specification D 1193.

8.3 *Acetic Acid* (1+9)—Mix 1 volume of glacial acetic acid with 9 volumes of water.

8.4 *Acetate Buffer*—Dissolve 410 g of sodium acetate trihydrate ($NaC_2H_3O_2 \cdot 3H_2O$) in 500 mL of water. Add glacial acetic acid to yield a solution pH of 4.5, approximately 500 mL.

8.5 *Barbituric Acid.*

8.6 *Calcium Hypochlorite Solution* (50 g/L)—Dissolve 5 g of calcium hypochlorite ($Ca(OCl)_2$) in 100 mL of water. Store the solution in an amber glass bottle in the dark. Prepare fresh monthly.

8.7 *Chloramine-T Solution* (10 g/L)—Dissolve 1.0 g of the white-colored, water-soluble grade powder chloramine-T in 100 mL of water. Prepare fresh weekly.

8.8 *Stock Cyanide Solution* (1 mL = 250 µg CN^-)—Dissolve 0.6258 g of potassium cyanide (KCN) (Warning-Precaution, See Note 3) in 40 mL of sodium hydroxide solution (40 g/L). Dilute to 1 L with water. Mix thoroughly.

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[6] "Reagent Chemicals, American Chemical Society Specifications," Am. Chemical Soc., Washington, DC. For suggestions on the testing of reagents not listed by the American Chemical Society, see "Reagent Chemicals and Standards," by Joseph Rosin, D. Van Nostrand Co., Inc., New York, NY, and the "United States Pharmacopeia."

standardize with standard silver nitrate solution following the titration procedure (see 16.2).

NOTE 3—Warning-Precaution — Because KCN is highly toxic, avoid contact or inhalation (see Section 9).

8.8.1 Standard Solution, *Cyanide I* (1 mL = 25 µg CN^-)—Dilute a calculated volume (approximately 100 mL) of KCN stock solution to 1 L with NaOH solution (1.6 g/L).

8.8.2 Standard Solution, *Cyanide II* (1 mL = 2.5 µg CN^-)—Dilute exactly 100 mL of KCN standard solution I to 1 L with NaOH solution (1.6 g/L).

8.8.3 Standard Solution, *Cyanide III* (1 mL = 0.25 µg CN^-)—Dilute exactly 100 mL of KCN standard solution II to 1 L with NaOH solution (1.6 g/L). Prepare fresh solution daily and protect from light.

8.8.4 Standard Solution, *Cyanide IV* (1 mL = 0.025 µg CN^-)—Dilute exactly 100 mL of KCN standard solution III to 1 L with NaOH solution (1.6 g/L). Prepare fresh solution daily and protect from light.

8.9 *Hydrogen Peroxide Solution*, 3 %—Dilute 10 mL of 30 % hydrogen peroxide (H_2O_2) to 100 mL. Prepare fresh weekly.

8.10 *Isooctane, Hexane, Chloroform* (solvent preference in the order named).

8.11 *Lead Acetate Test Paper.*

8.12 *Lead Carbonate* ($PbCO_3$), *Lead Acetate* ($Pb(C_2H_3O_2)_2 \cdot 3H_2O$), or *Lead Nitrate* ($Pb(NO_3)_2$)—Lead acetate and lead nitrate can be put in solution with water, if desired, at a suggested concentration of 50 g/L.

8.13 *Lime*, hydrate ($Ca(OH)_2$), powder.

8.14 *Magnesium Chloride Solution*—Dissolve 510 g of magnesium chloride ($MgCl_2 \cdot 6H_2O$) in water and dilute to 1 L.

8.15 *Potassium Iodide-Starch Test Paper.*

8.16 *Pyridine-Barbituric Acid Reagent*—Place 15 g of barbituric acid in a 250-mL volumetric flask and add just enough water to wash the sides of the flask and wet the barbituric acid. Add 75 mL of pyridine and mix. Add 15 mL of hydrochloric acid (sp gr 1.19), mix, and cool to room temperature. Dilute to volume with water and mix until all of the barbituric acid is dissolved. This solution is usable for about 6 months if stored in a cold dark place.

8.17 *Rhodanine Indicator Solution* (0.2 g/L)—Dissolve 0.02 g of (p-dimethylaminobenzylidene) in 100 mL of acetone.

8.18 Standard Solution, *Silver Nitrate* (0.01 *N*)—Dissolve 1.6987 g of silver nitrate ($AgNO_3$) in water and dilute to 1 L. Mix thoroughly. Store in a dark container.

8.19 *Sodium Arsenite Solution* (20 g/L)—Dissolve 2 g of $NaAsO_2$ in 100 mL of water.

NOTE 4—Precaution-Warning — This material has appeared on lists of suspected and known carcinogens. Avoid contact with skin.

8.20 *Sodium Hydroxide Solution* (40 g/L)—Dissolve 40 g of sodium hydroxide (NaOH) in water and dilute to 1 L with water.

8.21 *Sodium Hydroxide Solution* (1.6 g/L)—Dilute 40 mL of NaOH solution (40 g/L) to 1 L.

8.22 *Sulfamic Acid Solution* (133 g/L)—Dissolve 133 g of sulfamic acid in water and dilute to 1 L.

8.23 *Sodium Thiosulfate Solution* (500 g/L)—Dissolve 785 g of sodium thiosulfate ($Na_2S_2O_3 \cdot 5H_2O$) in water and dilute to 1 L.

8.24 *Sulfuric Acid* (1+1)—Slowly and carefully add 1 volume of sulfuric acid (H_2SO_4, sp gr 1.84) to 1 volume of water, stirring and cooling the solution during the addition.

8.25 *Zinc Acetate Solution* (100 g/L)—Dissolve 120 g of zinc acetate [$Zn(C_2H_3O_2)_2 \cdot 2H_2$] in 500 mL of water. Dilute to 1 L.

9. Safety Hazards

9.1 Because of the toxicity of cyanide, great care must be exercised in its handling. Acidification of cyanide solutions produces toxic hydrocyanic acid (HCN). All manipulations must be done in the hood so that any HCN gas that might escape is safely vented.

9.2 Many of the reagents used in these test methods are highly toxic. These reagents and their solutions must be disposed of properly.

10. Sample and Sample Preservation

10.1 Collect the sample in accordance with Practice D 3370.

10.2 Minimize exposure of samples to ultraviolet radiation that causes photodecomposition of some metal cyanide complexes and may significantly increase the concentration of free cyanide in the sample. It is recommended that all manipulations of the sample be performed in a well-ventilated hood under incandescent light.

10.3 Oxidizing agents (chlorine) will destroy the cyanide in storage. Sulfide can convert the cyanide to thiocyanate, especially at the pH of the stabilized sample. The presence of either oxidizing agents or sulfides should be determined before the addition of sodium hydroxide preservation or further analysis.

10.3.1 *Oxidizing Agents*—Test for the presence of chlorine by placing a drop of the sample on a strip of potassium iodide-starch test paper which has been previously moistened with the acetic acid solution. Darkening (bluish) of the test paper normally indicates the presence of chlorine. (Manganese dioxide, nitrosyl chloride, etc., if present, may also cause discoloration of the test paper.) Add sodium arsenite solution dropwise to the sample and retest. In the event that a bluish discoloration is still perceptible, repeat the sodium arsenite addition.

10.3.2 *Sulfide*—Test for the presence of sulfide by placing a drop of the sample on a strip of lead acetate test paper which has been previously moistened with the acetic acid solution. Darkening of the test paper indicates the presence of sulfide. The presence of sulfide can be assumed to indicate the absence of oxidizing agents in the sample. Sulfide is removed by treating the sample with small increments of powdered lead carbonate or with the dropwise addition of lead nitrate or lead acetate solution. Black lead sulfide precipitates in samples containing sulfide. Repeat the operation until no more lead sulfide forms, as indicated by testing the supernatant liquid with lead acetate test paper. Immediately filter through dry paper into a dry beaker and stabilize the sample according to 10.4 or 10.5.

10.4 If the sample cannot be analyzed immediately, stabilize it by the addition of sodium hydroxide (NaOH) lets to a pH of 12 to 12.5 and store it in a closed bottle ırk bottle if available) in a dark and cool environment.

10.5 Stabilize effluents high in carbonate (coal gassifica- n wastes, atmospheric emission scrub waters. etc.) by the of hydrated lime ($Ca(OH)_2$) with constant stirring to pH of 12 to 12.5. Allow to settle and decant sufficient lume of sample from the calcium carbonate and store as in .4.

. Elimination of Interferences

11.1 The following treatments are for the removal or luction of substances that can interfere in the various ethods. Care must be taken to keep time of pretreatment at ninimum to avoid loss of cyanide (see 9.1).

11.2 Fatty acids that distill and form soaps in the absorp- n solution can be removed by extraction. Acidify the mple with dilute (1+9) acetic acid to a pH 6 to 7, recaution: See Note 5). Extract with *iso*octane, hexane or loroform (preference in order named), with a solvent lume equal to 20 % of the sample volume. One extraction usually sufficient to reduce the fatty acids below the terference level. Avoid multiple extractions or a long ntact time at low pH in order to keep the loss of HCN to a inimum. When the extraction is complete, immediately ise the pH of the sample to 12 to 12.5 with NaOH solution.

NOTE 5: Precaution—Perform this operation in the hood and leave sample there until it is made alkaline after the extraction.

11.3 Aldehydes combine with cyanides to form cyanohy- ins which can hydrolyze to acids under distillation condi- Hydrogen cyanide is not liberated and is not available ntitative determination in the absorption solution. ie formation of cyanohydrins also interferes in the direct lorimetric determination (Test Method D and spot test). entification and removal of aldehydes is described in ppendix X2.

11.3.1 Glucose and other sugars if present in the sample n also form cyanohydrins with cyanide at the pH of eservation.

11.4 Carbonate, in high concentration, can affect the stillation procedures by causing violent release of carbon oxide with excessive foaming when the acid is added, and lowering the pH of the absorption solution. Use of lcium hydroxide to preserve the sample (10.5) will elimi- ite these interferences.

11.5 Nitrite and nitrate in the sample can react under nditions of the distillation with other contaminants esent to form cyanides. The addition of an excess of lfamic acid to the sample prior to the addition of sulfuric id will eliminate this interference.

11.6 Thiocyanate and other sulfur containing compounds n decompose during distillation. Sulfur, hydrogen sulfide, lfur dioxide, etc., formed can be distilled into the absorp- on solution. The addition of lead ion to the absorption lution before distillation followed by filtration of the lution before the titration or the colorimetric procedure is ed will eliminate sulfur and sulfide interference. Absorbed lfur dioxide forms sodium sulfite which reacts with ine-T in the colorimetric determination. Test for the ce of chloramine-T by placing a drop of solution on a rip of potassium iodide test paper previously moistened with dilute acetic acid. If the test is negative, add chloramine-T until a positive test is obtained.

11.7 Thiocyanate in the presence of ferric ion is quantitatively determined by the colorimetric procedure. Test Method D outlines a procedure for masking any cyanide amenable to chlorination in order to determine thiocyanate by difference.

11.8 Substances which contribute color or turbidity interfere with Test Method D.

TEST METHOD A—TOTAL CYANIDES AFTER DISTILLATION

12. Scope

12.1 This test method covers the determination of cyanides in water, including the iron cyanide complexes (total cyanide).

12.2 The cyanide in some cyano complexes of transition metals, for example, cobalt, gold, platinum, etc., is not determined.

12.3 Either the titration, colorimetric or selective ion electrode procedure can be used to quantify the cyanide concentration.

12.4 This test method has been used successfully on reagent and surface water and coke plant, refinery, and sanitary waste waters. It is the user's responsibility to assure the validity of the test method for the water matrix being tested.

13. Interferences

13.1 All the chemical compounds as listed in Section 6, can interfere.

13.2 For the removal of these interferences, proceed as instructed in Sections 10 and 11.

14. Apparatus

14.1 The schematic arrangement of the distillation system is shown in Fig. 1.

14.2 For the required equipment, instructions, and parts, refer to Section 7.

15. Reagents and Materials

15.1 Refer to reagents and materials listed in Section 8.

16. Procedure

16.1 *Distillation Procedure:*

16.1.1 Set up the apparatus as shown in Fig. 1.

16.1.2 Add 10.0 mL of NaOH solution (40 g/L) to the absorber. Dilute with water to obtain an adequate depth of liquid. Do not use more than 225 mL of total volume in the absorber.

16.1.3 Attach the absorber to the vacuum and connect to the condenser.

16.1.4 Place 500 mL of the sample in the flask. If cyanide content is suspected to be more than 10 mg/L, use an aliquot so that no more than 5 mg of cyanide is in the distilling flask and dilute to 500 mL with water. Annex A1 describes a procedure for establishing the approximate cyanide content. Verify a negative reaction in the spot-plate technique by using 500 mL of the sample.

16.1.5 Connect the flask to the condenser.

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16.1.6 Turn on the vacuum and adjust the air flow to approximately 1 bubble per second entering the boiling flask through the air-inlet tube.

16.1.7 Add 20 mL of magnesium chloride solution (8.14) through the air inlet tube. If the sample contains nitrite or nitrate, add 15 mL of sulfamic acid solution (8.23).

16.1.8 Rinse the air-inlet tube with a few mL of water and allow the air flow to mix the content of the flask for approximately 3 min.

16.1.9 Carefully add 50 mL of H_2SO_4 solution (1+1) through the air-inlet tube.

Note 6—Precaution-Warning —Add slowly; heat is generated and foaming may occur.

16.1.10 Turn on the condenser cooling water. Heat the solution to boiling, taking care to prevent the solution from backing into the air-inlet tube.

16.1.11 Maintain the air flow as in 16.1.6.

16.1.12 Reflux for 1 h.

16.1.13 Turn off the heat, but maintain the air flow for at least an additional 15 min.

16.1.14 Quantitatively transfer the absorption solution into a 250-mL volumetric flask. Rinse absorber and its connecting tubes sparingly with water and add to the volumetric flask.

16.1.15 Dilute to volume with water and mix thoroughly.

16.1.16 Determine the concentration of cyanide in the absorption solution by one of the three procedures (16.2, 16.3, or 16.4).

16.2 *Titration Procedure:*

16.2.1 Place 100 mL of the absorption solution or an accurately measured aliquot diluted to 100 mL with NaOH solution (1.6 g/L) in a flask or beaker.

16.2.2 Add 0.5 mL of rhodanine indicator solution.

16.2.3 Titrate with standard silver nitrate solution (8.19) using a microburet to the first change from yellow to salmon pink.

16.2.4 Titrate a blank of 100 mL of NaOH solution (1.6 g/L) (8.22).

16.2.5 Record the results of the titration and calculate the cyanide concentration in the original samples according to instructions given in 17.1.

16.3 *Colorimetric Procedure:*

16.3.1 *Standardization:*

16.3.1.1 Prepare a series of cyanide standards based on the cell path which is used (Table 1). For this purpose use 50-mL glass-stoppered volumetric flasks or graduated cylinders.

16.3.1.2 Follow steps 16.3.2.2 through 16.3.2.6 of the procedure.

16.3.1.3 Calculate the absorption factor (17.2.1).

16.3.2 *Procedure:*

16.3.2.1 Pipet an aliquot of the absorption liquid, such that the concentration falls within the standardization range, into a 50-mL glass-stoppered volumetric flask or graduated cylinder.

16.3.2.2 Dilute to 40 mL with the NaOH solution (1.6 g/L).

16.3.2.3 Place 40 mL of NaOH solution (1.6 g/L) in a flask or cylinder for a blank. (Carry out the following steps of the procedure on the blank also.)

TABLE 1 Guide for Selection of Appropriate Cell Paths

Standard Solution No.	Millitres of Standard Solution	Final Concentration, µg CN/mL	Cell Length, cm		
	50 mL		1.0	5.0	10.0
IV	5.0	0.0025			X
IV	10.0	0.0050		X	X
IV	15.0	0.0075		X	X
IV	20.0	0.0100		X	X
IV	25.0	0.0125		X	X
IV	30.0	0.0150		X	X
IV	40.0	0.0200		X	
III	5.0	0.0250	X	X	
III	10.0	0.0500	X		
III	15.0	0.0750	X		
III	20.0	0.1000	X		
III	25.0	0.1250	X		
III	30.0	0.1500	X		
	0.0 (blank)		X	X	X

16.3.2.4 Add 1 mL of chloramine-T solution and 1 mL of acetate buffer, stopper, mix by inversion two or three times, and allow to stand for exactly 2 min.

16.3.2.5 Add 5 mL of pyridine-barbituric acid reagent, dilute to volume with water, mix thoroughly, and allow to stand exactly 8 min for color development.

16.3.2.6 Measure at the absorbance maximum at 578 nm. Measure absorbance (A) versus water.

16.3.2.7 Calculate the concentration of cyanide (mg CN/L) in the original sample following instructions given in 17.2.

16.4 *Selective Ion Electrode Procedure:*

16.4.1 Standardization:

16.4.1.1 Place 100-mL aliquots of standard solutions I, II, III, and IV in 250-mL beakers.

16.4.1.2 Follow 16.4.2.2 and 16.4.2.3.

16.4.1.3 Pipet 10- and 50-mL aliquots of standard solution IV into 250-mL beakers and dilute to 100 mL with NaOH solution (1.6 g/L).

16.4.1.4 Follow 16.4.2.2 and 16.4.2.3 of the procedure, starting with the lowest concentration.

16.4.1.5 Plot concentration values of the standardizing solutions on the logarithmic axis of semilogarithmic graph paper versus the potentials developed in the standardizing solutions on the linear axis. Follow manufacturer's instructions for direct-reading ion meters.

16.4.2 Procedure:

16.4.2.1 Place 100 mL of the absorption solution (or an accurately measured aliquot diluted to 100 mL with NaOH solution (1.6 g/L)) in a 250-mL beaker.

Note 7—Check a small portion of the solution for sulfide. If it is present, add either the $PbCO_3$ or $Pb(C_2H_3O_2)_2$ before inserting the electrodes.

16.4.2.2 Place the beaker on a magnetic stirrer, place a TFE-fluorocarbon-coated stirring bar in the solution, stir at a predetermined constant rate, and maintain constant temperature.

16.4.2.3 Insert the cyanide specific ion electrode and the reference electrode in the solution and measure potential or the cyanide concentration following the manufacturer's instructions.

16.4.2.4 Use values found from the graph or direct-reading ion meter to calculate the concentration in the

TABLE 2 Reagent Water (Test Method A)

Technique	Amount Added, mg/L	Amount Found, mg/L	n	S_r	Bias	% Bias	Statistical Significance, 95 % CL
	0.060	0.060	26	0.0101	0.000	0	No
Colorimetric	0.500	0.480	23	0.0258	−0.020	−4	No
	0.900	0.996	27	0.0669	0.096	11	Yes
Electrode	0.060	0.059	18	0.0086	−0.001	2	No
	0.500	0.459	18	0.0281	−0.041	−8	Yes
	0.900	0.911	18	0.0552	0.011	1	No
	5.00	5.07	18	0.297	0.07	1	No
Titrimetric	2.00	2.10	18	0.1267	0.10	5	Yes
	5.00	4.65	18	0.2199	−0.35	−7	Yes
	5.00	5.18	18	0.2612	0.18	4	Yes

original sample following the instructions given in 17.3.

17. Calculation

17.1 *Titration Procedure*—Calculate the concentration in milligrams of CN per litre in the original sample as follows:

$$\text{mg CN/L} = [(A - B) \times N\ \text{AgNO}_3 \times 0.052/\text{mL original sample}] \times (250/\text{mL aliquot used}) \times 10^6$$

where:

A = $AgNO_3$ solution to titrate sample, millilitres, and

B = $AgNO_3$ solution to titrate blank, millilitres.

17.2 *Colorimetric Procedure*—Calculate the concentration in milligrams of CN per litre as follows:

17.2.1 *Absorption Factor:*

$$\text{Factor, mg CN/L}/A = \frac{\dfrac{\text{mg CN/L}}{A - A_B}}{n}$$

ere:

= sample absorbance,

A_B = blank absorbance, and

n = number of solutions.

17.2.2 *Concentration:*

$$\begin{aligned}\text{mg CN/L} &= (A - A_B) \times \text{Factor} \\ &\quad \times \text{mL final dilution/mL original sample in final dilution} \\ &= \text{net } A \times \text{Factor} \\ &\quad \times (250/\text{mL original sample}) \\ &\quad \times (50/\text{aliquot from } 250)\end{aligned}$$

17.3 *Selective-Ion Electrode Procedure*—Calculate the concentration in mg/L as follows:

$$\text{mg CN/L} = \text{mg CN/L from graph or meter} \times (100/\text{aliquot}) \times (250/\text{mL original sample})$$

18. Precision and Bias[7]

18.1 *Precision:*

18.1.1 *Colorimetric*—Based on the results of nine operators in nine laboratories, the overall and single-operator precision of this test method within its designated range may be expressed as follows:

Reagent Water	$S_T = 0.06x + 0.003$
	$S_o = 0.11x + 0.010$
Selected Water Matrices	$S_T = 0.04x + 0.018$
	$S_o = 0.04x + 0.008$

18.1.2 *Electrode*—Based on the results of six operators in five laboratories, the overall and single-operator precision of this test method within its designated range may be expressed as follows:

Reagent Water	$S_T = 0.06x + 0.003$
	$S_o = 0.03x + 0.008$
Selected Water Matrices	$S_T = 0.05x + 0.008$
	$S_o = 0.03x + 0.012$

18.1.3 *Titrimetric*—Based on the results of six operators in three laboratories, the overall and single-operator precision of this test method within its designated range may be expressed as follows:

Reagent Water	$S_T = 0.04x + 0.038$
	$S_o = 0.01x + 0.018$
Selected Water Matrices	$S_T = 0.06x + 0.711$
	$S_o = 0.04x + 0.027$

18.1.4 where:

S_T = overall precision,

S_o = single operator precision, and

x = cyanide concentration, milligrams per litre.

18.1.5 Since this is an existing test method which has results from a minimum of three laboratories for a total of six operators, it does not require further collaborative testing in accordance with Practice D 2777.

18.2 *Bias*—Recoveries of known amounts of cyanide from Reagent Water Type II and selected water matrices are shown in Tables 2 and 3.

18.3 The precision and bias information given in this section may not apply to waters of untested matrices.

TEST METHOD B—CYANIDES AMENABLE TO CHLORINATION BY THE DIFFERENCE

19. Scope

19.1 This test method covers the determination of cyanides amenable to chlorination in water.

19.2 Iron cyanides are the most commonly encountered compounds not amenable to chlorination.

19.3 This test method has been used on reagent, surface, and industrial waste waters. It is the user's responsibility to assure the validity of the test method for the water matrix being tested.

20. Interferences

20.1 All the chemical compounds listed in Section 6, can interfere.

20.2 For the removal of these interferences, proceed as instructed in Sections 10 and 11.

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[7] Supporting data are available from ASTM Headquarters. Request RR: D 19 - 1131.

TABLE 3 Selected Water Matrices (Test Method A)

Technique	Amount Added, mg/L	Amount Found, mg/L	n	S_t	Bias	% Bias	Statistical Significance, 95 % CL
Colorimetric	0.060	0.060	25	0.0145	0.000	0	No
	0.500	0.489	26	0.0501	−0.011	−3	No
	0.900	0.959	24	0.0509	0.059	7	Yes
Electrode	0.060	0.058	14	0.0071	−0.002	−3	No
	0.500	0.468	21	0.0414	−0.032	−6	No
	0.900	0.922	19	0.0532	0.022	2	No
	5.00	5.13	20	0.2839	0.13	3	No
Titrimetric	2.00	2.80	18	0.8695	0.80	40	Yes
	5.00	5.29	18	1.1160	0.29	6	No
	5.00	5.75	18	0.9970	0.75	15	Yes

20.3 This test method can be affected by compounds that are converted during chlorination to volatile compounds which are collected in the absorption solution and can interfere in the final determination.

21. Apparatus

21.1 The schematic arrangement of the distillation system is shown in Fig. 1.

21.2 For the required equipment, instruments and parts, refer to Section 7.

22. Reagents and Materials

22.1 Refer to reagents and materials listed in Section 8.

23. Procedure

23.1 *Sample Preparation*—Divide the sample into two equal portions of 500 mL or less. Determine the total cyanide in one portion as indicated in 23.2. Place the other portion in a 1-L beaker and chlorinate as outlined in the following steps.

NOTE 8—Protect the solution in the beaker from ultraviolet radiation by wrapping the beaker with aluminum foil or black paper and cover with a wrapped watch glass during chlorination.

23.1.1 Place the beaker on a magnetic stirrer, insert a TFE fluorocarbon-coated stirring bar in the beaker, and start stirring.

23.1.2 If necessary, adjust the pH to between 11 and 12 with NaOH solution (40 g/L).

23.1.3 Add $Ca(OCl)_2$ solution (50 g/L) 3 drops at a time until there is an excess of chlorine indicated on a strip of potassium iodide-starch test paper previously moistened with acetic acid solution.

23.1.4 Maintain the pH and excess chlorine for 1 h while stirring. Add $Ca(OCl)_2$ solution or NaOH solution, or both, 2 drops at a time when necessary.

23.1.5 At the end of the hour remove any residual chlorine by the dropwise addition of $NaAsO_2$ solution (2 g/100 mL) or by adding 8 drops of H_2O_2 solution (3 %) followed by 4 drops of $Na_2S_2O_3$ solution (500 g/L). Test with potassium iodide-starch test paper.

23.2 Follow steps 16.1.1 through 16.1.16 of Test Method A for total cyanide.

24. Calculations

24.1 Calculate the total cyanide in each portion of the sample following the appropriate step, 17.1, 17.2, or 17.3.

24.2 Calculate the concentration of cyanide amenable to chlorination as follows:

$$\text{CN, mg/L} = G - H$$

where:

G = cyanide, determined in the unchlorinated portion of the sample, milligrams per litre, and

H = cyanide determined in the chlorinated portion of the sample, milligrams per litre.

25. Precision and Bias[7]

25.1 *Precision:*

25.1.1 *Colorimetric*—Based on the results of eight operators in seven laboratories, the overall and single-operator precision of this test method within its designated range may be expressed as follows:

Reagent Water	$S_T = 0.18x + 0.005$
	$S_o = 0.06x + 0.003$
Selected Water Matrices	$S_T = 0.20x + 0.009$
	$S_o = 0.05x + 0.005$

25.1.2 *Titrimetric*—Based on the results of six operators in three laboratories, the overall and single-operator precision of this test method within its designated range may be expressed as follows:

Reagent Water	$S_T = 0.01x + 0.439$
	$S_o = 0.241 - 0.03x$
Selected Water Matrices	$S_T = 0.12x + 0.378$
	$S_o = 0.209 - 0.01x$

25.1.3 where:

S_T = overall precision,

S_o = single operator precision, and

x = cyanide concentration, milligrams per litre.

25.2 *Bias*—Recoveries of known amounts of cyanide amenable to chlorination from reagent water Type II and selected water matrices were as shown in Tables 4 and 5.

25.3 The precision and bias information given in this section may not apply to waters of untested matrices.

TEST METHOD C—WEAK ACID DISSOCIABLE CYANIDES

26. Scope

26.1 This test method covers the determination of cyanide compounds and weak acid dissociable complexes in water.

26.2 The thiocyanate content of a sample usually does not cause interference.

26.3 Any of the three procedures, titration, colorimetric, or selective ion electrode, can be used to determine the cyanide content of the absorption solution. The lower limits

TABLE 4 Reagent Water (Test Method B)

Technique	Amount Added, mg/L	Amount Found, mg/L	n	S_t	Bias	% Bias	Statistical Significance, 95 % CL
Colorimetric	0.008	0.009	21	0.0033	0.001	13	No
	0.019	0.023	20	0.0070	0.004	21	Yes
	0.080	0.103	20	0.0304	0.018	23	Yes
	0.191	0.228	21	0.0428	0.037	19	Yes
Titrimetric	1.00	0.73	18	0.350	−0.27	−27	Yes
	1.00	0.81	18	0.551	−0.19	−19	No
	4.00	3.29	18	0.477	−0.71	−18	Yes

of detectability are the same as Test Method A—Total Cyanide.

26.4 This test method has been used successfully on reagent and surface water and coke plant, refinery and sanitary waste waters. It is the user's responsibility to assure the validity of the test method for the water matrix being tested.

27. Interferences

27.1 All the chemical compounds listed in Section 6 can interfere.

27.2 For the removal of these interferences proceed as instructed in Sections 10 and 11.

28. Apparatus

28.1 The schematic arrangement of the distillation system is shown in Fig. 1.

28.2 The required equipment, instruments, and parts are listed in Section 7.

Reagents and Materials

29.1 Refer to reagents and materials listed in Section 8.

29.2 *Methyl Red Indicator Solution.*

30. Procedure

30.1 *Distillation Procedure:*

30.1.1 Set up the apparatus as shown in Fig. 1.

30.1.2 Add 10.0 mL of NaOH solution (40 g/L) to the absorber. Dilute with water to obtain an adequate depth of liquid. Do not use more than 225 mL of total volume in the absorber.

30.1.3 Attach the absorber to the vacuum and connect to the condenser.

30.1.4 Place 500 mL of sample in the flask. If cyanide content is suspected to be more than 10 mg/L, use an aliquot so that no more than 5 mg of cyanide are in the flask, and dilute to 500 mL with water.

30.1.5 Connect the flask to the condenser.

30.1.6 Turn on the vacuum and adjust the air flow to approximately 1 bubble per second entering the boiling flask through the air-inlet tube.

30.1.7 Add 20 mL each of the acetate buffer and zinc acetate solutions through the air-inlet tube. Add 2 or 3 drops of methyl red indicator solution.

30.1.8 Rinse the air-inlet tube with a few mL of water and allow the air flow to mix the content of the flask. (If the solution is not pink, add acetic acid (1+9) dropwise through the air-inlet tube until there is a permanent color change.)

30.1.9 Turn on the condenser cooling water, heat the solution to boiling, taking care to prevent the solution from backing into the air inlet tube.

30.1.10 Maintain the air flow as in 30.1.6.

30.1.11 Reflux for 1 h.

30.1.12 Turn off the heat, but maintain the air flow for at least an additional 15 min.

30.1.13 Quantitatively transfer the absorption solution into a 250-mL volumetric flask. Rinse the absorber and its connecting tubes sparingly with water and add to volumetric flask.

30.1.14 Dilute to volume with water and mix thoroughly.

30.1.15 Determine the concentration of cyanide in the absorption solution by one of the three procedures 16.2, 16.3, or 16.4.

31. Calculation

31.1 Calculate the concentration of weak acid dissociable cyanide in the sample following the appropriate step, 17.1, 17.2, or 17.3.

32. Precision and Bias[7]

32.1 *Precision:*

32.1.1 *Colorimetric*—Based on the results of nine operators in nine laboratories, the overall and single-operator precision of this test method within its designated range may be expressed as follows:

Reagent Water $S_T = 0.09x + 0.010$
$S_o = 0.08x + 0.005$

TABLE 5 Selected Water Matrices (Test Method B)

Technique	Amount Added, mg/L	Amount Found, mg/L	n	S_t	Bias	% Bias	Statistical Significance, 95 % CL
Colorimetric	0.008	0.013	17	0.0077	0.005	63	Yes
	0.019	0.025	18	0.0121	0.006	32	Yes
	0.080	0.100	18	0.0372	0.020	25	Yes
	0.191	0.229	18	0.0503	0.038	20	Yes
Titrimetric	1.00	1.20	18	0.703	0.20	20	No
	1.00	1.10	18	0.328	0.10	10	No
	4.00	3.83	18	0.818	−0.17	−4	No

TABLE 6 Reagent Water (Test Method C)

Technique	Amount Added, mg/L	Amount Found, mg/L	n	S_r	Bias	% Bias	Statistical Significance, 95 % CL
Colorimetric	0.030	0.030	25	0.0089	0.000	0	No
	0.100	0.117	27	0.0251	0.017	17	Yes
	0.400	0.361	27	0.0400	−0.039	−10	Yes
Electrode	0.030	0.030	21	0.0059	0.000	0	No
	0.100	0.095	21	0.0163	−0.005	−5	No
	0.400	0.365	21	0.0316	−0.035	−9	No
	1.000	0.940	21	0.0903	−0.060	−6	No
Titrimetric	1.00	1.35	18	0.4348	0.35	35	Yes
	1.00	1.38	18	0.3688	0.38	38	Yes
	4.00	3.67	18	0.1830	−0.33	−8	No

Selected Water Matrices $S_T = 0.08x + 0.012$
$S_o = 0.05x + 0.008$

32.1.2 *Electrode*—Based on the results of six operators in five laboratories, the overall and single-operator precision of this test method within its designated range may be expressed as follows:

Reagent Water $S_T = 0.09x + 0.004$
$S_o = 0.02x - 0.009$
Selected Water Matrices $S_T = 0.08x + 0.005$
$S_o = 0.02x + 0.004$

32.1.3 *Titrimetric*—Based on the results of six operators in three laboratories, the overall and single-operator precision of this test method within its designated range may be expressed as follows:

Reagent Water $S_T = 0.532 - 0.10x$
$S_o = 0.151 - 0.01x$
Selected Water Matrices $S_T = 0.604 - 0.06x$
$S_o = 0.092 + 0.02x$

32.1.4 where:

S_T = overall precision,
S_o = single-operator precision, and
x = cyanide concentration, milligrams per litre.

32.2 *Bias*—Recoveries of known amounts of cyanide from reagent water Type II and selected water matrices were as shown in Tables 6 and 7.

32.3 The precision and bias information given in this section may not apply to waters of untested matrices.

TEST METHOD D—CYANIDES AMENABLE TO CHLORINATION WITHOUT DISTILLATION, SHORT-CUT METHOD

33. Scope

33.1 This test method covers the determination of free CN^- and CN^- complexes that are amenable to chlorination in water. The procedure does not measure cyanates nor iron cyanide complexes. It does, however, determine cyanogen chloride and thiocyanate.

33.2 Modification is outlined for its use in the presence of thiocyanate.

34. Interferences

34.1 All chemical compounds, as listed in Section 6, can interfere.

34.2 For removal of these interferences, proceed as instructed in Sections 10 and 11.

34.3 The thiocyanate ion which reacts with chloramine-T will give a positive error equivalent to its concentration as cyanide.

34.4 Color and turbidity can interfere.

34.4.1 When color or turbidity producing substances are present, it is recommended that Test Method B or C be used.

34.4.2 Color and turbidity can be extracted from some samples with chloroform without reduction of the pH.

34.4.3 It is possible with some samples to compensate for color and turbidity by determining the absorbance of a second sample solution to which all reagents except chloramine-T have been added.

34.5 Reducing compounds such as sulfites can interfere by preferentially reacting with chloramine-T.

34.6 The color intensity and absorption is affected by wide variations in the total dissolved solids content of the sample.

34.6.1 For samples containing high concentrations of dissolved solids, 3 000 to 10 000 mg/L, add 6 g of NaCl to each litre of NaOH solution (1.6 g/L) used to prepare the standards. For samples containing dissolved solids concentration greater than 10 000 mg/L, add sufficient NaCl to the NaOH solution to approximate the dissolved solids content.

TABLE 7 Selected Water Matrices (Test Method C)

Technique	Amount Added, mg/L	Amount Found, mg/L	n	S_r	Bias	% Bias	Statistical Significance, 95 % CL
Colorimetric	0.030	0.029	15	0.0062	0.001	3	No
	0.100	0.118	24	0.0312	0.018	18	Yes
	0.400	0.381	23	0.0389	−0.019	−5	Yes
Electrode	0.030	0.029	20	0.0048	−0.001	−3	No
	0.100	0.104	21	0.0125	0.004	4	No
	0.400	0.357	21	0.0372	−0.043	−11	No
	1.000	0.935	21	0.0739	−0.065	−7	No
Titrimetric	1.00	1.55	18	0.5466	0.55	55	Yes
	1.00	1.53	18	0.4625	0.53	53	Yes
	4.00	3.90	18	0.3513	−0.10	−3	No

TABLE 8 Reagent Water (Test Method D)

Amount Added, mg/L		Amount Found, mg/L	n	S_t	Bias	% Bias	Statistical Significance, 95 % CL
CN	SCN						
0.005		0.007	42	0.0049	0.002	40	Yes
0.027		0.036	41	0.0109	0.009	25	Yes
0.090		0.100	42	0.0167	0.010	11	Yes
0.090	0.080	0.080	39	0.0121	−0.010	11	Yes
0.270		0.276	42	0.0320	0.006	2	No

35. Apparatus

35.1 *Spectrophotometer or Filter Photometer*, suitable for measurements in the region of 578 nm, using 1.0-cm absorption cells. Filter photometers and photometric practices used in these test methods shall conform to Practice E 60. Spectrophotometers shall conform to Practice E 275.

35.2 *Water Bath*, capable of maintaining temperature at 27 ± 1°C.

36. Reagents and Materials

36.1 Refer to reagents and materials listed in Section 8.

36.2 *Pyridine-Barbituric Acid Reagent*—For the preparation of this reagent, refer to 8.17; however, for this test method, prepare a fresh solution weekly. Longer storage affects the results of the test.

36.3 *EDTA Solution* (18.5 g/L)—Dissolve 18.5 g of the disodium salt of ethylenediamine tetraacetic acid dihydrate in water and dilute to 1 L.

36.4 *Formaldehyde Solution* (10 %)—Dilute 27 mL of formaldehyde (37 %) to 100 mL.

36.5 *Hydrochloric Acid* (HCl) (sp gr 1.19) (1+9)—Slowly add 1 volume of concentrated HCl (sp gr 1.19) to 9 volumes water, stirring during the addition.

36.6 *Phosphate Buffer* Solution (138 g/L)—Dissolve 159 g of sodium dihydrogen phosphate ($NaH_2PO_4 \cdot H_2O$) in water, dilute to 1 L and refrigerate.

36.7 *Sodium Carbonate* (Na_2CO_3), anhydrous.

36.8 *Sodium Chloride* (NaCl), crystals.

37. Standardization

37.1 From the cyanide standard solutions, pipet a series of aliquots containing from 0.5 to 5.0 µg of cyanide in volumes not exceeding 20 mL into 50-mL volumetric flasks.

37.2 Dilute each solution to 20 mL with NaOH solution (1.6 g/L). Follow steps 38.3 through 38.7 of the procedure.

37.3 Calculate the absorption factor (17.2.1).

38. Procedure

38.1 Adjust the pH of a small volume of sample (50 mL) to between 11.4 and 11.8. If the addition of acid is needed, add a small amount (0.2 to 0.4 g) of sodium carbonate and stir to dissolve. Then add dropwise while stirring HCl solution (1+9). For raising the pH, use NaOH solution (40 g/L).

38.2 Pipet 20.0 mL of the sample into a 50-mL volumetric flask. If the cyanide concentration is greater than 0.3 mg/L, use a smaller aliquot and dilute to 20 mL with NaOH solution (1.6 g/L). Do not exceed the concentration limit of mg/L.

8.3 To ensure uniform color development, both in calibration and testing, it is necessary to maintain a uniform temperature. Immerse the flasks in a water bath held at 27 ± 1°C for 10 min before adding the reagent chemicals and keep the samples in the water bath until all the reagents have been added.

38.4 Add 4 mL of phosphate buffer and swirl to mix. Add one drop of EDTA solution, and mix.

38.5 Add 2 mL of chloramine-T solution and swirl to mix. Place 1 drop of sample on potassium iodide-starch test paper which has been previously moistened with acetate buffer solution. Repeat the chloramine-T addition if required. After exactly 3 min, add 5 mL of pyridine-barbituric acid reagent and swirl to mix.

38.6 Remove the samples from the water bath, dilute to volume and mix. Allow 8 min from the addition of the pyridine-barbituric acid reagent for color development.

38.7 Determine the absorbance at 578 nm in a 1.0-cm cell versus water.

38.8 Calculate the concentration of cyanide as milligrams per litre, in the original sample following instructions given in 17.2.

38.9 If the presence of thiocyanate is suspected, pipet a second 20-mL aliquot of pH-adjusted sample solution into a 50-mL volumetric flask. Add 3 drops of 10 % formaldehyde solution. Mix and allow to stand 10 min. Place in a water bath at 27 ± 1°C for an additional 10 min before the addition of the reagent chemicals and hold in the bath until all reagents have been added.

38.10 Continue with 38.4 through 38.7.

38.11 Calculate the concentration of cyanide, as milligrams per litre, in the original sample following instructions given in 17.2.

38.12 In the presence of thiocyanate, cyanide amenable to chlorination is equal to the difference between the concentration of cyanide obtained in 38.8 and that obtained in 38.11.

39. Precision and Bias[8]

39.1 *Precision:*

39.1.1 Based on the results of 14 operators in nine laboratories, the overall and single-operator precision of this test method within its designated range may be expressed as follows:

Reagent Water	$S_T = 0.10x + 0.006$ $S_o = 0.07x + 0.005$
Selected Water Matrices	$S_T = 0.11x + 0.007$ $S_o = 0.02x + 0.005$

39.1.2 where:

S_T = overall precision,

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[8] Supporting data are available from ASTM Headquarters. Request RR: D 19 – 1074.

TABLE 9 Selected Water Matrices (Test Method D)

Amount Added, mg/L		Amount Found, mg/L	n	S_t	Bias	% Bias	Statistical Significance, 95 % CI
CN	SCN						
0.005		0.003	40	0.0042	−0.002	40	Yes
0.027		0.026	42	0.0093	−0.001	4	No
0.090		0.087	42	0.0202	−0.003	3	No
0.090	0.080	0.068	37	0.0146	−0.022	24	Yes
0.270		0.245	41	0.0319	−0.025	9	Yes

S_o = single-operator precision, and

x = cyanide concentration, milligrams per litre.

39.2 *Bias*—Recoveries of known amounts of cyanide from reagent water Type II, seven creek waters, one diluted sewage (1+20) and one industrial waste water are as shown in Tables 8 and 9.

39.3 This precision and bias information may not apply to waters of untested matrices.

40. Quality Assurance/Quality Control

40.1 Before these test methods are applied to the analysis of samples of unknown concentration, the analyst should conduct six duplicate analyses of known and nearly the same concentration by the complete procedures to be used (distillation, chlorination, etc. plus colorimetric, electrode or titrimetric).

40.2 Calculate the standard deviation of the data (Practice D 4210). If the value obtained is within that given in the procedure for single operator precision, construct a preliminary control chart.

40.3 Continue to analyse samples in duplicate until at least 40 data points have been accumulated. Follow suggestions in Section 5, Practice D 4210.

40.4 Prepare a control chart with upper and lower limits from data obtained from analysing replicate standard solutions by the finish procedure selected (colorimetric, electrode or titrimetric) following Section 6, Practice D 4210.

40.5 To monitor precision and bias, a minimum of one standard and one sample of known value or a spiked sample should be analyzed each day.

40.6 Other quality assurance/quality control (QA/QC) portions of this test method have not been completely established at this time. Analysts performing this test method will be required to measure their performance against the performance level achieved by the laboratories that participated in the ASTM round-robin studies done on the test methods. These formal QA/QC procedures will be incorporated at such time as they have been officially accepted by the ASTM.

ANNEX

A1. SPOT TEST FOR SAMPLE SCREENING

A1.1 Scope

A1.1.1 The spot test procedure allows a quick screening of the sample to establish if more than 0.05 mg/L (ppm) of cyanides amenable to chlorination, cyanogen chloride, or thiocyanate are present in water, waste water, and saline water.

A1.1.2 The test may also be used to establish the presence and absence of cyanogen chloride by omitting the addition of chloramine-T.

A1.1.3 With the addition of formaldehyde to the sample, the amenable cyanide can be masked and under these conditions, the test is specific to thiocyanate. It is possible therefore to distinguish between the presence of cyanide and thiocyanate or possibly judge the relative levels of concentration for each.

A1.1.4 With practice or dilution, the test can be used to estimate the approximate concentration range of these compounds, judging from the color development and comparing it to similarly treated samples of known concentration.

A1.2 Interferences

A1.2.1 All the chemical compounds listed in Section 6, with the exception of the nitrites, may interfere. For their removal refer to Sections 10 and 11.

A1.2.2 The thiocyanate ion reacts in the same manner as the cyanide. The cyanide can be masked and then the test is specific for thiocyanate.

A1.2.3 The presence of large amounts of reducing substances in the sample interferes by consuming the chloramine-T added. Repeat the chloramine-T addition, if necessary.

A1.3 Apparatus

A1.3.1 *Spot Plate*, porcelain with 6 to 12 cavities preferred.

A1.4 Reagents

A1.4.1 Refer to reagents listed in Sections 8 and 36.

A1.4.2 *Formaldehyde*, 37 %, pharmaceutical grade.

A1.4.3 *Hydrochloric Acid* (1+9)—Mix 1 volume of concentrated (HCl (sp gr 1.19) with 9 volumes of water.

A1.4.4 *Sodium Carbonate*, anhydrous Na_2CO_3.

A1.5 Procedure

A1.5.1 If the solution subject to spot tests is alkaline in a pH range greater than 10, neutralize a 20 to 25-mL portion.

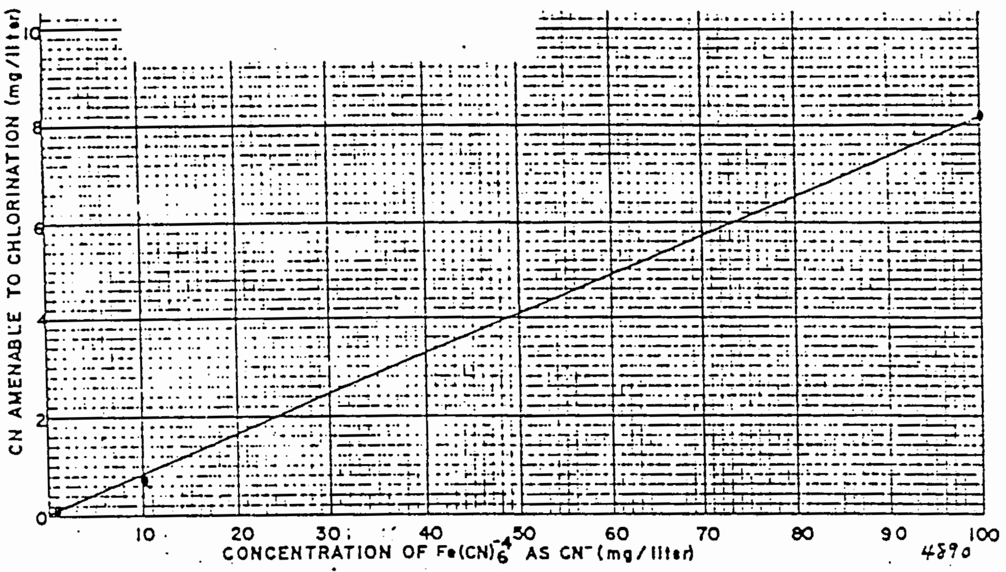

FIG. X1.1 Photodecomposition Rates for $Fe(CN)_6^{4}$ in Direct Sunlight, 20°C, pH 7, in Buffered Distilled Water, 75 mm Solution Layer, 1 h Exposure

concentration ranges, aiding dissociation which is accelerated by complexing the cyanide ion with chloramine-T. The latter frees additional cyanide ion to reestablish the equilibrium that was disturbed. The pH is reduced significantly by adding the pyridine-barbituric acid reagent (pH 5 to 5.5), and the sample is previously heated to accelerate the dissociation and complexing with chloramine-T. The test therefore has the necessary ability to measure certain undissociated cyanides, which could be converted by dissociation to toxic cyanides as a result of pH changes or dilution of the sample.

X1.2.8 All metal cyanide complexes are in equilibrium with the hydrolyzed HCN molecule, the concentration being dependent on the pH of the water and the dissociation constant of the particular metal cyanide complex present. The tightest complex is formed with iron. Since there is little dissociation, we may say that the ferrocyanide and ferricyanide compounds are themselves nontoxic (15, 16). The iron cyanide complex is so tight that the standard alkaline chlorination procedure will not affect it. Reported analytical data showing a slight reduction in ferrocyanide content, either in the chlorination step or recovery in the colorimetric analysis procedure, is most likely due to impurity in the reagent or the handling of the sample. Analytical-grade ferrocyanide when dissolved always contains some dissociated CN^-(HCN). The sample has to be handled carefully to avoid any photodecomposition which will appear as an oxidizable portion of the total ferrocyanide present (17, 18, and 39). All other metal cyanide compounds will be chlorinated at a slower rate due to the slow dissociation of the metal cyanide complex. The equilibrium of the metal cyanide complex and molecular HCN is continuously upset, and as the dissociation occurs, the hypochlorite ion will react with the cyanide ion, leading to further dissociation of the metal cyanide complex and then allowing further oxidation by chlorination. This implies a time dependence regarding the chlorination reaction with the cyanide ion that is complexed by such metals as silver, gold, and nickel. The chlorination of nickel cyanide at a concentration of 20 mg/L CN, as an example, may not be complete after 1 h even when hypochlorite was added at a 10 % excess of the stoichiometric amount (14, 19, 20). Because iron cyanide complexes are not destroyed by the practical methods of "alkaline chlorination" and cyanide in contact with iron salts causes iron cyanide to be always present in metal finishing waste, the question of proper waste treatment, or its lack, was many times raised when analyzing industrial waste using the standard analytical procedures. There is important practical value, therefore, that a distinction be made and analytical procedures be developed for "Cyanides Amenable to Chlorination" (10, 14). As it has been established that the ferrocyanide complex is not toxic (1, 2, 15, 16) it might be assumed that a low-cyanide concentration of 1 to 10 mg/L; if not amenable to chlorination such as iron cyanides, would have no toxic effect on the environment. However, this assumption is based on the following two factors:

X1.3 *The Iron Cyanides Undergo Dissociation from Photodecomposition* (16 and 39).

X1.3.1 Under strong sunlight, 10 mg/L iron cyanide, expressed as CN^-, may release 1 mg/L HCN in 1 h (Fig. X1.1).

X1.4 *Dilution and Dispersion of the Treated Waste in the Receiving Waters:*

X1.4.1 The kind of dilution, mixing in the diluting stream, clarity of the receiving waters, and the quantity of HCN release that may be expected are dependent upon particular environmental conditions, considering that only the top layers of the receiving waters will be subject to the strong sunlight to cause decomposition. Oxidation by air and bacterial decomposition in the receiving waters will be additional factors mitigating against the development of toxic concentration levels.

X1.4.2 Deliberate complexing of simple cyanides with iron salts as an economical means of waste treatment naturally should be unacceptable. Higher concentrations of iron cyanides, in view of the foregoing, require treatment.

Suitable processes for the oxidative destruction of iron cyanides are available (21), leading to the complete destruction of the cyanide and precipitation of iron oxide. Insoluble iron cyanide precipitates are soluble in alkali. Therefore, being insoluble under normal conditions is not an rance that the environment is protected.

X1.5 *Cyanogen Chloride:*

X1.5.1 Presently the destruction of cyanide compounds in waste treatment processes is done by oxidation with hypochlorite (OCl^-) because the oxidation reaction is rapid and can be carried to completion using near stoichiometric equivalent of the reacting chemical. The chlorination reaction has to be conducted at an alkaline pH because the first reaction product formed is cyanogen chloride, a toxic gas, having very low solubility. The toxicity of cyanogen chloride may exceed the toxicity of HCN, both in water and in the atmosphere (<0.1 mg/L) (22, 23). Cyanogen chloride hydrolyzes at an alkaline pH to cyanate (CNO^-). The rate of hydrolysis is dependent on the pH conditions and the available excess chlorine, the higher the pH or the more chlorine present, the faster will the reaction go to completion. At a pH of 9, with no excess chlorine present, cyanogen chloride may persist in the treated water for more than 24 h (24, 25, 26). In view of the low solubility of cyanogen chloride and the time dependence for its hydrolysis, it is desirable to maintain the alkalinity during chlorination at pH 11 or higher. A pH of 12 to 13 may be required when the chlorination reaction is carried out on a waste water containing high concentrations of cyanide (>100 mg/L). The low solubility of cyanogen chloride is reduced further by the reaction heat generated upon addition of chlorine. The vapor sure of the cyanogen chloride gas is increased. Rapid rolysis of the cyanogen chloride is the only means available to avoid the escape of cyanogen chloride into the atmosphere. When conducting continuous treatment of an effluent, the pH of the waste stream is lowered after a few minutes of reaction time because a neutral effluent has to be discharged. After the pH is reduced, any cyanogen chloride that has not yet undergone hydrolysis will escape as the toxic cyanogen chloride in the effluent. At pH 11 and at 10°C, the half-life period of cyanogen chloride before hydrolysis to CNO^-, and in the absence of excess chlorine, is 12.5 min (24, 25, 26). It is regrettable that the importance of this reaction and these conditions are not appreciated by Regulatory Agencies and waste treatment engineers. Analysis for cyanogen chloride is not performed, whereas concern is shown for the possible cyanate content of a treated waste. An analytical procedure for the distinction between HCN, ferro- and ferricyanide, respectively was published by Kruse and Thibault (9).

X1.6 *Cyanate Compounds:*

X1.6.1 As discussed in X1.5, the cyanogen chloride that is formed due to the reaction of OCl^- with cyanide ions and HCN during the chlorination reaction will hydrolyze to cyanate (CNO^-). The reported toxicity of cyanate in water is >100 mg/L. The reversion of cyanate to cyanide was attempted with photodecomposition and reduction, but could not be accomplished (27). Theoretical calculations also cate that cyanate cannot be reduced to cyanide.

1.6.2 Acidification and dilution of the cyanate leads to hydrolysis of cyanate to the ammonium ion (NH_4^+). Ammonia toxicity was reported in the 2 to 2.5 mg/L range in hard water (15). Doudoroff reports toxic effects at even lower levels (<1 mg/L), (22). It can be assumed therefore that the toxicity of cyanate is mainly due to the fact that it will yield ammonia. Since chlorination is conducted at high pH, and the treated waste normally then neutralized, further pH reduction may occur due to the lower pH condition of natural waters. Therefore, we may assume that harmful concentrations of cyanate will not be easily encountered in a natural environment. A cyanate determination within ASTM has not yet been formalized. Recommended analytical procedures are available from the literature (27, 28, 29, 30).

X1.7 *Thiocyanate Compounds:*

X1.7.1 The relatively nontoxic thiocyanate compounds (15) may become extremely toxic due to conversion to cyanogen chloride (see X1.5) when a waste stream containing the thiocyanate ion undergoes chlorination for disinfection (22, 23). The probable reaction is: $KCNS + 4Cl_2 + 4H_2O \rightarrow CNCl + KCl + H_2SO_4 + 6\ HCl$.

X1.7.2 According to Doudoroff, this reaction will occur even if the chlorine added to the waste stream is not sufficient to provide a residual (22). Thiosulfate, a common reducing chemical used to detoxify chloramines, is not as effective for cyanogen chloride unless a large excess is used (23).

X1.7.3 The determination for "cyanides amenable to chlorination" will also include the thiocyanate ion due to the conversion to cyanogen chloride by chloramine-T. A specific test for thiocyanates is contemplated.

X1.8 *Total Cyanide:*

X1.8.1 The distillation method, followed by the various analytical techniques to establish the quantitative cyanide content of the sample, has proven to be reliable. Extensive investigation and testing conducted in Germany has aided the evaluation of the recommended procedures (31, 32, 33, 34, 35, 36, 37). Cobalt cyanide is not recovered completely during the distillation. The explanation for this condition was given by Leschber (34) and referred to by original investigations by Bassett and Corbet (38). Potassium cobalt cyanide, when boiled with dilute sulfuric acid, partially breaks down to carbon monoxide, carbon dioxide, and ammonium sulfate.

X1.8.2 The determination of total cyanide retains its significance. As discussed earlier in X1.2, iron cyanides will not be revealed by the Cyanides Amenable to Chlorination analysis methods. To a lesser extent, some of the nickel cyanide, cobalt cyanide, silver and gold cyanide will also not be completely recovered. Neither will the standard alkaline chlorination practices break down these complexes. It has been noted that the toxic effects of these compounds are also considerably less and of a different nature: photodecomposition for iron cyanides; slow dissociation for nickel-, cobalt-, silver-, and gold cyanides. At the same time, there are many waste treatment installations that are either not designed properly, or not operated properly; therefore, more cyanide compounds that could have been treated are discharged in the effluent. There are also some processes generating excessively large quantities of these complex cyanides, thereby producing a significant pollution hazard.

As examples, we should list:

TABLE X1.1 Solubility of Metal Cyanide Precipitates in Water

Precipitate	Solubility in Water, g/L	Temperature, °C
Silver cyanide	0.000028	18
Zinc cyanide	0.0058	18
Copper cyanide	0.014	20
Nickel cyanide	0.0592	18
Cadmium cyanide	17	15
Mercuric cyanide	93	14

(a) *Heat treating processes;*

(b) Coke and blast furnace operations;

(c) Cyanide-type processes used for stripping nickel and cobalt-nickel alloy deposits;

(d) Rinse waters from silver and gold plating operations;

(e) Accidentally mixed waste coming from nickel plating solutions and cyanide floor spill;

(f) Regeneration and backwash waters from ion exchange type waste treatment processes used for the removal of plating salts from rinse water waste. The treatment of these wastes consists usually of mixing, partially deliberately, partially due to the process, and partially accidentally, nickel and iron salts with cyanide compounds; and

(g) Some waste treatment processes still recommended the use of iron sulfate for the neutralization of cyanide salts, etc.

X1.8.3 The total cyanide determination therefore must be used to ensure good waste treatment practices. The mistaken belief that the enumerated cyanide compounds are not "toxic" must be avoided. The fact is that the toxicity is only of a lesser magnitude.

X1.9 *Cyanide in Solid Waste:*

X1.9.1 The waste treatment needs for soluble cyanide sludges is assumed, for example, sludges from plating solutions; cyanide salts removed from heat treat pots or in frozen condition as drag-out from heat treatment; or cyanide salts as residue from the evaporation of processing solutions or rinse waters. The treatment requirements for these highly toxic residues is obvious.

X1.9.2 Most of the metal cyanide complexes are insoluble and are made soluble in water only in the presence of excess alkali metal cyanides. Milne (4) quotes a few examples which, while not complete, should be sufficient to show the insolubility of some metallic cyanides.

X1.9.3 During waste treatment, if the process is not conducted carefully, as the breakdown of the alkali metal cyanide is progressing, the metal cyanide will become insoluble, and will precipitate as the slightly soluble cyanide compound of the particular metal originally present. As seen from Table X1.1, some sludges may contain high levels of relatively insoluble metallic cyanides having high potential toxicity. Lancy and Zabban have reported (14) the cyanide content in the precipitates when conducting slow chlorination and with no or minimal chlorine excesses. The complete treatment and removal of the cyanide concentration in the sludge can be accomplished only by either significant chlorine excess in the waste water, or by rapid chlorination to allow breakdown of the metal cyanide complex before it is precipitated and buried in the sludge. Some newer waste treatment processes, such as treatment with peroxygen compounds, will yield considerably higher available cyanide concentrations in the sludge.

X1.9.4 Iron cyanide is always present in electroplating solutions. The concentration is usually in the range from 20 to 25 g/L. Only a small quantity of this iron cyanide will appear in the rinse water effluent, and as it escapes chlorination, it may form insoluble iron cyanide compounds with other metals present, such as copper, zinc, iron, etc. The metal iron cyanide compounds may be considered insoluble and nontoxic, but can become soluble in the alkaline range (pH >9) if the solid waste is leached with alkaline waste. The resolubilized iron cyanide can undergo photodecomposition as discussed in X1.2. The insoluble iron cyanide content of solid waste may be a result of the best treatment that modern technology can do with regard to treatment and disposal of particular cyanide compounds. The usual disposal is burial or landfill where acid conditions are far more common than excessive alkalinity which would cause the redissolution.

X1.9.5 The insoluble cyanide content of a solid waste can be determined by placing a 500-mg sample with 500 mL of distilled water into the distillation flask and following the total cyanide distillation. The calculations should consider a multiplication by 1000 to give the cyanide content of the solid waste sample in ppm. Insoluble iron cyanides in the solid waste can be leached out before analysis by stirring a weighed sample for 12 to 16 h in a 10 % caustic soda solution. The leachate and wash waters of the solid waste will give the iron cyanide content of the sample using the distillation procedure. A previous chlorination will have eliminated all cyanide amenable to chlorination from the sample. The sample should not be exposed to sunlight. A method allowing differentiation between HCN, ferro- and ferricyanide, as mentioned earlier, is referenced (9, 39).

X2. DETECTION AND ELIMINATION OF THE INTERFERENCE CAUSED BY ALDEHYDES

X2.1 Introductory Comments

X2.1.1 The inference caused by the presence of aldehydes, causing the conversion of cyanide to cyanohydrins has been explained in 11.3. Section 6.4 discusses the cyanohydrin formation when aldose is present in the sample. The same interference removal technique developed for the removal of the complexation caused by aldehydes may also be useful for the demasking of the complexes caused by the reaction with aldose. The aim is to recover the cyanide that is in a labile complex which also depends on the relative concentrations of the cyanide and complexing organics, the time past since the reacting chemical mixtures occurred, the temperature of the solution, and the organics present forming the various cyanohydrins.

X2.2 Summary of Methods

X2.2.1 *Silver Nitrate Method*—Formaldehyde present in the sample in excess of 0.5 mg/L noticeably interferes with the CN^- determination (0.02 mg CN^-/L). The cyanohydrin that is formed by the interaction of the cyanide and aldehyde in the sample is in equilibrium. This equilibrium is upset by the addition of silver nitrate which oxidizes the aldehyde to the noninterfering carboxylic acid prior to the cyanide determination. The EDTA solution complexes the iron, if present in the sample, to avoid the formation of iron cyanide.

X2.2.2 *Ethylene Diamine Method*—Ethylene diamine is a suitable demasking agent for the recovery of cyanide from labile cyanohydrins.

X2.3 Description of Spot Test

X2.3.1 E. Sawicki, et al, have developed a suitable colorimetric method for the detection and estimation of aliphatic aldehydes in water (41, 42, 43). This method has been adapted for a spot test procedure.

X2.4 Apparatus

X2.4.1 *Spot Plate*, white, with 6 to 12 cavities.

X2.5 Reagents and Materials

X2.5.1 *Ethylene Diamine Solution* (3.5 %)—Dilute 3.5 mL of pharmaceutical grade anhydrous $NH_2CH_2NH_2$ to 100 mL with water.

X2.5.2 *EDTA Solution* (0.1 *N*)—Dissolve 37.2 g of sodium-ethylenediamine-tetraacetate, dihydrated, in water and dilute to 1 L.

X2.5.3 *Ferric Chloride Oxidizing Solution*—Dissolve 1.6 g of sulfamic acid and 1 g of $FeCl_3 \cdot 6H_2O$ in 100 mL of water.

X2.5.4 *MBTH Indicator Solution*—Dissolve 0.05 g of 3-methyl, 2-benzothiazolone hydrochloride in 100 mL of water. Filter if turbid.

X2.5.5 *Silver Nitrate Solution* (17 g/L)—Dissolve 17 g of silver nitrate ($AgNO_3$) crystals in water and dilute to 1 L.

X2.6 Procedure

X2.6.1 If the sample is alkaline, add sulfuric acid (1 + 1) dropwise to 10 mL of the sample to adjust the pH to less than 8.0. Place 1 drop of sample and 1 drop of water for a blank in separate cavities of the spot plate. Add 1 drop of MBTH solution and then 1 drop of $FeCl_3$ oxidizing solution to each spot. Allow 10 min for color development. The color change will be from a fruit green-yellow to a deeper green with blue-green to blue at high concentrations of aldehyde. The blank should remain yellow. The sensitivity of the test is approximately 0.2 mg/L CH_2O.

X2.6.2 *Silver Nitrate Method:*

X2.6.2.1 Add $AgNO_3$ solution dropwise to the sample and retest on the spot plate. For each drop of $AgNO_3$ add also 2 drops of EDTA solution. One milligram CH_2O/100 mL of sample will require approximately 2 drops of $AgNO_3$ solution and 4 drops of EDTA solution.

X2.6.2.2 The silver nitrate may also precipitate some of the thiocyanate if present in the sample. If this should be avoided, add a few drops of concentrated ammonium hydroxide to the sample. In case $AgNO_3$ solution has been added in excess and it is found that AgCN has precipitated, ammonium hydroxide can be added subsequent to the CH_2O removal to resolubilize the CN^- and Ag^+. The dark precipitate that has formed is metallic silver and can be filtered off if turbidity interferes with the test method.

X2.6.3 *Ethylene Diamine Method:*

X2.6.3.1 Add 2 mL of the ethylene diamine solution for each 100 mL of sample to be used for the cyanide determination. It has been found that this quantity of ethylene diamine addition is suitable to overcome the interference caused by up to 50 mg/L CH_2O present.

X2.6.4 When applying a spike in testing or evaluation of the methods do not expect necessarily 100 % recovery of the CN^-. Recovery will depend on CH_2O excess that has been present, time of contact, and temperature of the sample.

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CYANIDE DESTRUCT
SYSTEMS INC.
CDS
458 MASSEY ROAD. GUELPH.
ONTARIO CANADA N1K 1B4
(519) 837-1899

Mr. J. Bou

Martin Marietta Corp.
Aluminum Properties
6801 Rockledge
Bethesda, Maryland
20817

January 30, 1989

Re: Cyanide Hydrolysis System
Our Quotation No. 8902

Dear Mr. Bou:

Per your request, we are pleased to offer our quotation for a cyanide hydrolysis system for treatment of cyanide contaminated groundwater. The quoted price includes: system design, equipment, installation, start-up, and training of operating personnel. The process design is based on treating the cyanide water to a maximum discharge level of 0.5 and 0.1 total and free cyanide respectively. Two size options are given:

Option 1: 60 US gallon/hour (for performance guarantee)
Components will provided allowing flows to about 90 USGPH
Option 2: 120 US gallon/hour (for performance guarantee)
Components will provided allowing flows to about 165 USGPH

A. General Process Description

Cyanide wastewater is pumped via a high pressure pump, through a tube in tube heat exchanger (countercurrent to treated effluent), and into a reaction vessel. Electric surface heaters are used to compensate for the difference between the heat exchanger outlet temperature and the reaction vessel operating temperature.

When the solution in the vessel rises to a predetermined setpoint, a level sensing device actuates a control valve on the effluent tube, and the treated, cooled effluent is discharged to owners receiving tankage. Either high or low level in the vessel will effect a complete process shutdown.

The normal operating pressure is approximately 625 psi. If pressure rises much beyond this point, a complete process shutdown will occur. If pressure continues to rise, a proportional pressure control valve is incorporated which will vent excess pressure. In the unlikely event of pressure continuing to rise (in the event of a fire, for example), a rupture disc in series with a pressure relief valve is included (relieving at 900 psi). This series arrangement has the advantage of allowing only a small amount of liquid to escape the vessel.

The cyanide hydrolysis system is designed to be completely failsafe. Any process variable falling outside of its normal operating range will result in a complete process shutdown.

B. Preliminary Equipment Description

1. Design: - 900 psi @ 500 F, ASME Section VIII, Division 1
   - Government inspected & approved ('U' Stamp)

2. Materials: - High nickel alloys (eg. Incoloy 825, Hastelloy C-276 and/or Inconel 600) will be used on all high temperature liquid contact parts (these expensive alloys are required to eliminate the possibility of stress corrosion cracking with the caustic/fluoride containing solution)

3. Reaction Vessel: - designed for ~ 15 - 20 minute time
   - various nozzle connections for inlet, outlet, relief valves etc.
   - exact configuration to be specified

4. Ancilliary Equip: - tube in tube heat exchanger
   - about 24 and 48 kw electric heaters required for Option 1 & 2 respectively
   - high pressure st.st./PTFE diaphragm pump
   - control panel c/w indicators & controls for continuous failsafe operation

5. Assembly: - Unit to be skid mounted and tested prior to shipment (skid ~ 20' x 5' x 8' high)

C. Delivery and Installation

Approximately 5 - 6 months from receipt of purchase order.

D. Price

Option 1: $ 105,000. (Cdn funds)
Option 2: $ 138,000. (Cdn funds)

E. Terms of payment

To be negotiated.

E. FOB Point

Guelph, Canada

CYANIDE DESTRUCT
SYSTEMS INC.

458 MASSEY ROAD, GUELPH,
ONTARIO, CANADA N1K 1B4

F. Performance Guarantee

CDS guarantees that the cyanide hydrolysis process, treating cyanide contaminated groundwater, at a flowrate of 60 US gallons/hour (Option 1), or 120 US gallons/hour (Option 2) will yield an effluent containing a maximum of 0.5 mg/l, of total and a maximum of 0.1 mg/l of free cyanide. CDS Inc., will, at its expense, modify the system to meet guarantee if not met during start-up. See the attached Terms and Conditions.

I hope that this quotation is acceptable to you. Please call with any questions or comments that you may have.

Your's very truly,

H.L. Robey, P.Eng.

CYANIDE DESTRUCT
SYSTEMS INC.
458 MASSEY ROAD. GUELPH.
ONTARIO. CANADA N1K 1B4
(519) 837-1899

Terms and Conditions of Sale

1. The shipping and installation time is an estimate. CDS Inc. will endeavor to meet that quoted, but CDS shall not be liable for any delays resulting from causes beyond their control.

2. Plant services required for operation of the system (ie. plant air, water for start-up and electricity) will be provided by the Purchaser at the selected location of the system.

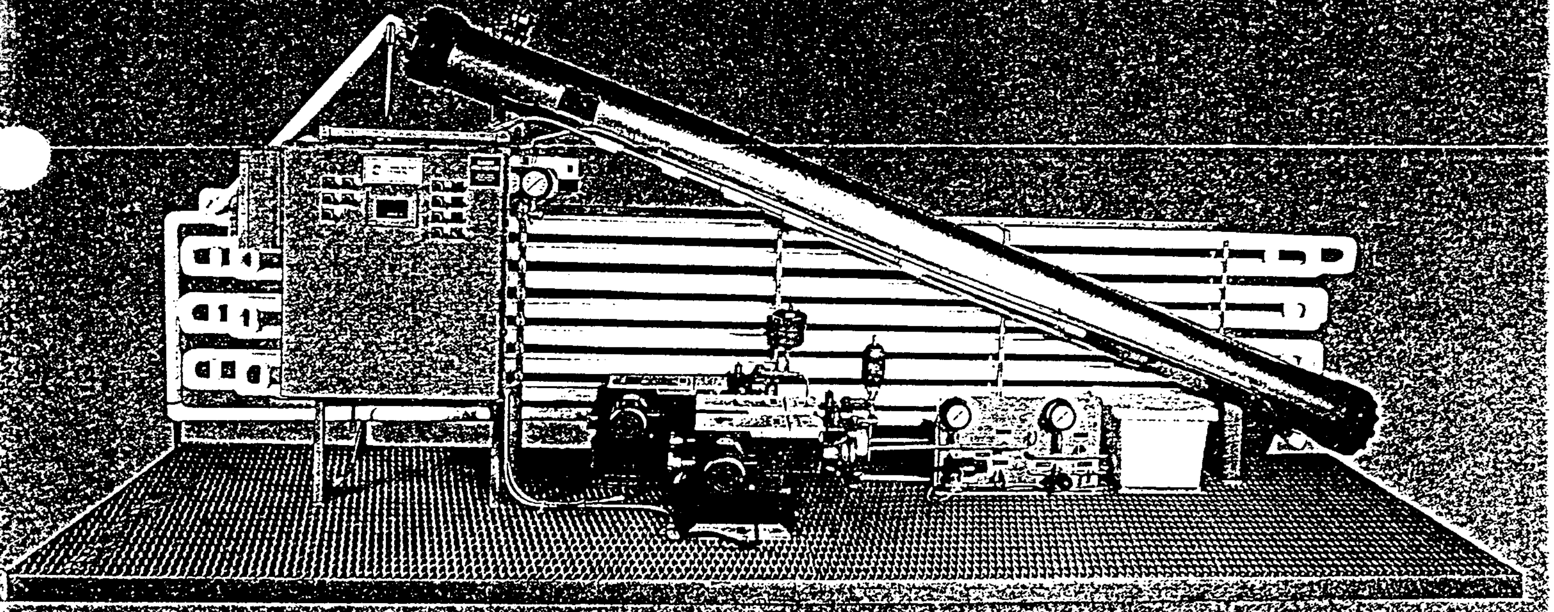
3. All feed and effluent tankage is the responsibility of the Purchaser, as is the piping of pressure relief lines.

4. CDS Inc. will not be held liable for any discharges from the hydrolysis process into sewers, receiving watercourses or soils which are above regulatory limits (ie. Purchaser is responsible for analyzing effluents to ensure compliance).

5. The cyanide destruction guarantee is based on results obtained from batch scale tests. If performance guarantee is not met, CDS Inc. retains the right to have another test conducted on a sample to ensure that it is consistent with the original test results. If the new test results are comparable to the original sample test results, suggesting that the full scale system design is at fault, the unit will be modified at CDS expense to meet target. If new and original sample test results are not comparable, suggesting that a non-representative sample was used for the original test, then CDS will modify unit to meet target at Purchasers expense.

6. Due to the present instability of the international nickel market, CDS Inc. reserves the right to adjust the quoted price in accordance with nickel prices at the time of sale.

Cyanide Destruction . . . Can You Afford Not To?



CYANIDE DESTRUCT
SYSTEMS INC.

CDS INC. .... Safe, reliabl

CYANIDE

Cyanide is an important industrial chemical. Its applications are numerous, and often there are no practical substitutions. The problem is how to dispose of this toxic residual of modern chemical processes. The regulations regarding this are very clear and result in a long-term liability with serious implications for all cyanide users.

EXISTING TECHNOLOGY

Currently, the most common treatment technique involves chlorine, in itself a toxic and regulated chemical, as an oxidation agent. There are two major disadvantages to the chlorination process—extremely high operating costs and the failure to destroy complex cyanides, particularly iron.

THE ANSWER

It's actually quite simple ...Cyanide hydrolysis. This reaction has been known for decades. It occurs naturally, even at room temperature, but the reaction takes far too much time to be economically feasible. If the temperature could be increased and the pressure rigidly controlled in a specially designed reaction vessel, this simple chemical reaction can destroy all cyanide complexes to well below compliance concentrations. All this at a rate and cost acceptable to businesses operating now and into the future.

PROVEN RESEARCH

With financial support from the American Electroplaters Society, the Ontario Research Foundation in Canada conducted a multi-year laboratory and field test program on the feasibility of cyanide destruction through "Thermal Hydrolysis". The results were conclusive. All cyanides, including iron, nickel and copper complexes, could be reduced to below acceptance levels.

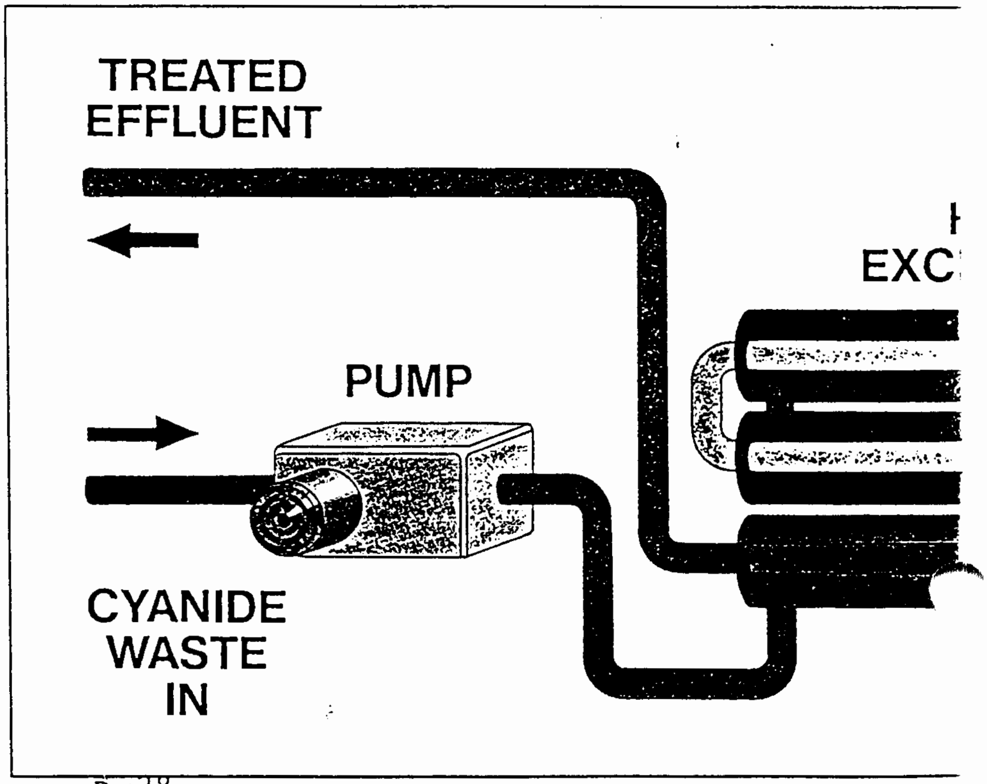
$$CN^{-}\ 2H_2O \rightarrow NH_3 + HCOO^{-}$$

CYANIDE DESTRUCT SYSTEMS INC.

Based on management's years of prior experience in thermal hydrolysis, Cyanide Destruct Systems Inc. was incorporated in 1986. Since then, CDS has continued to develop this hydrolysis process. With a corporate mission to design, manufacture and install this equipment, CDS has successfully created a market niche. A clear understanding of the process and a firm commitment to after sale support has resulted in a product that meets the needs of cyanide users large or small.

Canadian and U.S. patents are pending.

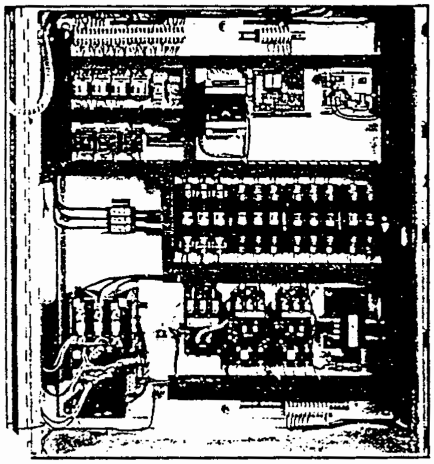
CONTINUOU

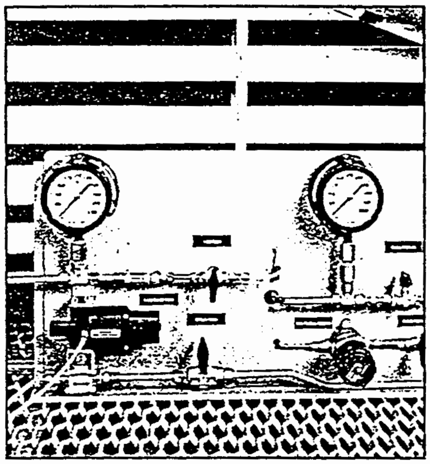


yanide hydrolysis systems

SAFETY AND CONTROL

In dealing with toxic material it is imperative that top quality industrial control systems are used. At CDS we use only the best commercially available materials and components. All units are tested to ensure maximum reliability and safety. Specifically designed control loops have been developed with safety, simplicity and operational reliability in mind. Any process variable falling outside of its operating range will result in a complete system shutdown and will automatically inform personnel of this occurrence.





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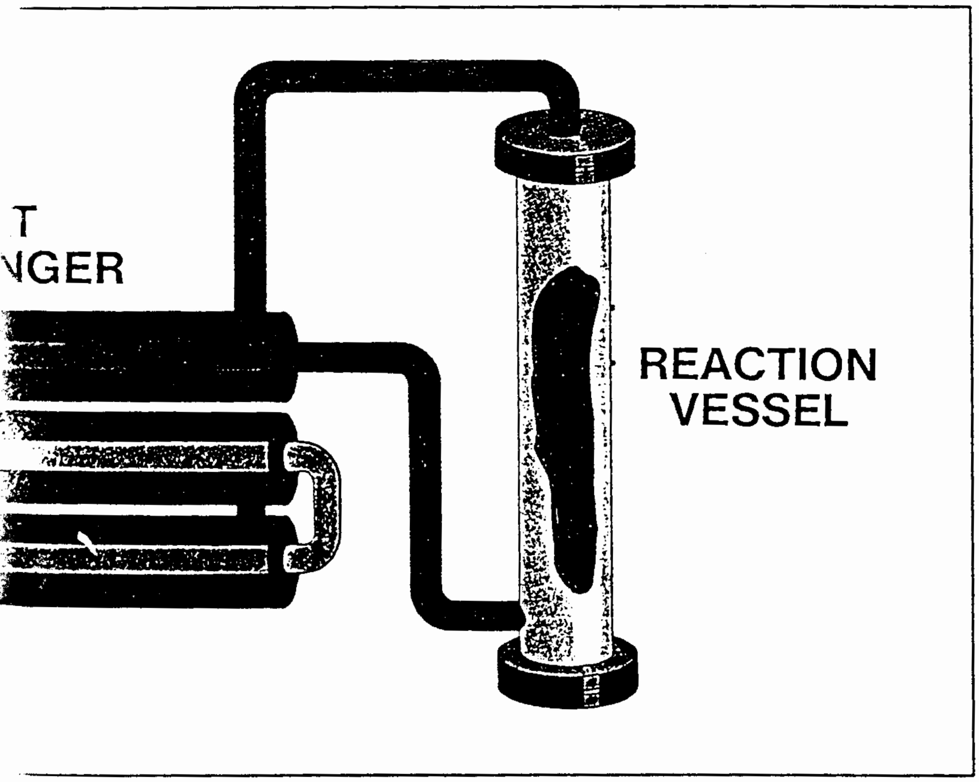
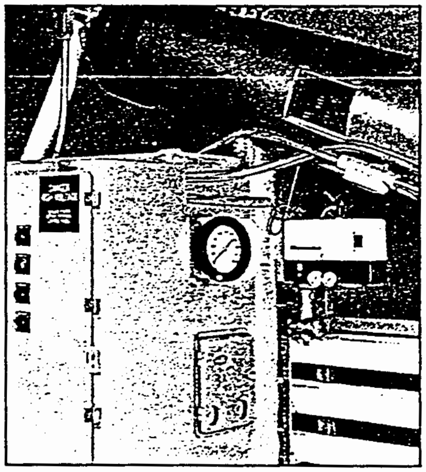


THE PROCESS EQUIPMENT

Cyanide hydrolysis installations can be utilized by either large or small generators of cyanide waste.

Smaller operations producing less than 300 gallons per day (gpd) can rely on the batch process for economical treatment of cyanide contaminated liquids or sludges. This alleviates the costly requirements and long-term liability of transportation to a hazardous waste land fill.

For larger requirements (over 300 gpd.), a continuous operating system may become more cost effective.



FEATURES

*no potentially dangerous chemicals involved
*ONLY known process capable of destroying complex cyanides to levels consistently below compliance
*requires minimal floor space
*low operating costs

CYANIDE DESTRUCT SYSTEMS INC.

458 MASSEY ROAD, GUELPH, ONTARIO, CANADA. N1K 1B4 (519) 837-1899

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GERAGHTY & MILLER
ENGINEERS, INC.

DCE/P
June 30, 1989

DESIGN CRITERIA EVALUATION PLAN/ PERMITTING ASSESSMENT

Prepared for:

Martin Marietta Corporation
The Dalles, Oregon

Prepared by:

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July 1989

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1.0 INTRODUCTION

The purpose of this work plan is to identify the constraints imposed upon the standard design practice by the need for adherence to the remediation goals and requirements mandated by the EPA. In general, the activities associated with the selected alternative presented in the Record of Decision (ROD) consist of the following:

- Excavating and consolidating materials from former cathode waste management areas consisting of: The Bath Recovery Pad; Old Cathode Waste Pile; Potliner Handling and Salvage Areas plus the Alumina Unloading Area into the existing landfill;
- One time collection and treatment of perched water beneath the Cathode Waste Management Areas (CWMA) during consolidation activities west of River Road and to the extent practical, east of River Road;
- Cap the existing landfill in place with a multi-media cap meeting RCRA performance standards;
- Collect and treat leachate generated from the existing landfill once construction of the cap is complete;
- Cover Scrubber Sludge Ponds (SSP) 2 and 3 with a soil cover;
- Abandon the following nearby production wells: Rockline, Animal Shelter, Klindt and Residence wells. Connection of the City of The Dalles water supply system will be provided for the users of the Rockline, Animal Shelter and Klindt wells. The Residence well is on Martin Marietta Corporation (MMC) property and will not receive a water system extension as MMC has no intentions of future use); and
- Implement a ground-water quality monitoring plan which contains a contingency plan to

perform recovery and treatment of ground water in the event ground-water quality does not meet standards.

In addition to these stated objectives, MMC intends to include as part of the excavation of former cathode waste management areas, the excavation of the materials contained in the Lined Pond. The Lined Pond is expected to be taken out of service in mid 1989 at which time it will no longer be required as part of the reduction facility process. MMC has determined that materials contained in the Lined Pond will be consolidated into the existing Landfill prior to capping.

The purpose of the Design Criteria Evaluation and Permit Assessment (DCE/P) Plan is to discuss the following elements:

- Description of Remedial Activities;
- Review of Performance Standards; and
- Design Criteria Evaluation.

The description of remedial activities presents a basic outline and narrative of the construction schedule MMC intends to pursue. Construction activities have been divided into two phases, one starting in 1989 and another in 1990.

Review of performance standard re-iterates the ARARs provided in the feasibility study (FS) and ROD. Performance standards for excavation, RCRA performance cap for the Landfill, soil cover for the Scrubber Sludge Ponds, and perched water treatment will be discussed.

The design criteria evaluation will provide insight into how performance standards are expected to be obtained and data required during the RD process to conduct the evaluations. Design criteria are primarily associated with treatment of perched water and leachate for cyanide and fluoride removal, and the capping and covering of the existing Landfill and Scrubber Sludge Ponds, respectively.

2.0 DESCRIPTION OF REMEDIAL ACTIVITIES

The Scope of Work (SOW) submitted by MMC as part of its good faith offer, provided that design shall be completed within 270 days after approval of the work plans and notice to proceed. Remedial action would be initiated 45 days after notice to proceed and completed 30 months there after. The remedial action duration provides the 1989, 1990, and 1991 construction seasons for implementation of the RA.

In order to execute the activities described in the selected remedial action as presented in the ROD, MMC intends to conduct the remediation in two phases. The construction season in The Dalles area is generally between the months of April through September. In order to take advantage of the 1989 construction season, MMC's goal is to implement a number of tasks which will result in complete remediation of certain areas of the site and to establish a basis for completing the remedial activities in the 1990 construction season. Collection of the engineering data required to provide compliance with design criteria is a critical path to being able to initiate construction activities in 1989.

The following text discusses the individual construction seasons, the relative construction goals and objectives for implementation, and basic sequencing of construction. Table 2-1 provides an overview of the construction activities desired by MMC to effect remediation by the end of the 1990 construction season.

TABLE 2-1

DCE/P
June 30, 1989

Construction Events Summary
Pre-Design Report: Martin Marietta Reduction Facility
Martin Marietta Corporation
The Dalles, Oregon

Phase I - 1989 Construction Scenario

1. Interim Stormwater Management
2. Cyanide Treatment Facility
3. Tank Storage Facility
4. Cover Scrubber Sludge Ponds
5. Installation of interior leachate collection system
6. Excavation/Consolidation/Reconstruction
    - Unloading Area
    - Potliner Handling Area
    - Lined Pond
7. Excavation/Consolidation/Regrade
    - Old Cathode Waste Pile Area
    - Salvage Area
    - Bath Recovery Pad Area
8. Well Abandonment/City Water Supply
9. Initiation of Perched Water Recovery

Phase - II 1990 Construction Scenario

1. Perimeter Leachate Collection Trench/System
2. Excavation/Consolidation/Reconstruction
    - Old Cathode Waste Pile Area
    - Salvage Area
    - Existing Landfill Leachate Collection Trenches
3. Perched Water Recovery
4. Landfill Cap Construction
5. Final Stormwater Management
6. Survey/Institutional

2.1 PHASE I - 1989 CONSTRUCTION SCENARIO

A summary of the 1989 construction activities consist of several site civil elements resulting in partial or complete remediation. However, the critical element in the initial construction season is the installation of the perched water treatment system which includes storage tank and cyanide destruction unit. Many of the Cathode Waste Management Areas cannot be remediated totally in 1989, due to perched water being encountered during excavation activities. These areas will be initiated in 1989 and completed in 1990. The elements presented in Table 2-1 for the 1989 activities are described briefly in the following text:

- <u>Interim Stormwater Management.</u> Primarily this task will focus on minimizing surface water entering the Landfill Sump Pump Station. The objective is to minimize the accumulation of additional perched water in this area.

- <u>Perched Water Treatment System.</u> The system by Cyanide Destruct Systems, Inc. will be utilized for the destruction of cyanide in the perched water and later for leachate from the Landfill after capping is complete. It is anticipated that treatment system will be installed and ready for startup in late 1989.

- <u>Perched Water Storage Facilities.</u> This facility must be erected prior to recovering any perched water. A bolted steel tank of approximately 250,000 gallons capacity has been selected by MMC and will have secondary containment designed to the requirements of 40 CFR 264 Subpart J.

- <u>Cover for Scrubber Sludge Ponds.</u> Placement of the cover may involve regrading of materials, removal of vegetation (trees, shrubs, etc.), placement of soil cover, grading for drainage and final surface treatment (vegetative cover). Ponds 2 and 3 together are between 8 and 10 acres in size. Opportunities to minimize stormwater runoff onto the Scrubber Sludge Ponds will be analyzed and implemented into the design of the cover. At the conclusion of remedial activity, a fence will be completed around Scrubber Sludge Ponds 1 through 4. Surface drainage would be towards River Road and the abandoned discharge channel. Vegetation will be permitted to develop in the areas in a similar manner as on adjacent Scrubber Sludge Ponds 1 and 4.

- Excavation/Consolidation/Reconstruction. Three areas will be completely remediated; the Unloading Area, Bath Recovery Pad Area and Potliner Handling Area. The materials will be consolidated into the Landfill and graded to shapes or slopes, as required. Perched water detected in these areas will be removed and the soils will be drained, at a minimum, to the extent that no liquid water will drain by gravity from the material before consolidation into the Landfill. There are a number of activities in the Potliner Handling Area which must be addressed during remediation. These activities are: crusher disassembly, stormwater catch basin and piping, railroad spur lines, buried utilities, etc.

- Excavation/Consolidation/Regrade. The Old Cathode Waste Pile and Salvage Area will be excavated in two phases. The first phase will be to excavate surface soils above the perched water table. The resulting area will be graded to slope towards the Landfill Ditch to facilitate surface water runoff. In both of these areas soils will be drained, at the minimum, to the extent that no liquid water will drain by gravity from the materials before consolidation into the Landfill. The Lined Pond is to be taken off-line in 1989 and the materials in this pond will be excavated and consolidated into the Landfill.

- Well Abandonment/City Water Supply. This task will include abandoning the Klindt, Animal Shelter, Rockline and Residence wells, and replacement of the Animal Shelter, Rockline and Klindt wells with city water. The Residence well in on MMC property and will not receive a city water system extension as MMC has no intentions of future use.

- Perched Water Recovery. The recovery of perched water will be initiated in 1989 for the purpose of conducting performance tests of the CDS system. Perched water will be collected from the trench excavations established in the Old Cathode Waste Pile and Salvage Area during the field investigations.

- Regrading of Landfill. With the addition of the materials from the Phase I excavations, the materials will be consolidated in the Landfill in a manner which will minimize future work activities.

- Verification Sampling. Following the approval of the Project Work Plans by the EPA and the ODEQ, verification sampling (as described in the SAP) will be conducted in the Salvage, Bath Recovery Pad, and Unloading Areas for the purpose of defining the limits of excavation.

2.2 PHASE II-1990 CONSTRUCTION SCENARIO

The elements presented in Table 2-1 for the 1990 activities are described briefly in the following text:

- Leachate Collection Trench. During excavation and consolidation activities, the leachate collection will be installed. The number of sumps and handling systems (for the leachate collection and conveyance to the treatment system) will be determined after the performance of the field investigation.

- Excavation/Consolidation/Reconstruction. The remaining materials in the Old Cathode Waste Pile Area, Salvage Area and existing ditches around the Landfill will be excavated, consolidated into the Landfill, and backfilled, as required. Perched water, if encountered, would be collected and sent to storage for treatment.

- <u>Perched Water Recovery.</u> All remaining perched waters will be recovered from the CWMA for storage and treatment in the cyanide hydrolysis treatment system.

- <u>Landfill Cap Construction.</u> Once all materials are consolidated and graded, then the installation of the Landfill cap will begin.

- <u>Final Stormwater Management.</u> Once all major construction activities are complete, final stormwater drainage construction will be implemented. Storm waters will be drained off-site from the Landfill and CWMA along new or existing drainage paths.

- <u>Survey/Institutional.</u> The waste management areas (Landfill and Scrubber Sludge Ponds) will be surveyed and deed restrictions filed. Other institutional controls and implementation mechanisms must be in place by the time construction is complete.

Key elements to be considered during the 1990 construction season are recovery of perched water, completion of consolidation activities, and cap construction over the consolidated materials in the existing Landfill. The treatment system will undergo start-up in late 1989 or early 1990. Installation of the remainder of the perimeter leachate collection trench system must be undertaken before grading of the Landfill. Construction of the multi-layer cap will begin after grading of the landfill is completed. The placement of the soil barrier must be accomplished expeditiously due to anticipated adverse climatological conditions (hot temperatures, high winds and low humidity). Covering of the soil barrier with the synthetic membrane should minimize the effect of climatological factors. However, quality assurance control measures to be taken to monitor adherence to the performance standard assigned to the soil barrier will be extensive and may deter the construction process from advancing as quickly as desired. Therefore, the soil barrier will require moisture monitoring. MMC's objective is to have the final cover over the Landfill before inclement wet weather begins in the fall and winter of 1990.

3.0 REVIEW OF PERFORMANCE STANDARDS (ARARS)

The purpose for identifying and evaluating the performance standards to be utilized in the remedial design process is to incorporate the known goals for site remediation with the regulatory requirements (ARARS) for the proper conduct of the site remediation. The combination of these two elements forms a cohesive plan for the safe and effective completion of the RD/RA.

The inputs for the evaluation of performance standards include the description of the selected remedy in the ROD and the scope of work (SOW) prepared for the RD/RA. In the following subsections the federal and state ARARs which may be applied to the RD/RA are discussed and subsequently incorporated into the preliminary design criteria.

3.1 DEFINITION OF PERFORMANCE STANDARDS

As determined in the Feasibility Study and presented in the ROD, the performance standards established for remediation of the MMRF site are defined for the major project tasks as follows.

3.1.1 Waste Material Consolidation into the Landfill

The residual cathode waste material, fill and contaminated soils from the Unloading Area and the Former Cathode Waste Management Areas will be excavated and consolidated into the existing Landfill. In addition, the materials existing between the Landfill and the northern bank of the Landfill Ditch will be consolidated into the Landfill.

The lateral and vertical extent of excavation will be limited in some areas by the known boundary of materials placed in the area.

The volumes of soils to be consolidated in the Landfill are dependent on the results of a verification sampling program. The verification sampling program shall be prepared by MMC as part of the SAP and submitted to EPA. The following parameters have been established as ARARS for the soil removal:

Arsenic	65 mg/kg
cPAHs	175 mg/kg
Fluoride	2,200 mg/kg

The contaminant specific criteria for each of the areas being excavated is identified in the SAP.

3.1.2 Perched Water and Landfill Leachate Treatment

The performance criteria for the treatment of perched water and Landfill leachate are based on the discharge concentration of free cyanide at the CDS system discharge, and the discharge of water containing fluoride is regulated by the NPDES permit for the in-plant treatment system. Discharge of fluorides to the in-plant treatment system has been accepted by the EPA and the discharge of in-plant waters containing fluoride are regulated by NPDES discharge criteria. Free cyanide discharge units of 0.4 mg/L and 0.1 mg/L have been established for perched water treatment during the remediation period and thereafter, respectively. Treatment of Landfill leachate will occur after remedial actions are completed and the discharge criterion for free cyanide to the in-plant system has been established by the NPDES at 0.1 mg/L.

3.1.3 Landfill Cap

The performance standards (ARARs) for the cap at the Landfill are the RCRA performance standards for final closure of a landfill, which are contained at 40 CFR 264.310(a)(1) through (5) and described in the following:

1. Provide long-term minimization of liquid migration through the capped area.
2. Function with minimum maintenance.
3. Promote drainage and minimize erosion or abrasion of cover.
4. Accommodate settling and subsidence so that the cover's integrity is maintained.
5. Have a permeability less than or equal to the permeability of the natural sub-soils that are present.

The above performance standards for the Landfill will be met through the use of man-made materials (geomembranes and geotextiles) and through the judicious selection and combination of available soil materials. The properties of bentonite-enhanced soil materials are being evaluated in order to determine an optimal low permeability layer configuration, which will address the performance standards for protection and permeability of the cap and minimize construction costs.

3.1.4 Scrubber Sludge Ponds Cover

The performance standards (ARARs) established for the cover for Scrubber Sludge Ponds 2 and 3 are the RCRA performance standards for final closure which are contained in 40 CFR 264.310(a) (2) through (4) and described in the following:

1. Function with minimum maintenance;
2. Promote drainage and minimize erosion or abrasion of cover; and
3. Accommodate settling and subsidence so that the cover's integrity is maintained.

3.2 DEFINITION OF ARARs

In addition to the performance standards presented in Section 3.1, the identification and application of Applicable, Relevant and/or Appropriate Requirements (ARARs) is required in the development of design criteria. The subjects to be addressed in the development of ARARs include:

1. Methods by which fugitive dust emissions are to be assessed and controlled during the RD/RA;
2. The protection of the health and safety of personnel involved in the site remediation;
3. The perched water treatment criteria; and
4. The constituents to be utilized in the verification sampling program.

Fugitive dust emissions are a concern to potential off-site recipients of the particulate matter. Applicable requirements for determining emission standards are contained in the Oregon Administrative Rules (OAR), Chapter 430, Sections 20, 21, and 31. Of particular concern are the special control area designation for particulate sources within three miles of a city having a population greater than

4,000 people (OAR 340-21-010.4). An assessment was performed by Versar, Inc. of the amounts of particulate matter which will be generated due to the remedial activities at the site. The analysis is presented as Appendix C of the Safety and Health Plan.

Responsibility for the protection of the safety and health of personnel involved in the site remediation is the joint responsibility of MMC and the remedial contractor. Consistent with the language of the scope of work for the RD/RA, MMC will prepare a Safety and Health Plan (SHP) for the protection of personnel involved in the data-gathering tasks of the RD. The remedial contractor is, with historic data and the additional data collected by MMC during the RD, responsible for preparing a SHP suitable for protection of the contractors personnel. The SHPs prepared for the site remediation will conform to the provisions of 29 CFR 1910.

A verification sampling program is proposed to determine the lateral extent of contaminated areas in the Unloading and former Cathode Waste Management Areas. The following constituents have been established as ARARs for the soil removal:

Arsenic ≤ 65 mg/kg
cPAHs ≤ 175 mg/kg
Fluoride ≤ 2200 mg/kg

Three areas of the site have been identified in which the lateral extent of contamination has not been adequately characterized. The verification sampling of the Unloading, Salvage and Bath Recovery Pad Areas is described in detail in the SAP and the specific constituents to be sampled, consistent with the results of the RI, are as follows:

Unloading Area - Fluorides

Bath Recovery Pad Area - Fluorides
cPAHs

Salvage Area - Fluorides
cPAHs

The specific cPAH compounds detected at the site, as identified in the Risk Assessment element of the RI, are as follows:

Benzo (a) anthracene
Benzo (b) fluoranthene
Benzo (k) fluoranthene
Benzo (a) pyrene
Chrysene
Dibenzo (a,h) anthracene
Indeno (1,2,3 - cd) pyrene

4.0 DESIGN CRITERIA EVALUATION

The finalization of the design criteria to be utilized in the development of the RD for the site is accomplished by: (1) incorporating the input from the ARARs as identified in the ROD; (2) incorporating the needs identified by the scheduling scenarios for the individual elements of the site remediation and; (3) incorporating the provisions for air monitoring, health and safety and verification sampling. For each of the major elements of the RD, the preliminary design parameters have been identified, as well as the additional data needs which require field investigation. The timing of the data gathering investigations to be performed at the site are influenced by the scheduling scenarios developed for the implementation of the RD.

4.1 DESIGN CRITERIA

The remediation of the MMRF site requires the application of standard civil engineering design practice in a number of different settings to achieve a number of different results. Therefore, the design criteria needs vary substantially and are usually particular to individual elements of the project. Table 4-1 presents a summary of the different areas of remediation, the remedial actions occurring in the area and the specific ARARs, performance criteria, design criteria and additional data needs associated with the area. Common elements to each of the design tasks presented in Table 4-1 are need for appropriate health and safety guidelines. Table 4-1 represents the basis of the Remedial Design for the different areas of the site.

TABLE 4-1

Preliminary Design Criteria

Martin Marietta Reduction Facility RD/RA

The Dalles, Oregon

Project Description	Remedial Action	ARARS/Performance Criteria	Additional Data Needs/ Design Criteria/ Permits Required	Bench/Pilot Studies
Potliner Handling Area (PHA)	Excavation of contaminated soil	Excavation of defined area Replacement of existing RR tracks Provide proper drainage for backfilled area Minimize erosion and settling of backfilled area	Air emission controls (as necessary) Backfill selection and placement criteria Identify the location of the storm sewer line Identify existence and location of any utility lines Design criteria for RR track replacement Coordination of activities with NWA operations	None

TABLE 4-1 (Continued)

Preliminary Design Criteria
Martin Marietta Reduction Facility RD/RA
The Dalles, Oregon

Project Description	Remedial Action	ARARS/Performance Criteria	Additional Data Needs/ Design Criteria/ Permits Required	Bench/Pilot Studies
Old Cathode Waste Pile Area	Excavation of contaminated soil	Excavation of defined area Minimize settling and erosion of backfilled area Provide proper drainage for backfilled area	Air emissions controls (as necessary) Protection of monitor well clusters Backfill selection and placement criteria Identify the existence and location of any utility lines	None
Salvage Area	Excavation of contaminated soil	Excavation of defined area Verification samplings as described in SAP Provide proper drainage for backfilled area Minimize settling and erosion of backfilled area	Air emissions controls (as necessary) Protection of monitor well clusters Backfill selection and placement criteria Identification and existence of any utility lines	None

TABLE 4-1 (Continued)

Preliminary Design Criteria

Martin Marietta Reduction Facility RD/RA

The Dalles, Oregon

Project Description	Remedial Action	ARARS/Performance Criteria	Additional Data Needs/ Design Criteria/ Permits Required	Bench/Pilot Studies
Bath Recovery Pad Area	Excavation of contaminated soil	Excavation of defined area Verification sampling as described in the SAP Minimize settling and erosion of finished area Protection of the structural integrity of the Bath Recovery Pad Provide proper drainage for backfilled area	Air emissions controls (as necessary) Backfill selection and placement criteria Identification and existence of any utility lines	None
Unloading Area	Excavation of contaminated soil	Excavation of defined area. Any residual soils contain <2200 mg/kg fluorides Provide proper drainage for backfilled area Minimize settling and erosion of backfilled area	Air emissions controls (as necessary) Backfill selection and placement criteria Identification and existence of any utility and process lines	None

TABLE 4-1 (Continued)

Preliminary Design Criteria

Martin Marietta Reduction Facility RD/RA

The Dalles, Oregon

Project Description	Remedial Action	ARARS/Performance Criteria	Additional Data Needs/ Design Criteria/ Permits Required	Bench/Pilot Studies
Landfill	Limited re-grading of existing wastes Leachate collection system installation Consolidation of contaminated soils and wastes Cap Construction Stormwater Management	Conformance with provisions of 40 CFR 264.110 through 264.120: Conformance with provisions of 40 CFR 264.310: o Minimize migration of liquid through capped area o Minimize long-term maintenance o Minimize erosion o Provide adequate drainage o Minimize and accommodate landfill subsidence Provide access and clearance for overhead power poles and lines owned by the Bonneville Power Administration	Bonneville Power Administration access and clearance requirements Identification of acceptable landfill cap configuration and materials Identification of adequate amounts of suitable backfill and cap materials Air emissions controls (as necessary)	None

TABLE 4-1 (Continued)

Preliminary Design Criteria
Martin Marietta Reduction Facility RD/RA
The Dalles, Oregon

Project Description	Remedial Action	ARARS/Performance Criteria	Additional Data Needs/ Design Criteria/ Permits Required	Bench/Pilot Studies
Landfill Leachate Collection System	Design and construction of a leachate collection and storage system	Conformance with provisions of 40 CFR 264.301	Blasting permit (if blasting is required)	None
		o Chemical resistance to leachate	Investigation trenches for determination of basalt surface elevations.	
		o Will function over life cycle without clogging		
		o System will not collapse under design loadings		
		Development of Blasting Plan (if blasting is required)		
Perched Water Collection System	Collection and handling of perched water	Collection of perched water beneath former CWMA	Construction of Investigation trenches	None
		Collection of perched water east of River Road	Design of system for transport of perched water to storage system	

TABLE 4-1 (Continued)

Preliminary Design Criteria

Martin Marietta Reduction Facility RD/RA

The Dalles, Oregon

Project Description	Remedial Action	ARARS/Performance Criteria	Additional Data Needs/ Design Criteria/ Permits Required	Bench/Pilot Studies
Perched Water Storage/Treatment System	Storage/Treatment System of collected contaminated water Treatment of Landfill leachate	Discharge Criteria: 0.4 mg/L of free cyanide during remediation, 0.1 mg/L of free cyanide after remediation Secondary containment required for storage/treatment system Discharge from cyanide treatment system to go to Northwest Aluminum in-plant treatment system, which will control fluoride to the level specified in the NPDES permit.	CDS design criteria	Performance testing of CDS unit Fluoride removal bench testing

TABLE 4-1 (Continued)

Preliminary Design Criteria

Martin Marietta Reduction Facility RD/RA

The Dalles, Oregon

Project Description	Remedial Action	ARARS/Performance Criteria	Additional Data Needs/ Design Criteria/ Permits Required	Bench/Pilot Studies
Extension of the Municipal Water System	Connect Rockline, Klindt and Animal Shelter establishments to the City of The Dalles municipal water system Abandon Rockline, Klindt, Animal Shelter and Residence production wells	Adherence to the City of The Dalles water system design standards Proper abandonment of the production wells in accordance with all applicable provisions of city, county, and state well construction codes	Locations of existing municipal system and acceptable tapping points City of The Dalles design standards for water systems Construction permit from City of The Dalles Applicable State and local well abandonment construction codes	None
Scrubber Sludge Ponds Cover	Consolidation of pond dikes and windblown sediments into pond Placement of soil cover	Minimize long-term maintenance of cover Minimize erosion of pond areas Promote draining and accommodate settling within the Scrubber Sludge Ponds	Characterization of Pond Sludge o Consolidation testing o Determination of moisture content o Atterberg limits	None

TABLE 4-1 (Continued)

Preliminary Design Criteria

Martin Marietta Reduction Facility RD/RA

The Dalles, Oregon

Project Description	Remedial Action	ARARS/Performance Criteria	Additional Data Needs/ Design Criteria/ Permits Required	Bench/Pilot Studies
Scrubber Sludge Ponds Cover (Continued)			Air emissions controls (as necessary)	
			Backfill selection and placement criteria	

5.0 PERMITTING ASSESSMENT

Permit requirements for the remediation of the MMRF site have been divided into two categories: those permits required for off-site and on-site remedial activities.

The EPA has concluded that no permits are required for work conducted entirely on-site. In the language of the Consent Decree issued for the site remediation (Special Notice Letter (42 U.S.C. 9622 [e]) V.B.2).

> " The United States has determined that no federal, state or local permits are required for work conducted entirely on-site as described in the Scope of Work. Settling Defendant shall obtain all permits or approvals necessary for off-site work under federal, state or local laws and shall submit timely applications and requests for any such permits and approvals."

A review of permitting agencies has identified off-site permit requirements for the RD/RA project. The permits include: (1) appropriate permits and approvals for construction of the City of The Dalles water supply extension to the Rockline and Animal Shelter establishments; (2) state and local permits for the abandonment of the Klindt, Residence, Rockline and Animal Shelter production wells; (3) any off-site modifications to existing drainage patterns will be permitted by the United States Soil Conservation Service or the local designee; (4) permits, as necessary, for the transport of fill materials to the site; and (5) permits for the removal of materials from the selected borrow areas.

Permit requirements have been identified for potential borrow sources. Wasco County will require a borrow area permit for any soil removals occurring in the county. The information required for the permit includes the definition of haul routes, the identification of "sensitive receptors" to the noise and dust associated with the borrow operations, and identification of excavation areas and quantities. In addition to the Wasco County requirements, portions of the Columbia River Gorge have been classified as a National Scenic Area (NSA) by the United States Department of the Interior. Removal of borrow materials within the NSA will involve additional permitting activities.

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GERAGHTY & MILLER
ENGINEERS, INC.

GWMP
June 30, 1989

GROUND-WATER MONITORING PLAN

Prepared for

MARTIN MARIETTA CORPORATION
The Dalles, Oregon

Prepared by

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July 1989

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June 30, 1989

INTERIM GROUND-WATER MONITORING PLAN

1.0 INTRODUCTION

As part of the Record of Decision (ROD) and negotiated in the Statement of Work (SOW), an Interim Ground-Water Monitoring Plan (IGWMP) and a Long-term Ground-Water Monitoring Plan (LTGWMP) are to be developed for the remediation activities at the Martin Marietta Reduction Facility (MMRF) in The Dalles, Oregon.

1.1 INTERIM GROUND-WATER MONITORING PLAN

The purpose of the IGWMP is to collect ground-water quality data from the initiation of Remediation Design (RD) activities through implementation of the Remedial Action (RA). The locations of the wells to be sampled, as identified in the ROD and negotiated in the SOW, are summarized in Table 1. Water-level measurements will be recorded on a quarterly basis for the wells presented in Figure 1 and identified in Table 2. Variations in ground-water quality in the vicinity of the Unloading Area (UA), the former Cathode Waste Management Areas (CWMA) and Chenoweth Wells will be monitored. Thus, a data base of ground-water quality and flow encompassing both temporal and spatial variations can be established prior to completion of the RA. The Quality Assurance Project Plan (QAPP) developed for the RD/RA will be utilized for the ground-water monitoring program. The wells to be monitored are screened in both the water table aquifer(s) and deeper aquifers to provide vertical monitoring of ground-water quality. Well construction details for the wells to be monitored are summarized in Table 3.

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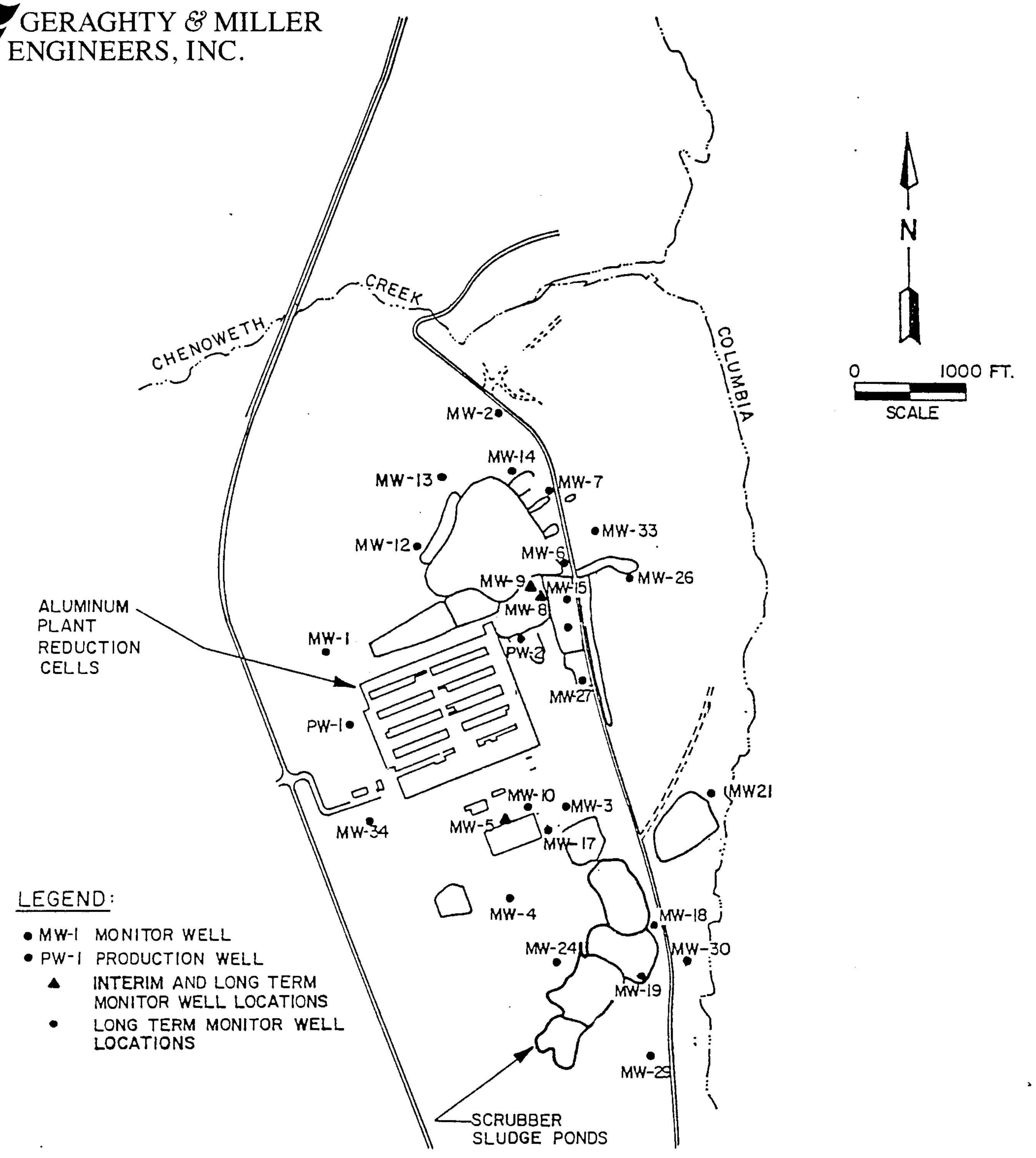

NOTE: CHENOWETH WELL #3 LOCATED APPROXIMATELY 1750 FEET SOUTHWEST FROM WELL MW-34.
CHENOWETH WELLS #1 AND #2 LOCATED APPROXIMATELY 2850 FEET SOUTH FROM CHENOWETH WELL #3

SOURCE: FINAL REMEDIAL INVESTIGATON REPORT
GERAGHTY & MILLER, INC.

FIGURE 1

DRAWING NO: FL0018-RD2-	
DRAWN BY: [illegible]	DATE: 3-7-89
CHECKED: DWM	DATE: 3-7-89
APPROVED: DCC	DATE: 3/1/89

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MONITOR WELL LOCATIONS

MARTIN MARIETTA REDUCTION FACILITY
MARTIN MARIETTA CORPORATON
THE DALLES, OREGON

TABLE 1. Monitoring Wells and Analytical Constituents
Interim Ground-Water Monitoring Program
Martin Marietta Reduction Facility
The Dalles Oregon

Aquifer System	Wells to be Monitored
S	5S, 8S, 9S
A	5A, 8A, 9A
B	8B, 9B
Other	Chenoweth Irrigation 1 or 2, and 3 if operating at time of sampling

Constituents to be analyzed: Total cyanide, free cyanide, fluoride, sulfate, pH and specific conductance.

TABLE 2. Monitor Wells for Water Level Measurement Interim Ground-Water Monitoring Program Martin Marietta Reduction Facility The Dalles, Oregon

Aquifer System	Wells to be Monitored
S	2S, 5S, 8S, 9S, 15S, 17S, 18S, 19S, 21S, 24S, 26S, 27S, 29S
A	1A, 4A, 5A, 6AA, 7A, 8A, 9A, 10A, 12A, 13A, 14A, 15A, 27A, 30S, 33A
B	1B, 3A, 8B, 9B, 12B, 14B, 18A, 26B, 27B, 33B, 34A
DGWR	PW-1
Other	Chenoweth Irrigation 1 or 2, and 3 if operating at time of sampling

TABLE 3 -- WELL CONSTRUCTION DETAILS SUMMARY

WELL ID	WELL DIAM (IN)	DATE INSTALLED	SCREENED INTERVAL (FT BLS)	TOTAL DEPTH (FT BLS)	GEOLOGIC UNIT	TOPC ELEVATION (FT MSL)	PUMP PORT ELEVATION (FT MSL)	RISER ELEVATION (FT MSL)	PAD ELEVATION (FT MSL)	RISER STICK-UP (FT)	NORTH COORDINATE	EAST COORDINATE	TOTAL DEPTH (FT BTOPC)	TYPICAL EVACUATION METHOD
MWR-1A	2	20-Jul-87	129.0 - 139.0	140.0	RU	146.62	NA	146.15	143.49	3.13	715,204.50	1,818,497.94	143.1	BAILER
MWR-1B	4	17-Jun-87	186.0 - 196.0	197.0	RL	146.81	146.16	146.06	143.71	3.10	715,207.95	1,818,481.56	200.1	SUB-PUMP
MW -2S	2	17-Jul-87	29.0 - 39.0	40.0	RS	111.47	NA	110.15	108.63	2.84	717,007.60	1,819,814.12	42.8	BAILER
MWR-3A	2	22-Jul-87	151.5 - 161.5	162.0	RL	138.30	NA	137.81	135.62	2.68	714,009.82	1,820,395.66	164.7	HYDROSTAR
MWR-4A	2	22-Jul-87	129.0 - 139.0	139.0	RU	140.21	NA	139.94	138.10	2.11	713,268.56	1,819,952.76	141.1	HYDROSTAR
MW -5S	2	18-Jul-87	10.5 - 20.5	20.5	L	141.56	NA	140.40	138.27	3.29	713,799.64	1,819,950.79	23.8	BAILER
MW -6AA	2	16-May-84	121.0 - 126.0	126.0	RU	130.58	NA	128.75	128.25	2.33	715,895.46	1,820,317.57	128.3	BAILER
MWR-7A	2	16-Jul-87	127.5 - 137.5	138.0	RU	129.38	NA	128.91	126.77	2.61	NA	NA	140.6	BAILER
MW -8S	2	25-Jun-87	40.0 - 50.0	50.0	RS	140.92	NA	140.49	137.63	3.29	715,568.18	1,820,238.72	53.3	BAILER
MWR-8A	6	02-Jul-87	120.0 - 140.0	140.0	RU	139.02	NA	NA	137.86	1.16	715,570.07	1,820,222.42	141.2	SUB-PUMP
MWR-8B	8	02-Jul-87	170.0 - 200.0	200.0	RL	139.54	NA	NA	138.13	1.41	715,571.48	1,820,200.09	201.4	SUB-PUMP
MW -9S	2	18-Jun-87	44.0 - 54.0	54.0	RS	141.47	NA	141.00	138.11	3.36	715,627.45	1,820,134.85	57.4	BAILER
MWR-9A	2	18-Jun-87	126.0 - 136.0	140.0	RU	141.45	NA	140.94	138.16	3.29	715,623.51	1,820,122.49	143.3	HYDROSTAR
MWR-9B	4	30-Jun-87	190.0 - 200.0	200.0	RL	141.73	141.24	141.13	138.71	3.02	715,611.97	1,820,135.79	203.0	SUB-PUMP
MW -10A	2	21-Mar-85	107.0 - 117.0	117.0	RT	140.59	NA	139.69	138.05	2.54	713,940.82	1,820,124.10	119.5	HYDROSTAR
MW -12A	2	05-Jun-86	131.5 - 120.9	131.7	RU	141.77	NA	141.36	139.34	2.43	716,188.01	1,819,164.71	134.1	BAILER
MW -12B	4	06-Jun-86	192.4 - 202.5	205.0	RL	142.47	NA	141.69	139.48	2.99	716,194.13	1,819,182.27	208.0	SUB-PUMP
MW -13A	2	Jun-87	121.2 - 131.8	132.0	RU	140.34	NA	139.47	137.85	2.49	716,577.70	1,819,361.18	134.5	BAILER
MW -14A	2	10-Jun-86	130.2 - 140.8	141.0	RU	138.39	NA	137.96	136.07	2.32	716,624.08	1,819,978.83	143.3	BAILER
MW -14B	4	04-Jun-86	192.7 - 203.3	204.0	RL	138.44	NA	137.62	135.75	2.69	716,623.32	1,819,955.79	206.7	SUB-PUMP
MW -15S	2	15-May-86	46.9 - 57.5	58.0	RS	142.35	NA	141.52	139.06	3.29	715,574.91	1,820,399.91	61.3	BAILER
MW -15A	2	12-Jun-86	112.2 - 122.8	123.0	RU	141.80	NA	141.37	138.79	3.01	715,588.64	1,820,395.71	126.0	BAILER
MW -17S	2	09-Jun-86	19.4 - 30.0	30.0	RS	139.09	NA	138.54	136.91	2.18	713,733.85	1,820,280.23	32.2	BAILER
MW -18S	2	09-Jun-86	11.4 - 22.0	22.0	RS	111.31	NA	110.92	109.03	2.28	713,002.83	1,821,186.90	24.3	BAILER
MW -18A	6	14-Jul-87	112.0 - 132.0	132.0	RL	111.61	NA	NA	108.76	2.85	712,998.69	1,821,172.19	134.9	--
MW -19S	2	09-Jun-86	15.4 - 26.0	26.0	RS	108.71	NA	108.37	105.70	3.01	712,552.44	1,821,072.93	29.0	BAILER
MW -21S	2	13-Jun-86	54.4 - 65.0	65.0	RT	106.46	NA	105.94	104.39	2.07	714,092.42	1,821,612.65	67.1	BAILER
MW -24S	2	18-Jul-87	11.5 - 21.5	21.5	L	141.13	NA	139.91	138.09	3.04	712,665.58	1,820,323.13	24.5	BAILER
MW -26S	2	08-Jul-87	40.0 - 50.0	50.0	B	132.85	NA	132.29	129.95	2.90	715,781.03	1,820,811.58	52.9	BAILER
MW -26B	4	08-Jul-87	181.5 - 191.5	192.0	RL	132.61	132.13	132.00	129.58	3.03	715,763.51	1,820,825.13	195.0	SUB-PUMP
MW -27S	2	Jul-87	42.0 - 52.0	54.0	B	138.64	NA	137.69	135.75	2.89	715,002.89	1,820,519.27	56.9	BAILER
MW -27A	2	10-Jul-87	127.0 - 137.0	138.0	RU	137.64	NA	137.52	135.67	1.97	715,013.45	1,820,516.31	140.0	BAILER
MW -27B	2	01-Jul-87	179.0 - 189.0	189.0	RL	138.60	NA	138.11	135.83	2.77	715,025.85	1,820,513.94	191.8	--
MW -29S	2	23-Jul-87	12.0 - 22.0	25.0	RS	114.72	NA	114.18	111.98	2.74	712,011.60	1,821,145.83	27.7	BAILER

MMRF, THE DALLES

TABLE 3 -- WELL CONSTRUCTION DETAILS SUMMARY

WELL ID	WELL DIAM (IN)	DATE INSTALLED	SCREENED INTERVAL (FT BLS)	TOTAL DEPTH (FT BLS)	GEOLOGIC UNIT	TOPC ELEVATION (FT MSL)	PUMP PORT ELEVATION (FT MSL)	RISER ELEVATION (FT MSL)	PAD ELEVATION (FT MSL)	RISER STICK-UP (FT)	NORTH COORDINATE	EAST COORDINATE	TOTAL DEPTH (FT BTOPC)	TYPICAL EVACUATION METHOD
MW -30S	2	18-Aug-87	51.5 - 61.5	61.5	RU	109.25	NA	108.79	106.30	2.95	712,685.95	1,821,406.12	64.5	--
MW -33A	2	20-Aug-87	117.0 - 127.0	127.0	RU	104.42	NA	103.85	101.42	3.00	716,286.76	1,820,532.47	130.0	BAILER
MW -33B	2	Aug-87	156.0 - 166.0	166.0	RL	104.69	104.49	104.16	101.47	3.22	716,295.05	1,820,531.84	169.2	HYDROSTAR
MW -34A	2	Aug-87	151.0 - 161.0	161.0	RL	146.58	NA	146.03	143.46	3.12	713,843.96	1,818,851.67	164.1	BAILER
PRODUCTION WELL														
PW -1	20	01-Jul-57	220.0 - 314.0	314	SG	NA	NA	NA	144.30	NA	NA	NA	NA	SUB-PUMP
OFF-SITE WELLS														
CHEN #1		May-46	OPEN HOLE	258	NA	NA	NA	NA	NA	NA	NA	NA	NA	SUB-PUMP
CHEN #2		1949	OPEN HOLE	260	NA	NA	NA	NA	NA	NA	NA	NA	NA	SUB-PUMP
CHEN #3		May-56	OPEN HOLE	275	NA	NA	NA	NA	NA	NA	NA	NA	NA	SUB-PUMP

NOTES:
FT MSL = FEET ABOVE MEAN SEA LEVEL
FT BLS = FEET BELOW LAND SURFACE
TOPC = TOP OF PROTECTIVE CASING
NA = NOT AVAILABLE/NOT APPLICABLE
B = BYRON
L = LOLO
RS = ROSALIA SUBAERIAL
RT = ROSALIA TRANSITION
RU = ROSALIA UPPER GLASS
RL = ROSALIA LOWER GLASS
SG = SENTINEL GAP

ALL WELLS COMPLETED WITH PVC WITH THE EXCEPTION OF WELLS 8A, 8B, 18A, PW-1, CHEN # 1, 2, AND 3, WHICH WERE COMPLETED WITH STEEL.

047DAL10:WELLCON.WK1

1.2 LONG-TERM GROUND-WATER MONITORING PLAN

During the last quarter of 1990, the LTGWMP shall be initiated to monitor variations in ground-water quality at the target remediation areas, and the effectiveness of the perched water recovery operation. Table 4 lists the monitoring wells that will be sampled as part of the long-term ground-water monitoring program, and the constituents that will be analyzed. The locations of long-term monitoring wells are provided on Figure 1, and well construction details are summarized in Table 3.

TABLE 4. Monitor Wells and Analytical Constituents
Long-Term Ground-Water Monitoring Program
Martin Marietta Reduction Facility
The Dalles, Oregon

Aquifer System	Wells to be Monitored
S	2S, 5S, 8S, 9S, 15S, 17S, 18S, 19S, 21S, 24S, 26S, 27S, 29S
A	1A, 4A, 5A, 6AA, 7A, 8A, 9A, 10A, 12A, 13A, 14A, 15A, 27A, 30S, 33A
B	1B, 3A, 8B, 9B, 12B, 14B, 18A, 26B, 27B, 33B, 34A
DGWR	PW-1
Other	Chenoweth Irrigation 1 or 2, and 3 if operating at time of sampling

Constituents to be analyzed: Total cyanide, free cyanide, fluoride, sulfate, pH and specific conductance.

FL0018.RD2\TBL\GWPTAB3

2.0 MONITORING PARAMETERS AND FREQUENCY

2.1 INTERIM GROUND-WATER MONITORING PLAN

The wells to be monitored during the interim period will be sampled on a quarterly basis and analyzed for temperature, pH, and specific conductance in the field and samples will be sent to the laboratory for analysis of fluoride, sulfate, total cyanide, and free cyanide.

2.2 LONG-TERM GROUND-WATER MONITORING PLAN

Monitoring shall be conducted quarterly in the long-term program for the first year, semi-annually for the second year, and annually thereafter through the end of year five. Laboratory analysis of total cyanide, free cyanide, fluoride, and sulfate will occur, in addition to field measurements of pH, temperature, and specific conductance. The analytical parameters are the same ones that will be measured during the Interim Monitoring Program. The monitoring program shall be reviewed by Martin Marietta and the USEPA on an annual basis, and modified if necessary. At the end of five years, Martin Marietta will evaluate the monitoring program, and determine, after review by EPA and ODEQ, if continued ground-water monitoring is required, or if adjustments to the existing program are needed. The program shall be evaluated annually thereafter.

3.0 FIELD PROCEDURES

Field protocol to be used in the implementation of the Ground-Water Monitoring Plan will be consistent with those used during the Remedial Investigation completed at the site. These procedures are outlined below.

3.1 GROUND-WATER LEVEL MEASUREMENTS

The static water level will be measured in each well with a steel tape or electric sounder prior to evacuating the well. Water levels will be measured in all wells listed on Table 3 during each sampling period. The total depth in each well will also be measured annually to determine if excessive silting has occurred. Redevelopment of the well will be carried out if excessive silting has occurred.

3.2 WELL PURGING

Prior to sampling, the wells will be purged by evacuating a minimum of four casing volumes. Purged water will be discharged through the NPDES via the Recycle Pond. If the well pumps dry prior to evacuating four casing volumes, the well will be left to recover until a sufficient volume of water enters the casing for sample collection. Wells will be evacuated using either a 1075 ml Galtek Teflon bailer, a pneumatic Hydrostar^{TM} pump, or an electric submersible pump. Evacuated volumes will be measured using a 5-gal bucket or a flow meter. The evacuation methods typically used for the wells to be monitored are summarized on Table 3.

3.3 SAMPLE COLLECTION

After evacuation of the well, a ground-water sample will be collected directly into the sample containers. For wells that are bailed, the water sample will be transferred directly from the bailer to the sample container. Dedicated bailers have been installed inside the well casing suspended by a Teflon-coated wire from the well cap. Ground-water samples taken from wells with submersible and Hydrostar^{TM} pumps will be taken from discharge spigots.

On-site testing of ground water will be performed during sample collection for water temperature, specific conductance and pH. The specific conductance apparatus will be calibrated daily using a Standard 1990 μmho/cm solution of KCl and the pH meter will be calibrated before each use to buffered pH7 and pH4 solutions.

4.0 SAMPLE PRESERVATION AND ANALYSIS

The samples will be stored with wet or blue ice in a cooler after collection. The types of bottles and preservatives to be used for analysis of the various parameters are identified in the QAPP.

All wells will be analyzed by the laboratory for total cyanide, free cyanide, fluoride, and sulfate, per the QAPP.

5.0 DOCUMENTATION

A "Water Sampling Log" as shown in Figure 2, will be filled out for each well sampled. The "Chain of Custody" form and protocol as discussed in the QAPP will be followed. One replicate and one field blank will be collected per 20 samples per matrix per sampling event. Equipment rinsate blanks will not be required because dedicated teflon bailers have been installed inside the well casing. Trip blanks will also not be required, because analyses for volatile organic compounds will not be performed. A copy of the sample bottle label is also shown in the QAPP.

Data validation will be performed as discussed in the QAPP according to USEPA Laboratory Data Validation Functional Guidelines.

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WATER SAMPLING LOG

Figure 2

Date: ______________ Sample I.D.: ______________

Time: ______________ Weather: ______________

Samplers: ______________________________

Witnesses: ______________________________

Film Exposure Number: __________ Plastic Ground Cover: Yes / No

Air Quality Measurements: __________ Instrument: __________

Evacuation Data:

A. Well Depth:________ ft B. Water Level:____ ft

C. Water Column (C=A-B): _____ ft D. Well Volumes (Gal/Ft)
2" = .16 6" = 1.46
4" = .65 8" = 2.61

E. Well Volume (E=CxD):____ gal F. Purge Volume (F=4XE): _____ gal

Pumping Rate: ________ gal/min Purge Time: ________ min

Purge Start: ____________ Purge End: ____________

Comments:______________________________

____

Sampling Data

Temperature: ________ pH: __/__/__/__ Specific Conductance: __/__/___/___

Physical Appearance: ______________________ Composite/Grab

Samples Taken:	Container	Preservative	Analysis

Comments: ______________________________

____

Signature:______________________

6.0 DATA REPORTING

6.1 INTERIM GROUND-WATER MONITORING PROGRAM

Water quality data and a summary of the water level elevations will be reported to the EPA and the Oregon DEQ on a quarterly basis (four weeks after receipt of final laboratory results). In addition, two water level contour maps (seasonal high and low) for each of the aquifers, monitoring well hydrographs, and data summaries of water quality parameters will be submitted on an annual basis. Trend analysis plots will be completed for any of the water quality parameters indicating significant variation.

6.2 LONG-TERM GROUND-WATER MONITORING PROGRAM

Reporting for the long-term ground-water monitoring program shall consist of annual reports and data submissions. The annual report will summarize the water quality data and the results of the data validation. The water level data will also be summarized and represented in a water level contour map. Reporting during the first two years, in addition to an Annual Report, shall consist of submitting the analytical data from the ground-water sampling events to EPA after the laboratory analysis has been completed. Thereafter, the Respondent shall submit annual reports. Likewise, on an annual basis, the reporting requirements and program shall be reviewed by Martin Marietta and EPA, and modified if necessary.

At the end of five years, Martin Marietta shall re-evaluate the entire ground-water monitoring program, and determine, after review by EPA and ODEQ, continued groundwater quality monitoring is required, or if adjustments to the existing program are needed. Re-evaluation shall occur annually thereafter.

7.0 ASSESSMENT MONITORING PLAN

An Assessment Monitoring Plan for ground water in the vicinity of the Unloading Area will be incorporated into the Interim Ground-Water Monitoring Plan. An Alternate Concentration Limit (ACL) of 9.7 mg/L has been proposed as the remediation criterion for fluoride in the shallow ground water (S-aquifer) at the MMRF site. The only well that currently exceeds the proposed remediation criterion (MW-5S) is located in the S-aquifer near the Unloading Area. It is anticipated that soon after removal of the residual cathode waste material from the Unloading Area, fluoride concentrations in the S-aquifer near the Unloading Area, as measured by Monitoring Well MW-5S, will begin to decrease.

Well MW-5S is included as part of the Interim Ground-Water Monitoring Plan. The quarterly monitoring data for fluoride for this well will be plotted and evaluated by trend analysis during the remedial design phase of the project and for a period of 5 years from completion of remediation of the Unloading Area.

The trend analysis plots will be reviewed periodically during this time period and, if at three years from initiation of remedial action they do not indicate that the ACL will be attainable within 5 years from initiation of remediation or that the water quality will continue to decline to below the ACL, then ground-water pumping and treatment will be implemented.

The RD/RA Scope of Work (2/89) discussed in detail the recovery well plan to be implemented, if necessary.

8.0 CONTINGENCY PLAN

The following plan would be implemented if the ground-water monitoring program indicates that appropriate ARARs or remediation criteria are exceeded. Different scenarios exists which would require ground-water response actions. These include: 1) contamination above an ARAR or other remediation criteria in the A-aquifer beneath the Landfill; and 2) contamination above an ARAR or other remediation criteria in the B-aquifer beneath the Landfill. Should an ARAR or other remediation criteria be exceeded in both the A- and B-aquifers, the response actions for both scenarios would be conducted simultaneously.

A-Aquifer Response Plan. It is anticipated that recovery of ground-water could be conducted by installing two four-inch diameter recovery wells downgradient of the Landfill. It has been estimated that each well would be pumped at a continuous flow rate of 20 gpm for a total recovery rate of 40 gpm. The recovered ground-water would be transferred to a treatment unit if cyanide performance standards are exceeded and would then be routed to the roof scrubber recycle system directly if fluoride criteria are exceeded.

B-Aquifer Response Plan. The recovery system here would be constructed by installing three four-inch diameter recovery wells in the B-aquifer downgradient of the Landfill. The recovery wells would be operated at a continuous flow rate of approximately 100 gpm for a combined flow rate of 300 gpm. The recovered ground water would be transmitted to a treatment unit if cyanide performance standards are exceeded and would then be routed to the roof scrubber recycle system directly if fluoride criteria are exceeded.

The recovery systems would require field testing to verify the design criteria presented herein. One recovery well would be installed initially and pumping tests (step and constant rate) would be performed to determine the location of additional recovery wells. The testing would also verify optimum pumping rates. Water quality sampling would also be conducted during test pumping to determine the fluctuation of the ARAR or remediation criteria with time.

A critical part of the contingency plan is the statistical analysis of ground-water data. The water quality data will be plotted for trend analysis. These plots will determine if the results from a specific analysis lie within a projected trend or are anomalous. They will also evaluate the effectiveness of the recovery system to determine if other actions are required.

Resampling will be required to substantiate water quality data prior to initiating any response action. The re-sampling of contaminated well(s) will occur within two weeks of data validation. If the second sample result is within remediation criteria then the well will be sampled again during the next scheduled sampling period to further verify that the earlier detected concentration was in error.

QUALITY ASSURANCE PROJECT PLAN FOR REMEDIAL DESIGN/REMEDIAL ACTION PROGRAM AND GROUND-WATER MONITORING PROGRAM FOR THE MARTIN MARIETTA REDUCTION FACILITY THE DALLES, OREGON

Prepared for

MARTIN MARIETTA CORPORATION
The Dalles, Oregon

by

Geraghty & Miller, Inc.

July 1989

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3.0 PROJECT DESCRIPTION

In March 1988, Martin Marietta Corporation (MMC) submitted to the U.S. Environmental Protection Agency (EPA), the final Remedial Investigation Report (RIR) for the Remedial Investigation and Feasibility Study (RI/FS) conducted at the Martin Marietta Reduction Facility (MMRF), The Dalles, Oregon by Geraghty & Miller, Inc. (G&M). The Feasibility Study of the RI/FS was submitted in June 1988 and presented the remedial alternatives evaluated for remediation of the MMRF.

A scope of work (SOW) for the selected Remedial Design/Remedial Action (RD/RA) was submitted in February 1989. In accordance with the EPA's Record of Decision (ROD), (dated September 29,1988) MMC is required to ensure that the accomplishment of the work specified in the SOW meets the performance standards set forth in the November 20, 1985 National Contingency Plan (NCP), the Superfund Amendments and Reauthorization ACT of 1986, the consent order, and the ROD for the site.

In order to achieve the objectives of the RD/RA, a Sampling and Analysis Plan (SAP) has been prepared. The purpose of the SAP is to provide input data to the RD through the use of field investigations and sample collection and analyses such that various parameters for the selected remedial action are designed to meet performance criteria. The remedial action consists of site civil work and unit treatment process evaluation. Site civil work includes excavation, backfill, and construction of a cover and cap meeting RCRA performance standards.

Elements described within the SAP include bench analysis and/or pilot studies for the design of treatment unit processes, and site geotechnical evaluation. The site civil work requires: (1) The collection and geotechnical analysis of material in the Scrubber Sludge Ponds; (2) The identification, classification, and geotechnical testing of local borrow areas for general fill and fine-grained cohesive soils; (3) The laboratory testing of amended soils; (4) The general earthwork activities required to define the alignment and required construction effort for various design elements; and (5) Verification sampling trenches to be excavated in the Salvage, Bath Recovery Pad, and the Unloading Areas to determine the lateral and vertical extent of contamination.

In order to ensure achievement of the required performance standards, sampling and monitoring plans must include a Quality Assurance Project Plan (QAPP). Sampling and laboratory analyses of soils, ground water, and other media must be performed in accordance with current EPA sampling and laboratory protocols and QA procedures. Therefore, a QAPP has been prepared in accordance with the EPA "Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans," QAMS-005/80. As such, this QAPP defines the quality assurance procedures to be followed during the sampling and analyses phases of the RD/RA and the subsequent Ground-Water Monitoring Program.

3.1 SCOPE OF WORK

The scope of work for this investigation will consist of the following:

3.1.1 Remedial Design/Remedial Action Program

The objectives of the RD/RA at the MMRF site are to accomplish the following:

- Consolidate the residual cathode waste material and underlying fill material from the former Cathode Waste Management Areas;
- Collect and treat perched water beneath the former Cathode Waste Management Areas during consolidation activities and east of River Road, to the extent practical;
- Consolidate the cathode waste material from the Unloading Area into the existing Landfill;
- Cap the existing Landfill in place with a multi-media cap meeting RCRA performance standards in 40 CFR 264.310;
- Collect and treat any leachate generated from the Landfill once construction of the cap is complete;
- Cover Scrubber Sludge Ponds 2 and 3 with a soil cover meeting performance standards at 40 CFR 264.310 (a) (2), (3) and (4);
- Abandon selected production wells specified in the SOW;
- Recover contaminated ground water from the Unloading Area, if required, and discharge it to the Recycle Pond where it will be treated by the in-plant process;
- Implement ground-water quality monitoring and a contingency plan to perform additional recovery and treatment of ground water, as required.

3.2 DESIGNATED TASKS

3.2.1 Site Civil Evaluations

3.2.1.1 Geotechnical Data

Geotechnical data will be gathered from Scrubber Sludge Ponds 2 and 3, the existing landfill, and local borrow sources. The sampling and testing of subsurface soils are requirements of the remediation efforts at the site, and will be performed in accordance with test methods identified in the Table 1 and in the SAP. The purpose of these activities is to provide geotechnical data including soil classification and properties, surface profiles of the underlying basalt formation, the properties of bentonite-soil admixtures and an evaluation of the quantity and quality of locally available borrow material sources. The details of the site civil evaluations are presented in the Section No. 2. of the SAP.

3.2.1.2 Verification Sample Trenches

Verification sampling to determine the lateral and vertical extent of contaminated areas is a requirement of the site remediation. The limits of contamination (as presented in Section 2.4 of the SAP) have been determined by the historic location of buildings and other structures on the site but, in some areas, the limits of the contaminated material cannot be precisely determined. MMC proposes to excavate and sample a series of test trenches to precisely establish the limits of areal excavation.

TABLE 1

Geotechnical Test Methods For Soil Evaluated at the MMRF, The Dalles, Oregon

NAME OF TEST	METHOD
Soil Description	ASTM D-2488
Soil Classification	ASTM D-2487
Water Content	ASTM D-2216
Atterberg Limits	ASTM D-4318
Particle-size Analysis	ASTM D-422
Moisture-density Relationship	ASTM D-698
Falling-head Permeability with Pressure Chamber (Saturated Sample)	EM 1110-2-1906 USCE App. VII (6)
One-Dimensional Consolidation	ASTM D-2435
Sampling by Auger Methods	ASTM D-1452
Thin-walled Tube Sampling	ASTM D-1587

NOTE: The individual tests to be conducted at each area identified in Tables 2-1 and 2-2 in the SAP (Appendix A).

FL0018.RD2\TBL\TABLE1.QAP

Verification sampling trenches will be excavated in the Salvage, Bath Recovery Pad, and the Unloading Areas for the purpose of verifying the boundaries of the contaminated areas. Samples will be obtained from the trench walls and tested for the presence of contaminants, as required, based on the identification of contaminants of concern in the particular verification sampling area. Details of the investigation methodology and laboratory testing are presented in Section 2.4 of the SAP. An investigation report summarizing the results of the verification analysis will be prepared and submitted with the final design documentation.

3.2.1.3 Field Quality Control

All procedures to be carried out for the development of geotechnical data will be done in accordance with the approved methods. All field activities will be recorded in Daily logs and all field measurements will be recorded in field logs as described in Sections 6.0 "Sampling Procedures" and Section 7.0 "Sample Custody Procedures." Soil samples collected for analysis during the verification sampling program will be obtained from the outside wall of each verification trench. Four soil samples will be collected from randomly selected locations for each 200 square feet of outside trench wall as described in Section 2.4 of the SAP. Soil samples will be composited into single samples for analysis as described in Section 6.0, "Sampling Procedures", and analyzed for the parameters described in Table 2.

Field quality control samples to be collected for the verification sampling program will consist of one aqueous field blank and one equipment rinsate blank. These field

TABLE 2

Summary of Soil Sampling Locations, Parameters, and Field Quality Control Samples for the Verification Sampling Program at the MMRF, The Dalles, Oregon

Location	Number of Samples	Parameters[1/]	Aqueous Field Blank	Rinsate Blanks	Total Soil	Total Blanks
Unloading Area	4	F[2/]	1	1	4	2
Bath Recovery Pad	4	F	-	-	4	-
	4	cPAHs[3/]	1	1	4	2
Salvage Area	4	F	-	-	4	-
	4	cPAHs	-	-	4	-

1/ Methods of analysis for parameters listed are presented in Table 3.

2/ F= Fluoride

3/ cPAHs = Carcinogenic polynuclear hydrocarbons listed in Table 4.

FL0018.RD2\TBL\TABLE 2.QAP

quality control samples will be collected at the locations shown in Table 2 and analyzed along with composite soil samples for the indicated parameters.

Documentation of sample collection and custody will be in accordance with procedures described in Section 7.0 "Sample Custody" and all samples will be submitted to the analytical laboratory in sealed coolers with standard Chain-of-Custody forms as described in Section 7.0. Analysis of identified parameters will be in accordance with methods described in Table 3.

3.2.2 <u>Evaluation of Treatment Systems</u>

As described in the SAP developed as part of the RD/RA, the evaluation of treatment processes for cyanide destruction and fluoride removal are requirements of the remediation efforts at the site. The following sub-sections outline the methods and procedures to be used in the evaluation of the unit processes.

3.2.2.1 Cyanide Destruction

As described in the SAP (Section 3.1.1), MMC proposes to purchase a cyanide hydrolysis unit based on the results of the bench scale analysis. MMC proposes to conduct performance tests on the installed unit to verify that it will meet the performance standards for cyanide destruction outlined in the NPDES permit for site discharges.

The performance tests will utilize perched water collected from the Cathode Waste Management Areas. The perched water will be pumped to a storage facility and then

TABLE 3

Selected Chemical Parameters and Methods of Analysis for Water and Soils at MMRF The Dalles, Oregon

Parameter	Method	Reference
Water Matrix		
Sulfate	375.4	1
Fluoride	340.2	1
Total Cyanide	335.2	1
Free Cyanide	412.H	2
Soil Matrix		
Fluoride	340.2 Mod	3
cPAHs	8270	4
Field Measurements		
pH	150.1	1
Specific Conductance	120.1	1
Temperature	170.1	1

1. Methods for Chemical Analysis of Water and Wastes, EPA-600/4-79-020.

2. Standard Methods for the Examination of Water and Waste-Water, 16th Edition, 1985.

3. Methods for Chemical Analysis of Water and Wastes, EPA 600/4-79-020. Method has been modified for analysis of fluoride in soil by employing a 24-hour leach of the soil sample and subsequent analysis of leachate. This procedure was presented in the Versar Inc., SOP, approved by EPA Region X, for the RI/FS.

4. Test Methods for Evaluating Solid Wastes, Physical/Chemical Methods, SW-846, 3rd Edition. Specific carcinogenic PAHs are listed in Table 4.

TABLE 4

Carcinogenic Polynuclear Aromatic Hydrocarbons to be Analyzed in Soil Samples at MMRF, The Dalles, Oregon

CARCINOGENIC PAHs
Benzo(a) anthracene
Benzo(b) fluoranthene
Benzo(k) fluoranthene
Benzo(a) pyrene
Chrysene
Dibenzo(a,h) anthracene
Indeno(1,2,3-cd) pyrene

FL0018.RD2\TBL\TABLE4.QAP

pumped to a cyanide hydrolysis unit for destruction of cyanide. The discharge from the cyanide hydrolysis unit will be recycled to the perched water storage facility during start-up and until the unit is operating under standard conditions. Under standard conditions, samples of the feed and discharge waters of the cyanide hydrolysis unit will be taken and analyzed by the analytical lab for total and free cyanide by methods described in Table 3. The discharge of the unit will continue to be recycled to storage until analytical results indicate compliance with the cyanide discharge criteria. At that time, the discharge will be sent to the in-plant treatment system. The efficacy of the treatment system will be determined by comparison of results obtained from analysis of the feed and discharge of the treatment system.

3.2.2.2 Fluoride Removal

Pilot testing for fluoride removal will be conducted to evaluate the degree of fluoride removal achievable by chemical precipitation. The feed source of fluoride contaminated water will be the discharge from the cyanide destruction system or the storage tank, as applicable. The purpose of the bench study will be to evaluate reagent usage and residence times required for achieving the fluoride discharge standard of 9.7 mg/L.

A sample of the feed source will be collected for fluoride analysis and will provide the initial fluoride concentration. The sample will be analyzed by the analytical laboratory for fluorides in accordance with the method listed in Table 3. Jar tests will be set up using gang stirrers or equivalent to initially screen reagent additions. Reagents will consist of caustic (NaOH), calcium chloride ($CaCl_2$) and lime (CaOH) in combination.

Theoretical dosages will be calculated based on initial fluoride concentrations. Caustic will be added to each jar to adjust pH and dosages of lime and/or calcium chloride will be added to the jars in sufficient quantities to bracket the theoretical values. Samples will be agitated and physical observations noted. Sediment formed will be dried using a vacuum filter and the dry solids will be weighed to estimate sludge volumes. The supernatant will be drawn off and analyzed for fluoride concentration. The process may be repeated as necessary to optimize dosages to meet 9.7 mg/L.

3.2.2.3 Field Quality Control

The sample collection techniques required for the collection of the samples for both the cyanide destruction evaluation and the fluoride removal study are described in Section 6.0 "Sampling Procedures" and the selected test methodology to be followed is presented in Table 1. The cyanide-containing samples collected will be screened for the presence of sulfide and oxidizers, properly preserved, and labeled. These include one feed, one discharge, and a field replicate of the feed.

The fluoride removal study (jar tests) will be conducted by MMC until dosage rates and residence times necessary to achieve the 9.7 mg/L discharge standard are obtained. Once the optimal dosage rates and residence times are determined, a sample of the discharge of the fluoride removal system will be collected and submitted to the analytical laboratory along with a field replicate for verification.

No sampler rinsate blanks or trip blanks will be required for either the cyanide destruction evaluation or the fluoride removal study. All samples will be submitted to the analytical laboratory with a field blank for fluoride and total and free cyanide. MMC will measure and record the pH, temperature, and specific conductance of all water samples at the time of collection. All samples will be analyzed within applicable holding times referenced in Section 5.0 "Data Quality Objectives" and will be collected, transported and stored in accordance with procedures referenced in Section 6.0 "Sampling Procedures" and Section 7.0 "Custody Procedures."

3.2.3 Ground-Water Monitoring Sampling and Analysis

The ground-water monitoring program for the RD/RA is divided into two phases, (1) interim ground-water monitoring and long-term ground-water monitoring. Each of these are separately discussed below.

3.2.3.1 Interim Ground-Water Monitoring Plan

The purpose of the Interim Ground-water Monitoring Plan is to collect ground-water quality data from the initiation of RD activities through completion of the RA. The wells to be monitored are shown on Figure 1 of the Ground-Water Monitoring Plan (GWMP).

Ground-water quality in the vicinity of the Unloading Area, the Former Cathode Waste Management Areas and selected Chenoweth wells will be monitored. Thus, a data base of ground-water quality and flow, encompassing both temporal and spatial variations, can be established prior to completion of the RA. The wells to be monitored are screened in both the water table aquifer(s) and deeper aquifers to provide vertical monitoring of ground-water quality. Well construction details for the wells to be monitored are presented in the GWMP.

The wells to be monitored during the interim period will be sampled on a quarterly basis and analyzed for temperature, pH, and specific conductance in the field. Ground-water samples will be sent to the analytical laboratory for analysis of fluoride, sulfate, total cyanide and free cyanide by methods specified in Table 3.

The static water level will be measured quarterly in each well as presented in the GWMP. Water-level measurements described in Section 6.0 will be made with a steel tape or electric sounder prior to evacuating the well.

3.2.3.2 Long-Term Ground-Water Monitoring Plan

During the last quarter of 1990, the long-term monitoring plan will begin in order to monitor the effectiveness of the remedial activities, in addition to verifying long-term ground water quality at the site. Long-term ground-water monitoring, as described in the GWMP, will be conducted semi-annually for the first year and annually thereafter, through the end of year five. However, on an annual basis, the ground-water monitoring program will be reviewed by the Respondent and EPA, and modified if necessary.

3.2.3.3 Field Quality Control

Interim Ground-Water Monitoring Plan

The total number of samples expected to be collected and analyzed during each quarter of the interim ground-water monitoring program including field QC samples (replicates and blanks) is 10 to 12 depending upon which Chenoweth wells are operating at the time of sampling.

Long-Term Ground-Water Monitoring Plan

The total number of samples expected to be collected and analyzed during each sampling period of the long-term ground-water monitoring program including field QC samples (replicates and blanks) is 43 or 44 depending upon whether the Chenoweth Irrigation Well No. 3 is operating at the time of sampling.

Field replicates for all parameters will be collected and analyzed along with the ground-water samples at a frequency of 1 per 20 samples per matrix per sampling event. Equipment rinsate blank will not be required because dedicated teflon bailers have been installed inside the well casing suspended by a Teflon-coated stainless steel wire from the well cap. Field blanks for all parameters will be prepared at a frequency of 1 per 20 samples per matrix per sampling event. Trip blanks for volatile organic compounds will not be required.

All samples for total and free cyanide analysis will be screened in the field prior to preservation, for the presence of sulfide and oxidizers in accordance with the procedures described in Section 6.0. All samples will be maintained on ice, transported in sealed coolers using standard chain-of-custody forms and seals, and analyzed by the analytical laboratory identified in Section 4.0 "Organization and Personnel," in accordance with the required water analysis techniques described above and presented in Table 3. All samples will be analyzed within acceptable holding times referenced in Section 5.0 "Data Quality Objectives," and will be collected, preserved, transported, and stored in accordance with procedures referenced in Section 6.0 "Sampling Procedures" and Section 7.0 "Custody Procedures."

All field work including soil borings, pumping tests, treatability studies and sample collecting activities will be supervised by qualified personnel.

3.2.4 Data Analysis and Report

Upon completion, the results of the geotechnical data analyses and the unit treatment process evaluations will be evaluated and included, as appropriate, in the RD. The laboratory results from the sampling of the monitor wells in the interim ground-water monitoring plan will be reported to EPA on a quarterly basis, as described in the SOW.

4.0 PROJECT ORGANIZATION AND RESPONSIBILITY

This section provides a description of the organizational structure of personnel to be used on this project. This description illustrates the lines of authority and identifies the key personnel assigned to each function for the project. A proposed organizational structure chart for the investigation is shown in Figure 1. The analytical laboratory for this project is Versar, Inc. which operates facilities in Columbia, Maryland and Springfield, Virginia. The organizational structure and staff qualifications for the Versar, Inc. are described in their Quality Assurance Plan, presented in Appendix A.

4.1 AUTHORITY AND RESPONSIBILITIES

The responsibilities of the individual positions for this project are described in the following sections.

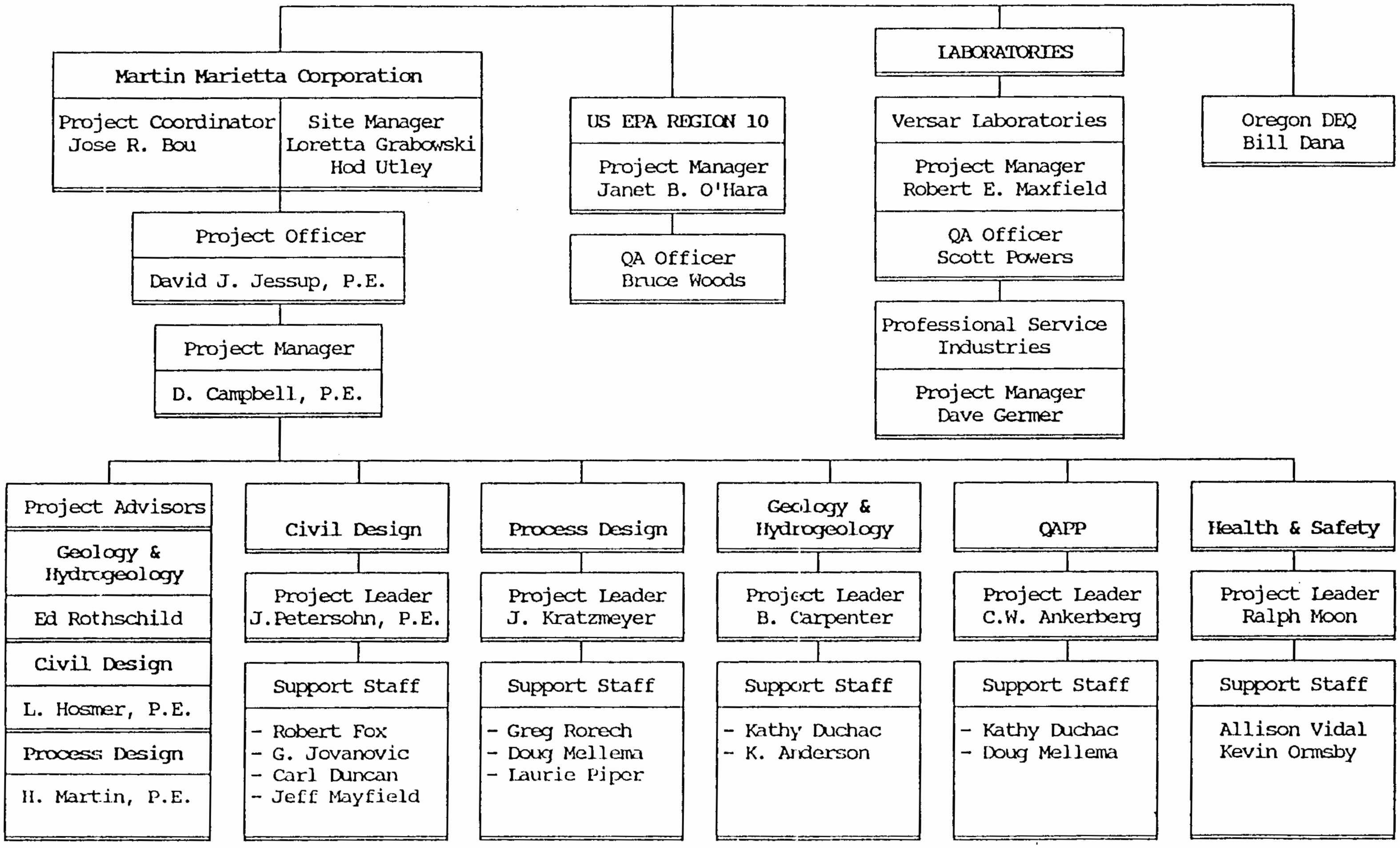
4.1.1 Corporate Project Coordinator:

Mr. Jose R. Bou, Vice President
Martin Marietta Aluminum Properties, Inc.
6801 Rockledge Drive
Bethesda, Maryland 20034
301-897-6809

The Corporate Project Coordinator will review and approve the work plans and work activities for the duration of the RD/RA and direct the coordination of corporate policy and environmental agency objectives.

FIGURE 1

QAPP PROJECT ORGANIZATION
MARTIN MARIETTA REDUCTION FACILITY
THE DALLES, OREGON



- **Martin Marietta Corporation**
  - Project Coordinator Jose R. Bou
  - Site Manager Loretta Grabowski, Hod Utley
  - Project Officer: David J. Jessup, P.E.
    - Project Manager: D. Campbell, P.E.
      - **Project Advisors**
        - Geology & Hydrogeology: Ed Rothschild
        - Civil Design: L. Hosmer, P.E.
        - Process Design: H. Martin, P.E.
      - **Civil Design**
        - Project Leader J.Petersohn, P.E.
        - Support Staff
          - Robert Fox
          - G. Jovanovic
          - Carl Duncan
          - Jeff Mayfield
      - **Process Design**
        - Project Leader J. Kratzmeyer
        - Support Staff
          - Greg Rorech
          - Doug Mellema
          - Laurie Piper
      - **Geology & Hydrogeology**
        - Project Leader B. Carpenter
        - Support Staff
          - Kathy Duchac
          - K. Anderson
      - **QAPP**
        - Project Leader C.W. Ankerberg
        - Support Staff
          - Kathy Duchac
          - Doug Mellema
      - **Health & Safety**
        - Project Leader Ralph Moon
        - Support Staff
          - Allison Vidal
          - Kevin Ormsby
- **US EPA REGION 10**
  - Project Manager Janet B. O'Hara
    - QA Officer Bruce Woods
- **LABORATORIES**
  - Versar Laboratories
    - Project Manager Robert E. Maxfield
    - QA Officer Scott Powers
  - Professional Service Industries
    - Project Manager Dave Germer
- **Oregon DEQ** Bill Dana

FL0018.RD1\FIG\PROJORG

4.1.2 Site Manager:

Ms. Loretta V. Grabowski
Martin Marietta Corporation
3313 W. 2nd Street
The Dalles, Oregon 97058
503-296-6118
503-296-3236 (FAX)

The Site Manager will assist the Corporate Project Coordinator in carrying out the on-site activities described in the RD/RA. These activities include the coordination of the technical support groups and assurance that all site activities are in agreement with the environmental policies of the corporation. In the event the Corporate Project Coordinator is not available, the Site Manager will assume those responsibilities. Hod Utley is an environmental specialist working with the Site Manager and will be responsible for ground-water sampling and providing background on site layout and history.

4.1.3 Project Officer

Mr. David J. Jessup, P.E.
Geraghty & Miller Engineers, Inc.
14497 N. Dale Mabry Hwy
Suite 200
Tampa, Florida
813-968-2248

The Project Officer will serve as the primary G&M contact for environmental agency representatives, Martin Marietta personnel and subcontractors. Other duties, as required, may include:

- Approval of project-specific procedures and internally prepared plans, drawings, and reports;
- Insuring that the technical, schedule and control requirements established by the QA Officer are enforced on the project;
- Serving as the "collection point" for project staff reporting any changes or deviations from the project work plan; and
- Determining the significance of these changes or deviations to the work plan, the appropriateness for reporting such items to the appropriate regulatory and MMC representative.

4.1.4 Project Manager

Mr. David C. Campbell, P.E.
Geraghty & Miller Engineers, Inc.
14497 N. Dale Mabry Hwy.
Suite 200
Tampa, Fl 33618
813-968-2248

The Project Manager is responsible for coordination of project personnel and the day-to-day management of financial, technical and scheduling activities for the project. Other duties, as required, include:

- Arranging subcontractor services;
- Assigning duties to the project staff and orientation of the staff to the requirements of the project; and
- Preparation of status update reports and revisions to the project work plan.

4.1.5 Quality Assurance Officer

Mr. Charles W. Ankerberg
Geraghty & Miller, Inc.
3820 Northdale Blvd.
Suite 200
Tampa, Florida 33624
813-961-1921
813-961-2599 (FAX)

The Quality Assurance Officer (QAO) will be responsible for liaison between the laboratory, G&M, MMC and the EPA QAO. The QAO will ensure the accuracy of the collected data through the performance of field and laboratory systems and performance audits, design of proper field sample collection techniques, analytical QA program design, design of field and analytical data validation procedures consistent with EPA guidelines, selection of the analytical laboratory, and preparation of laboratory contracts.

4.1.6 Health and Safety Officer

Dr. Ralph E. Moon
Geraghty & Miller, Inc.
3820 Northdale Blvd.
Suite 200
Tampa, Fl 33624
813-961-1921

The Health and Safety Officer is responsible for the evaluation of health and safety risks imposed by on-site activities as described in the plan. In addition, he is responsible for the enforcement of safety procedures that satisfy State and Federal regulations appropriate to the site.

4.1.7 Project Advisor - Geology and Hydrogeology:

Mr. Edward R. Rothschild
Geraghty & Miller, Inc.
14655 Bel-Red Rd., Suite 202
Bellevue, WA, 98007
206-644-7226

The Project Advisor - Geology/Hydrogeology is responsible for assuring the validity and review of ground-water monitoring plans and the review and analysis of ground-water data. He will act as the reviewer of technical documentation regarding ground-water contingency planning and monitoring.

4.1.8 Project Advisor - Civil Design

Mr. J. Lawrence Hosmer, P.E.
Geraghty & Miller Engineers, Inc.
929 West St., Suite 310
Annapolis, Maryland 21401
301-280-0024

The Project Advisor - Civil Design is responsible for the review and analysis of design work products and for providing input and guidance on technical activities for the project.

4.1.9 Project Advisor - Process Design:

Mr. Hugh J. Martin, P.E.
Geraghty & Miller Engineers, Inc.
14497 N. Dale Mabry Hwy., Suite 200
Tampa, Florida 33618
813-968-2248

The Project Advisor - Process Design is responsible for the review and analysis of unit treatment process designs. The project advisor will provide input on the characterization of perched water, design assumptions and on the start-up and operations of treatment systems.

4.1.10 Project Leader - Civil Design:

Mr. Jeffrey A. Petersohn, P.E.
Geraghty & Miller Engineers, Inc.
14497 N. Dale Mabry Hwy, Suite 200
Tampa, Florida 33618
813-968-2248

The Project Leader - Civil Design is responsible for civil design aspects of the Remedial Design including the preparation of construction plans, technical specifications, borrow area investigations, construction cost estimates and design reports.

4.1.11 Project Leader - Geology and Hydrogeology

Mr. Bruce A. Carpenter
Geraghty & Miller, Inc.
14655 Bel-Red Rd., Suite 202
Bellevue, WA., 98007
206-644-7226

The Project Leader - Geology and Hydrogeology is responsible for the development and implementation of ground-water monitoring plans and programs at the site and will participate in the development of well abandonment criteria for wells neighboring the project site.

4.1.12 Project Leader - Process Design

Mr. Jack L. Kratzmeyer
Geraghty & Miller Engineers, Inc.
75 E. Wacker Drive
Chicago, Ill 60601
312-263-6703

The Project Leader - Process Design is responsible for the conduct and summary of bench and/or pilot studies at the site, and the preparation of construction plans and technical specifications for the perched water treatment system.

4.1.13 EPA Project Coordinator

Ms. Janet B. O'Hara
U.S. Environmental Protection Agency
Region X
1200 Sixth Avenue
Seattle, Washington 98101
206-442-7215

4.1.14 EPA Quality Assurance Officer

Mr. Bruce Woods
U. S. Environmental Protection Agency
Region X
1200 Sixth Avenue
Seattle, Washington 98101
206-442-7215

4.2 ANALYTICAL LABORATORY

The analytical laboratory selected for this project is Versar, Inc. with two locations as shown below.

Versar, Inc.
9200 Rumsey Road
Columbia, MD 21045
301-964-9200
Contact: Mr. Doug McGinnes

Versar, Inc.
6850 Versar Center
Springfield, Virginia 22151
703-750-3000
Contact: Mr. Robert E. Maxfield

The primary laboratory for this project will be Versar in Columbia. However, it is possible that samples may be analyzed by Versar's Spingfield facility in the event of an overload. Both laboratories are within close proximity to each other and inter-laboratory transfers are common. In addition, both laboratories are approved EPA CLP laboratories in inorganics and organics analyses and have numerous other certifications including the U.S. Army Corps of Engineers.

Versar's Laboratory Director is Mr. Robert E. Maxfield, who is located at Versar's Springfield facility. The Central Project Coordinator for this project will be Mr. Doug McGinnes, who is located at Versar's Columbia, Maryland facility. Mr. McGinnes will be responsible for liaison between Versar and the G&M QAO and Project Manager. He also will be responsible for reviewing all analytical reports from each laboratory to ensure: (1) data quality objectives have been met; (2) all requested work has been completed; (3) all reports have identical format; (4) quality assurance reporting requirements are complete; and, (5) timely delivery of the proper number of report copies to designated recipients. He will also be indirectly involved with sample receipt, log-in and tracking, analysis, quality assurance, report preparation, and initial review.

Versar's Quality Assurance Officer is Mr. Scott Powers. He is responsible for the establishment of identical quality assurance programs within each Versar Laboratory to provide consistency, accuracy and precision in the analysis of samples. He is also responsible for internal laboratory data validation programs and quality assurance audits.

Qualifications of the Martin Marietta Corporation Consultant's personnel are presented in Section 17.0; Versar's personnel qualifications are described in their generic QAP presented in Appendix A.

4.3 GEOTECHNICAL LABORATORY

The selected geotechnical laboratory will be Professional Service Industries, Inc., (PSI) located at 611 S.E. Harrison Street, Portland, Oregon, 97214, Telephone (503) 232-2183.

5.0 DATA QUALITY OBJECTIVES

5.1 WATER AND SOIL QUALITY

The overall quality assurance objective is to ensure that data of known and acceptable quality are provided. All measurements will be made so as to yield consistent results representative of the media and conditions measured and reflective of the project objectives. All data will be calculated and reported in units consistent with those of other agencies and organizations to allow comparability of data bases.

Quality assurance objectives for analytical data including parameters, units of measure, methods, and detection limits are presented in Table 5. Quality assurance objectives for precision, accuracy, and completeness also have been established by Versar for each measurement variable where possible and are presented in Table 5 and in Versar's generic QAP referenced in Appendix A.

Detection limits for the water analyses (also presented in Table 5) are specified by the analytical methods. These methods have been selected in order to meet the required soil and water quality criteria, (ARARS) where possible. For the purposes of the unit process evaluation, extremely low levels of detection are not required. Instances may occur in which the condition of the sample will not permit attainment of the desired detection limits for various parameters either because of matrix interferences or high analyte concentrations requiring sample dilution. In Section 11.0 the laboratory is instructed to provide sufficient

TABLE 5

QA Objectives For Measurement Data

Parameter	Units	Method	Detection Limits	Precision	Accuracy	Completeness
Water matrix						
Sulfate	mg/L	375.4	10	+/-25%	+/-10%	95%
Fluoride	mg/L	340.2	2	+/-10%	+/-10%	95%
Total CN-[1]	mg/L	335.2	0.02	+/-15%	+/-15%	95%
Free CN-[1]	mg/L	412.H	0.02	+/-15%	+/-15%	95%
Soil Matrix						
Fluoride	mg/kg	340.2Mod.[2]	200	+/-40%	+/-40%	95%
cPAHs[3]	mg/kg	8270	MDL[4]	+/-40%	+/-40%	95%
Field Measurements						
pH	pH units	150.1	----	+/-0.05 pH	+/-0.2 pH	95%
Temperature	degrees C	170.1	----	+/-0.1 C	+/-0.2 C	100%
Conductivity	umhos/cm	120.1	-	+/-7.6 umhos/cm	+/-2umhos/cm	95%

1/ Samples to be analyzed for cyanide should be screened for sulfides and oxidizers first as described in the method prior to preservation. If detected samples must be treated to remove the sulfides and/or oxidizers prior to preservation. This task requires filtration and must be accomplished within twenty four hours of sample collection. It is recommended that the laboratory be notified and prepared to screen and treat samples if field screens turn up positive.

2/ Methods for Chemical Analysis of Water and Wastes, EPA 600/4-79-020. Method has been modified for analysis of fluoride in soil by employing a 24-hour leach of the soil sample and subsequent analysis of leachate. This procedure was presented in the Versar Inc., SOP, approved by EPA Region X, for the RI/FS.

3/ Test Methods for Evaluating Solid Wastes, Physical/Chemical Methods, SW-846, 3rd Edition. Specific carcinogenic PAHs are listed in Table 4.

4/ MDL = Method Detection Limits.

information with each data package to allow reviewers of the data to be aware of analytical problems encountered.

5.2 SITE GEOTECHNICAL INTERPRETATIONS

Geologic interpretations made during field operations for the collection of geotechnical data will be recorded on Sample/Core Log forms such as shown in Figure 2. The purpose of developing geotechnical data is to provide information for the remedial design activities in regard to: (1) classification and soil properties of materials present at the site and from potential borrow sources; (2) determine the properties of various bentonite-soil admixtures for design of the Landfill cap; (3) to define the quantity of locally available borrow material sources; and (4) identify surface profiles of the underlying basalt surface. To obtain this information various geotechnical tasks and tests are scheduled to be performed as presented in the SAP. In these tasks selected samples will be taken of soils for geotechnical analysis. The methods of analysis are presented in Table 1 in Section 3.2.1. Soil classification tests will define the types of soils encountered at the site and at the borrow areas. Moisture content tests will be used in combination with Atterberg Limits determination to further define the effects of regrading and subsequent compaction of the materials. Consolidation tests will determine some of the engineering properties of the sludge material to be isolated from contact with the environment. Particle-size analysis and permeability tests will evaluate soil porosity and relative flow characteristics of liquids through the soils.

SAMPLE/CORE LOG

Boring/Well ________ Project/No. ____________________ Page ______ of ______

Site Location ____________________ Drilling Started __________ Drilling Completed __________

Total Depth Drilled __________ (feet)

Hole Diameter __________ (inches) Type of Sample/ Coring Device ____________________

Length and Diameter of Coring Device ____________________ Sampling Interval __________ feet

Drilling Fluid Used ____________________ Drilling Method ____________________

Drilling Contractor ____________________ Driller __________ Helper __________

Prepared By ____________________ Hammer Weight ________ Hammer Drop ________ inches

Sample/Core Depth (feet below land surface)		Core Recovery (feet)	Time/Hydraulic Pressure or Blows per 6 Inches	Sample/Core Description
From	To			

Figure 2 - Sample/Core Log

5.3 WATER-LEVEL MEASUREMENTS

The measurement of water levels is a critical aspect of any ground-water investigation. Water-level measurements are required during the course of the remediation and afterward to confirm the ground-water flow direction. As described in the Interim and Long-Term Ground-Water Monitoring Program water-level measurements are to be taken by the sampling team personnel during quarterly sampling events. All water-level measurements will be recorded to the nearest one one-hundredth of a foot.

Water-level measurements will be made either with the use of a chalked tape or electronic measuring device. The use of a chalked tape and electronic measuring devices is described as follows: Chalk rubbed on a weighted steel tape will discolor or be removed when in contact with water, and the distance to the water surface can be obtained by subtracting the wet chalked length from the total measured length. The tape should be withdrawn quickly from the well because water has a tendency to rise up the chalk due to capillary action. These electronic measuring devices consist of a spool of dual conductor wire, a probe attached to the end, and an indicator. When the probe comes in contact with the water, the circuit is closed and a meter light and/or buzzer attached to the spool will signal the contact. Penlight batteries are normally used for a power source.

All devices used to measure ground water levels shall be calibrated against the Invar steel surveyor's chain. These devices shall be calibrated to 0.01 foot per 10 feet length. Before each use, these devices shall be prepared according to the manufacturer's instructions (as appropriate) and checked for obvious damage. These devices shall be rinsed with deionized water after use and also before being used in the next well to be measured. All calibration and maintenance data shall be recorded in the field log. All water-level measurement data will be referenced to mean sea level or common datum.

6.0 SAMPLING PROCEDURES

The quality of the data collected in an environmental study depends on the quality of the sampling activities. Field operations must be well conceived and carefully implemented. Detailed procedures and protocols for site selection, sample collection, handling, preservation, shipping and storage must be specified and documented.

6.1 GENERAL SAMPLING PROCEDURES

The general sampling plan that will be followed is described in Section 3.2.1 through 3.2.4. All sampling will be accomplished in accordance with generally accepted protocols established by the EPA and as explained in the following sub-sections.

6.1.1 Types of Samples

Samples to be collected for analysis by the laboratory will consist of soil samples from the verification sampling program and ground water from monitoring and irrigation wells. The number of samples of each matrix to be collected for each parameter to be analyzed, and the number of pertinent field QC samples required to be submitted for each parameter are described in the text and tables presented in Sections 3.2.1 through 3.2.4.

6.1.2 Sample Containers

All sample containers supplied for the collection of soil and ground-water samples by Versar will be new, precleaned, and pre-baked as appropriate. Table 6 summarizes the required sample containers, handling and preservation procedures required for each type of sample and parameter. Sample containers will be kept closed and in the cooler until use. Containers for geotechnical samples will be the undisturbed sample tubes provided by the contracted geotechnical laboratory. Other soil and material sample containers will be in accordance with the requirements established by the methods presented in Table 1.

6.1.3 Sample Labels and Soil and Water Sampling Logs

Samples, including geotechnical samples, will be fully labeled as they are collected. Sample label information is presented in Section 7.0. Sample collection data, including label information, will be recorded in the bound field log book as the samples are collected. All recorded entries will be made in indelible ink. No erasures will be made. If an error is made, a correction may be made by drawing a line through the error, initialing the error, and starting a new entry on the next line. Sample containers will be returned to the cooler as soon as possible after sampling.

A soil/sediment sampling log similar to the one presented in Figure 3 will be completed for the collection of every soil composite sample. A water-sampling log similar to the one presented as Figure 4 will be completed for the collection of ground-water samples. These records will be completed as samples are collected. Field replicate samples will be clearly identified on the water-sample log and in the field log book.

TABLE 6

Recommendation for Sampling and Preservation of Samples According to Measurement[1]

The Dalles, Oregon

Measurement	Vol. Req. (ml)	Container[2]	Preservative[3,4]	Holding Time[5]
WATER MATRIX				
Physical Properties				
Conductance	100	P,G	Cool, 4°C	28 Days
pH	25	P,G	None Required	Analyze Immediately
Temperature	1,000	P,G	Non Required	Analyze Immediately
Inorganics, Non-Metallics				
Cyanides	500	P,G	Cool, 4°C NaOH to pH>12 0.6g ascorbic acid[6]	14 Days[7]
Fluoride	300	P,G	None Required	28 Days
SOIL MATRIX				
Fluoride	1L	P	None Cool, 4°C	28 Days
cPAHs	1L	G	None Cool, 4°C	14 Days

Notes:

1. More specific instructions for preservation and sampling are found with each procedure as detailed in this manual. A general discussion on sampling water and industrial wastewater may be found in ASTM, Part 31, p. 72-82 (1976) Method D-3370.

TABLE 6

Recommendation for Sampling and Preservation of Samples According to Measurement[1]
The Dalles, Oregon

Notes:
Continued

2. Plastic (P) or Glass (G). For metals, polyethylene with a polypropylene cap (no liner) is preferred.

3. Sample preservation should be performed immediately upon sample collection. For composite samples each aliquot should be preserved at the time of collection. When use of an automated sampler makes it impossible to preserve each aliquot, then samples may be preserved by maintaining at 4°C until compositing and sample splitting is completed.

4. When any sample is to be shipped by common carrier or sent through the United States Mails, it must comply with the Department of Transportation Hazardous Materials Regulations (49 CFR Part 172). The person offering such material for transportation is responsible for ensuring such compliance. For the preservation requirements of Table 1, the Office of Hazardous Materials, Materials Transportation Bureau, Department of Transportation has determined that the Hazardous Materials Regulations do not apply to the following materials: Hydrochloric (HCl) in water solutions at concentrations of 0.04% by weight or less (pH about 1.96 or greater); Nitric acid (HNO_3) in water solutions at concentrations of 0.15% by weight or less (pH about 1.62 or greater); Sulfuric acid (H_2SO_4) in water solutions at concentrations of 0.35% by weight or less (pH about 1.15 or greater); Sodium hydroxide (NaOH) in water solutions at concentrations of 0.080% by weight or less (pH about 12.30 or less).

5. Samples should be analyzed as soon as possible after collection. The times listed are the maximum times that samples may be held before analysis and still considered valid. Samples may be held for longer periods only if the permittee, or monitoring laboratory, has data on file to show that the specific types of sample under study are stable for the longer time, and has received a variance from the Regional Administrator. Some samples may not be stable for the maximum time period given in the table. A permittee, or monitoring laboratory, is obligated to hold the sample for a shorter time if knowledge exists to show this is necessary to maintain sample stability.

6. Should only be used in the presence of residual chlorine.

7. Maximum holding time is 24 hours when sulfide is present. Optionally, all samples may be tested with lead acetate paper before the pH adjustment in order to determine if sulfide is present. If sulfide is present, it can be removed by the addition of cadmium nitrate powder until a negative spot test is obtained. The sample is filtered and then NaOH is added to pH 12.

SOIL/SEDIMENT SAMPLING LOG

Project No. ____________________ Page ____ of ____

Site Location ____________________

Sample ID No. ____________________ Coded/Replicate No. ____________

Date ____________________ Time of Sampling: Begin ________ End ________

Weather ____________________

Site Description ____________________

____

____

SAMPLING DATA

Collection Method ____________________

Depth ____________ Moisture Content ____________ pH ______

Color ____________ Odor ____________

Description ____________________

____

____

Analyses Required	Container
____________	____________
____________	____________
____________	____________
____________	____________

Sample Monitoring (TIP, OVA, HNU, etc.) ____________

____

____

Remarks ____________________

____

Sampler(s) ____________________

Figure 3 - Soil/Sediment Log

WATER SAMPLING LOG

Project/No. ____________________ Page _____ of _____

Site Location ____________________

Site/Well No. __________ Coded/ Replicate No. __________ Date __________

Weather __________ Time Sampling Began __________ Time Sampling Completed __________

EVACUATION DATA

Description of Measuring Point (MP) ____________________

Height of MP Above/Below Land Surface __________ MP Elevation __________

Total Sounded Depth of Well Below MP __________ Water-Level Elevation __________

Held _____ Depth to Water Below MP __________ Diameter of Casing __________

Wet _____ Water Column in Well __________ Gallons Pumped/Bailed Prior to Sampling __________

Gallons per Foot __________

Gallons in Well __________ Sampling Pump Intake Setting (feet below land surface) __________

Evacuation Method ____________________

SAMPLING DATA/FIELD PARAMETERS

Color __________ Odor __________ Appearance __________ Temperature _____ °F/°C

Other (specific ion; OVA; HNU; etc.) ____________________

____

Specific Conductance, umhos/cm __________ pH __________

Sampling Method and Material ____________________

Constituents Sampled	Container Description From Lab _____ or G&M _____	Preservative
__________	__________	__________
__________	__________	__________
__________	__________	__________

Remarks ____________________

Sampling Personnel ____________________

WELL CASING VOLUMES

GAL/FT	1-¼" = 0.077	2" = 0.16	3" = 0.37	4" = 0.65
	1-½" = 0.10	2-½" = 0.24	3-½" = 0.50	6" = 1.46

Figure 4 - Water Sampling Log

6.1.4 Equipment Cleaning Procedures

Sampling equipment cleaning procedures (pre- and post-sampling) in the field, will be in accordance with standard EPA approved cleaning procedures for field equipment.

6.1.4.1 Introduction

The cleaning procedures are to be used by all sampling personnel to clean sampling and other field equipment as well as sample containers prior to field use. Sufficient clean equipment and sample containers should be transported to the field so that an entire inspection or investigation can be conducted without the need for cleaning equipment in the field. However, this may not always be possible when using specialized field equipment. Emergency field sample container cleaning procedures are also included; however, they should not be used unless absolutely necessary. Specific cleaning procedures are presented in the following sections.

The cleaning materials referred to in this discussion are defined in the following paragraphs.

The laboratory detergent shall be a standard brand of phosphate-free laboratory detergent such as Alquinox™ or Liquinox™. The use of any other detergent must be justified and documented in the field logbooks and inspection or investigative reports.

The standard cleaning solvent shall be pesticide-grade isopropanol. However, solvents may be substituted for a particular investigation, if needed. Pesticide-grade acetone or methanol are both acceptable. However, it should be noted that if pesticide-grade acetone is used, the detection of acetone in samples collected with acetone rinsed equipment is suspect. Pesticide-grade methanol is much more hazardous to use than either pesticide-grade isopropanol or acetone, and use is discouraged. Pesticide-grade hexane and petroleum ether are not miscible with water; therefore, these two solvents are not effective rinsing agents unless equipment is dry. The use of any solvent other than pesticide-grade isopropanol for equipment cleaning purposes must be justified and its use must be documented in field logbooks and inspection or investigation reports.

Tap water may be used from any municipal water treatment system. The use of an untreated potable water supply is not an acceptable substitute for tap water. Deionized/organic-free water will be used at all times during all cleaning procedures for field equipment. The deionized water should contain no heavy metals or other inorganic compounds (i.e., at or above analytical detection limits) as defined by analysis of appropriate field and rinsate blanks submitted with samples. Organic-free water is defined as tap water that has been treated with activated carbon and deionizing units. Organic-free water should contain no pesticides, herbicides, extractable organic compounds, and less than 50 μg/L of purgeable organic compounds as measured by appropriate analysis of field and rinsate blanks submitted with samples. The solvents, laboratory detergent, and rinse waters used to clean equipment shall not be reused.

Field or sampling equipment that needs to be repaired shall be identified with a red tag. Any problems encountered with the equipment and needed repairs shall be noted on this tag. Field equipment and reusable sample containers needing cleaning or repairs shall not be stored with clean equipment, sample tubing, or sample containers. All non-dedicated sampling equipment (stainless steel scoops, spoons, bowls, and augers) will be scrubbed with laboratory detergent solution, rinsed with deionized water, rinsed again with isopropanol, and triple rinsed with deionized water.

Ground-water samples collected by bailing from monitoring wells at the site will be obtained by dedicated Teflon bailer suspended from the well cap in each monitor well by a Teflon coated stainless steel wire. Consequently, equipment rinsate blanks are not required. However, bailers will be decontaminated before being placed back in the well.

6.1.4.2 Quality Control Procedures for Cleaning Operations

This section establishes guidelines for specific quality control procedures to monitor the effectiveness of the sampling equipment and sample container cleaning procedures. All quality control procedures shall be recorded in a logbook maintained in the washroom. All quality control data shall be maintained in a separate quality assurance file.

The quality of the deionized and organic-free water used shall be monitored by collecting samples at every sampling period in standard precleaned, sample containers and submitting them to the analytical laboratory, as described in Sections 3.2.2.3 and 3.2.3.3.

The effectiveness of field cleaning procedures shall be monitored by rinsing field cleaned equipment with organic-free water and submitting the rinse water in standard sample containers to the laboratory as described in Sections 3.2.2.3 and 3.2.3.3. Any time equipment is cleaned in the field at least one such quality control sample shall be collected. No more than five percent of the equipment cleaned during large scale field studies shall be subjected to these procedures.

Cleaning procedures for Teflon and/or stainless steel sampling equipment used for the collection of samples for trace organic compounds and/or metals analyses:

1. Equipment will be washed thoroughly with laboratory detergent and water using a brush to remove any particulate matter or surface film.
2. The equipment will be rinsed thoroughly with deionized water.
3. Rinse equipment twice with isopropanol solvent; rinse equipment thoroughly with deionized water.
4. Wrap equipment completely with aluminum foil to prevent contamination during storage and/or transport to the field.
5. Rinse the Teflon or glass sampling equipment thoroughly with tap water in the field as soon as possible after use.

6.2 SOIL SAMPLING

Soil samples will be collected from the outside walls of trenches during the verification sampling program as described in Section 3.2.1.2 and in the SAP. The sampling grids and grid locations will be identified in the field log and notes pertaining to physical conditions of the grid area. To prevent interference of the sampling areas by any smear or contact with other materials introduced by the excavation process, three inches of material will be removed from a selected area before sample collection begins, will be obtained using stainless steel scoops and/or spoons. Composite samples will be obtained by combining sub-samples collected from four locations selected at random (as described in the SAP) from the outside trench wall every 200 square feet. Each sub-sample will be of approximately equal volume and coarseness as may be obtained and will be combined in a stainless steel bowl. Following collection, the sample will be carefully mixed to ensure homogeneity and then arranged into a cone in the center of the mixing bowl. The mixed sample pile will then be divided and separated into four smaller piles. Proceeding in a clockwise direction small but approximately equal portions of each quarter pile will then be placed sequentially into the sample container continuing until the container is filled. Containers will then be closed, labeled and placed on ice in a cooler.

Sampling equipment will be decontaminated between the collection of each composite sample as described in Section 6.1.4 or separate, clean stainless steel scoops, spoons and bowls will be used.

6.3 GROUND-WATER SAMPLING

6.3.1 Sampling Preparation

Prior to the sampling event, the field personnel should be adequately prepared. The following items should be included for the field sampling:

- Site map, names of contacts, and access keys
- Water sampling logs, chain-of-custody forms, sample labels, waterproof-ink pen, and tape
- Sample containers (check for proper number, type, and preservatives), coolers, and ice
- Cooler custody seals
- Water-level measurement equipment
- Well purging equipment
- Water sampling equipment (Teflon bailers, pumps, etc)
- Power source
- Field analysis (pH, temperature, specific conductivity) instruments and standards
- Teflon-coated cord or wire or disposable nylon rope, knife, and miscellaneous tools
- Gloves and towels
- Appropriate Safety & Health equipment and dress
- Laboratory grade detergent and deionized water
- Five-gallon bucket

All equipment must be checked for proper operation. Equipment that will come in contact with the ground water must be properly cleaned before use.

Arrange for site access prior to leaving for the sample location. Upon arriving at the site, the field personnel should inform appropriate people of their presence and the approximate time they will be at the site. Field personnel can be apprised of any changes at the site of which the project manager was unaware.

6.3.2 Well Preparation

Upon arriving at the well, check the well for any above-ground damage and the grout for structural integrity. Unlock and remove the well cap (a wrench may be required) and allow the well water level to come to equilibrium with the atmosphere. Clean the top of the well casing prior to purging and sampling. Preliminary information can be recorded on the well sampling log at this time.

6.3.3 Ground-Water Level and Total Sounded Depth Measurements

The static water level and the total sounded depth of the well should be measured prior to purging and sampling well water. An electronic water-level indicator (M-scope) or chalked steel tape may be used for the water-level measurement. Measurements should be referenced to the survey point (top of well casing).

The total depth of the well will be measured from top of casing and be recorded. This is accomplished by lowering the tape or cable until the weighted end is felt resting on the bottom of the well. In deep wells, where the weight of the length of tape or cable lowered into the well is approximately equal to or greater than the weight of the weight at the tape or cable end, it can be difficult to determine when the bottom of the well is reached.

Appropriate weights will be available and used to provide accurate definition of total well depth. This datum can be used to confirm that the proper well has been identified, if the construction specifications are available, the well has not filled with silt, and if the volume of standing well water can be accurately calculated. Prior to measuring another well, wash the tape with a detergent solution and then rinse with deionized water. All total well depth measurements must be made and recorded to the nearest 0.2 foot.

All devices used to measure ground-water levels shall be calibrated against the Invar steel surveyor's chain. These devices shall be calibrated to 0.01 foot per 10 feet length. Before each use, these devices shall be prepared according to the manufacturer's instructions (if appropriate) and checked for obvious damage. These devices should be rinsed after use and also before being used in the next well to be measured. All calibration and maintenance data shall be recorded in a logbook.

6.3.4 Purging the Well

After a water-level measurement has been taken, the well should be purged to remove the standing water. Purging can be accomplished by pumping or bailing, but pumping is preferred. As the water level drops, the pump or suction tube intake should be lowered so that the water in the well casing is completely and efficiently removed. The tube should be removed before suction has been discontinued. Bailing the well is acceptable (except for deep wells); however, if a bailer is employed, use extreme care in lowering the bailer into the well to avoid "surging" the water in the casing, which could disturb the formation deposits (i.e., sand) at the bottom of the well.

The criterion used for determining the proper purging of the well is that four times the calculated standing well water volume is to be removed from the well. The volume of well water (in gallons) is calculated using the following equation:

$$V = 7.48 \quad \pi r^2 h$$

where, v = volume of standing water (gallons)
r = radius of well casing (ft.)
h = height of standing water (ft.)

Wells that recharge slowly (those not filled back to the static level within eight hours), should be purged completely once and then sampled after the water level has recovered approximately 75 percent. The rate of recharge for all wells should be recorded for each sampling interval.

Deciding when the required volume of water has been purged from the well can be determined by directly measuring the amount discharged into a container of known volume or by measuring the time of pumping with a calibrated pump. Flow measurement is preferred for submerged pumps in as much as pumping rates are a function of head. A purge pump (peristaltic or submersible) may be calibrated (i.e., the pumping rate may be determined) by measuring the time required to fill a container of known volume. Once the required volume to be purged and the pumping rate are known, the time necessary to pump the required amount may be calculated by the formula:

$$T = \frac{V}{R}$$

where, T = Time (minutes)
V = Volume of standing water (gallons)
R = Rate of flow (gallons/minute)

Field water sample logs should have a table of well bore volumes per linear foot for various well sizes to allow calculation of well volumes in the field.

6.3.5 Field Measurements

After pumping the well, a water sample should be collected to obtain measurements of pH, temperature, and specific conductivity. Before obtaining these measurements, the field instrumentation must be properly calibrated with reference standards as described in Section 8.0. Calibration of pH meters should be in accordance with the manufacturer's recommendations and shall be checked at least daily against two different pH standards. Conductivity meters should be checked against known standards to assure they are performing properly. Calibration results should be recorded on daily logs. After calibrations, place the appropriate instrument probe in the water sample and allow it to equilibrate. Take the sample reading and record the values on the field well water sampling log.

6.3.6 Sample Collection

After obtaining the field measurements, the well is sampled for the parameters of interest. Care should be exercised when selecting sampling equipment to ensure that the materials that make up the equipment are compatible with the sample parameters and also comply with state and federal regulatory requirements for sampling. Generally speaking, Teflon is preferred but stainless steel, polyethylene, or PVC may be acceptable. Teflon is universally accepted by the EPA. All wells at the site have dedicated Teflon bailers.

When samples require preservation, take care not to overfill the pre-preserved container. If the container needs to be preserved, use the appropriate preservative as listed in Table 6 and adjust to the correct pH if a preservative has not already been added by the laboratory.

When bottle filling is complete, identify each sample container with a properly completed label as described in Section 7.0.

6.3.7 Screening for Sulfides and Oxidizers

Some of the sample bottles require preservation (total and free cyanide). However, containers for samples to be analyzed for cyanides will not be pre-preserved because cyanide samples must be screened for sulfides and oxidizers before being preserved in accordance with the procedure described in Appendix B. Following this screen the samples should be preserved as described in Table 6 if the presence of sulfide and oxidizers has been ruled out.

6.4 GEOTECHNICAL SAMPLING

All geotechnical sampling will be performed in accordance with ASTM methods identified in Table 1. Geotechnical samples shall be sealed, shipped, and stored in accordance with the following procedures.

6.4.1 Disturbed Soil Samples

Disturbed soil samples shall be placed in sealable containers. Samples shall then be placed in appropriate containers, such as cardboard boxes, with dividers for each jar to prevent movement and minimize breakage. Only borings from one location shall be placed in a shipping container. The containers shall be taped shut in the field and labeled on the top and two adjacent sides to show the project name and number, identification of sample location contained in the box, total depth interval of the samples, and other information as required by the on-site geologist or engineer.

If the samples are to be temporarily stored on site, they shall be protected from the weather, including excessive heat and freezing. Indoor storage shall be employed, where possible. For commercial shipment, the containers should be marked "keep from heat and freezing". Samples shipped or hand carried to the geotechnical laboratory shall be accompanied by a chain of custody and laboratory log form providing a record of the samples.

6.4.2 Undisturbed Soil Samples

Upon recovery of a thin-walled tube used to obtain an undisturbed sample, at least one-half inch of soil shall be cleaned from each end of the tube and the ends of the soil sample squared off. Usually, the tip of the sample will contain drill cuttings and these must be removed prior to sealing. The in situ soil which has been cleaned from the tube can be used to give a visual classification for the sample. Under certain circumstances, a tube may be allowed to drain prior to the sealing process.

To seal the tube, the resulting space at each end shall be filled with a hot paraffin wax or equivalent melted sealing material or with expandable packers as approved by the on-site geologist or engineer. As an alternate for tubes containing partial samples, after sealing the ends of the sample (using approximately one inch of melted sealing material), a dry, clean filler, sand, etc., and be placed in the void areas and sealing again conducted. The filler prevents the sample from breaking the initial end seals during handling and shipment. The ends of the tube shall then be closed with tight-fitting metal or plastic caps and the seam, between the cap and tube, wrapped with tape. Finally, the ends of the tube shall be dipped in hot wax, beyond the tape, as a final sealing measure.

The tubes shall be hand carried to the geotechnical laboratory in a vertical position to maintain an in situ orientation and shall be marked with a "way-up" arrow, using an indelible marker. This means that if the tubes are being transported via airplane, they shall be carried on the plane and not checked as baggage. If the tubes are to be transported by truck or automobile, they shall be carefully padded and wedged in placed to prevent movement (e.g., through use of a tube rack). If tubes must be shipped as freight, they shall be packed in secure wooden boxes which have dividers built in to prevent movement of tubes the tubes, or the boxes shall be tightly filled with packing material such as wood chips, paper, etc., to prevent movement. The boxes should be marked "fragile" and "keep from heat and freezing". All packaging of tubes for shipment will be directed by the on-site geologist or engineer.

6.5 CHANGES IN PROCEDURES

Any changes in the sampling procedures as outlined in this QAPP will be discussed with the On-site coordinator and with the EPA project personnel to obtain technical concurrence and all changes will be documented in the field log book and described on the Sample Alteration Checklist (Figure 5). Approval from the Site Manager will be necessary to implement on-site changes, major modifications of the sampling design or procedures.

FIGURE 5

SAMPLING ALTERATION CHECKLIST

Sample Program Identification:____________________

Material to be Sampled:____________________

Measurement Parameter:____________________

Standard Procedure for Analysis:____________________

Reference:____________________

Variation from Standard
Procedure:____________________

Reason for
Variation:____________________

Resultant Change in Field Sampling
Procedure:____________________

Special Equipment, Material, or Personnel Required:__________

Author's Name:____________________Date:__________

Approval:____________________Title:__________

Date:____________________

7.0 SAMPLE CUSTODY

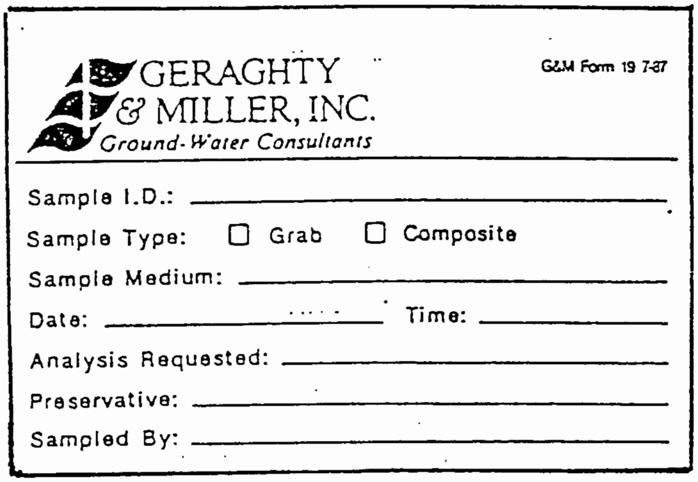
Sample custody is a vital aspect of remedial action programs as well as ground-water monitoring studies because these type of programs generate data that may be used as evidence in a court of law. The samples must be traceable from the time of sample collection until the time the data are introduced as evidence in enforcement proceedings.

7.1 FIELD RECORD LOG BOOK

The key aspect of documenting sample custody is thorough record-keeping. A bound field log book with sequentially numbered pages will be maintained during the course of the field work to document the collection of every sample. In addition, sample/core logs (geologic logs) , well completion logs, soil sample logs and water sample logs previously described in Section 6.0 will be filled out for each well drilled and sampled. All loose-leaf log sheets will be arranged in sequential order and bound together upon completion of each site audit.

7.2 SAMPLE LABELING

Sample containers will be labeled at the time of sampling with the following information: project code number, sampling date and time, sample identification number, parameters of interest, preservative, and initials of sample collector. An example of a typical sample label is presented in Figure 6.



GERAGHTY
& MILLER, INC.
Ground-Water Consultants

G&M Form 19 7-87

Sample I.D.: ______________________
Sample Type: ☐ Grab ☐ Composite
Sample Medium: ______________________
Date: ____________ Time: ____________
Analysis Requested: ______________________
Preservative: ______________________
Sampled By: ______________________

Figure 6 Sample Bottle Label- Example

At the time of sampling, the appropriate sample containers will be selected, and the sample number for each subsample recorded on the sample log form. After each bottle is filled and before it is placed in storage, the sampler will initial the label to document proper sample handling.

7.3 SAMPLE CONTAINER CUSTODY

All sample containers to be provided by Versar for this project must be prepared as described in Section 6.0. All containers will be shipped to the designated location from the designated Versar Laboratory described in Section 4.0 by common carrier in sealed coolers and will remain in the custody of Versar until received by a representative of the sampling team or the Site Manager. Versar will include a shipping form listing all containers shipped, specifying the purpose of each container. This list will become part of the Chain-of-Custody record.

Thin-walled tube samplers to be provided by Professional Service Industries for this project must be prepared as described in Section 6.0.

7.4 SAMPLE CUSTODY, SHIPMENT AND LABORATORY RECEIPT

For the purpose of these procedures, a sample is considered in custody if it is:

- In actual possession of the responsible person;
- In view, after being in physical possession;

- Locked so that no one can tamper with it, after having been in physical custody; or
- In a secured area, restricted to authorized personnel.

The field samples to be collected can be classified into two categories: (a) in situ measurements, and (b) laboratory analyses.

In Situ Measurements: These are those measurements made immediately after the sample has been collected. The data will be recorded directly in bound field logbooks along with identifying information on sampling conditions and location. In situ measurements include the following: pH, temperature, and conductivity.

Laboratory Measurements: These refer to samples collected and/or preserved in the field, to be shipped to the appropriate laboratory for chemical analysis or geotechnical evaluation. Identifying information on sampling conditions and location will be recorded as indicated above together with a record of the required analyses for each of the samples collected.

All samples will be maintained in the custody of the sampling personnel. At the end of each sampling day and prior to the transfer of the samples off-site, chain-of-custody entries will be made for all samples using the standard chain-of-custody form illustrated in Figure 7. All information on the chain of custody form and the sample container labels will be checked against the sample field log entries and samples will be recounted before leaving the sampling site. Upon transfer of custody, the chain-of-

Figure 7 - Chain-of-Custody Record

GERAGHTY
& MILLER, INC.
Ground-Water Consultants

GERAGHTY & MILLER
ENGINEERS, INC.

CHAIN-OF-CUSTODY RECORD

Project/Number ______________________

Shipping Container ID: ______________________

Sampler(s) ______________________

____

		SAMPLE CONTAINER DESCRIPTION													
SAMPLE IDENTITY	Date Sampled													Total	Remarks

Total No. of Containers ______

Relinquished by: ______________________ Organization: ______________________ Received by: ______________________ Organization: ______________________

Date: ____________ Time: ____________ Date: ____________ Time: ____________

Relinquished by: ______________________ Organization: ______________________ Received by: ______________________ Organization: ______________________

Date: ____________ Time: ____________ Date: ____________ Time: ____________

Relinquished by: ______________________ Organization: ______________________ Received by: ______________________ Organization: ______________________

Date: ____________ Time: ____________ Date: ____________ Time: ____________

Delivery Method: ______________________ (attach shipping bill, if any)

(Use extra sheets, if

custody form will be signed by the sample team leader, including the date and time. Since common carriers (Federal Express, Purolator Courier, etc.) will not sign chain-of-custody forms, the chain-of-custody records will be sealed in plastic within each cooler of samples.

A signed, dated custody seal (Figure 8) will be placed over the lid opening of the sample cooler to indicate if the cooler has been opened during shipment prior to receipt by the laboratory. All chain-of-custody forms received by the laboratory must be signed and dated by the Site Manager (see Section 4.0). The signed chain-of-custody forms will be placed in the cooler prior to sealing.

The custodian at the laboratory will also note the condition of each sample received as well as questions or observations concerning sample integrity. The sample custodian will also maintain a sample-tracking record that will follow each sample through all stages of laboratory processing. The sample tracking records must show the date of sample extraction or preparation, and sample analysis. These records will be used to determine holding time limit of compliance during lab audits and data validation.

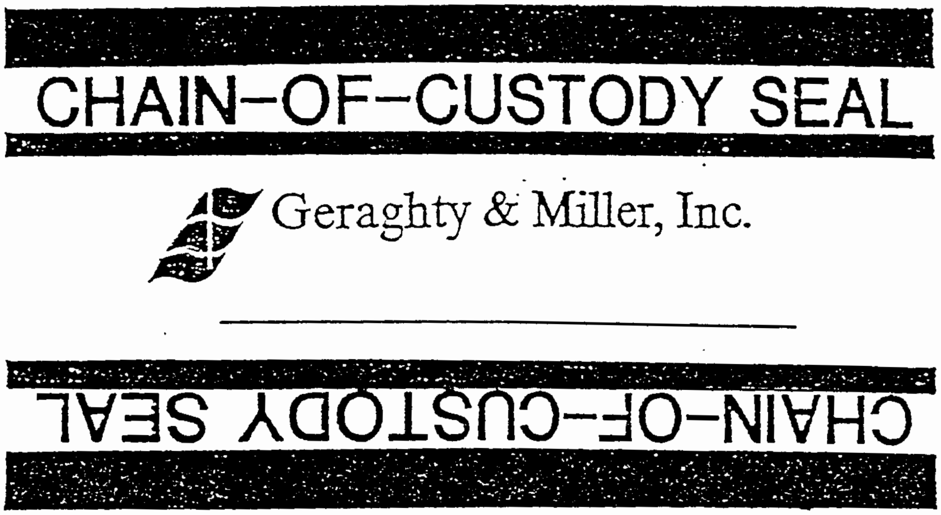


Figure 8 Chain-of-Custody Cooler Seal

8.0 CALIBRATION PROCEDURES AND FREQUENCY

Calibration procedures, calibration frequency, and standards for measurement variables and systems will be employed by Versar in accordance with procedures stated within their generic QAP and Standard Operating Procedures Manual and PSI in accordance with ASTM standards referenced in the SAP. Notwithstanding the foregoing, all calibration procedures will be, at a minimum, in accordance with the calibration requirements and frequencies specified by the EPA in the methods selected.

For all inorganic methods, calibration curves must be prepared from fresh standards analyzed at a minimum of three to five concentrations and each curve must be verified for accuracy with every analytical run by analyzing a known independent QC Check Standard.

Procedures for calibration of field equipment for measurement of pH and specific conductance that will be employed for this project will be as described in Section 6.0 and will be in conformance with the manufacturers instructions. All calibration and maintenance activities will be recorded in the field logbook.

9.0 ANALYTICAL PROCEDURES

The analytical procedures used for the RD/RA project described in this QAPP are described in Table 3 in Section 3.2.1.3. Analysis of samples collected at the MMRF facility will only be performed by laboratories with established protocols and QA procedures that meet U.S. EPA guidelines. Versar is capable of meeting these requirements.

Conductivity, pH and temperature will be measured in the field according to the procedures discussed in Section 6.0 and instrument manufacturers instructions.

During the RI conducted at the MMRF, The Dalles, Oregon, ground-water and surface-water samples tested for cyanides were pre-screened in the field for the presence of sulfides and oxidizers as required by the method (Appendix B). In addition the laboratory also employed an optional sulfide scrubber in the analysis of the samples, (Section 8.2 of method 335.2 for samples that contain sulfide). No sulfides were ever detected in any ground-water or surface water samples during the RI and the use of the optional sulfide scrubber proved to be an unnecessary and cumbersome addition to the analytical distillation equipment. Therefore, during the RD/RA and the ground-water monitoring program the pre-screening of ground-water samples for sulfide and oxidizers in the field will be continued as described in Appendix B but the use of the sulfide scrubber during distillation will not be required.

10.0 INTERNAL QUALITY CONTROL CHECKS

Internal laboratory control checks used by Versar are described in their generic QAP referenced in Appendix A. Versar will demonstrate the ability to produce acceptable results using the methods recommended. The data will be evaluated by Versar based on the following criteria (as appropriate for inorganic chemical analyses):

- o Performance on method tests the following QA checks:
    - Calibration curves
    - Initial calibration verification standards
    - Blanks
    - Continuing calibration verification standards
    - Spike recoveries (matrix and surrogate)
    - RPDs between Matrix spikes and matrix spike duplicates, samples and laboratory duplicates
    - Recoveries of laboratory control samples and independent QC Check samples
- o Percent recovery of internal standards
- o Adequacy of detection limits obtained
- o Precision of replicate analyses
- o Comparison of the percentage of missing or undetected substances among replicate samples (not known by lab)

Internal quality control checks of sampling procedures and laboratory analyses will be conducted periodically. These checks will consist of the preparation and submittal of sampler (equipment) rinsate blanks, field blanks, trip (travel) blanks, and field replicates for analysis of all parameters at frequencies described in Section 3.2.

The above field QC blanks and replicates included as internal QC checks are described below as follows:

- <u>Equipment Rinsate blank:</u> An equipment rinsate blank is made by taking organic-free deionized or distilled water and placing it in contact with the field sampling apparatus (bailer, pump tubing, etc.) or with the air near a well that conceivably could be a source of contamination. The water is then sealed in the same type of sample bottle as the other samples, preserved in the same manner (using the exact preservative source) transported to the laboratory with the samples and analyzed for the parameters of interest.

- <u>Field Blanks:</u> A field blank consists of sample containers filled in the field with organic-free, deionized or distilled water prepared and preserved in the same manner as the samples. The field blank is transported to the laboratory with the samples and analyzed along with the field samples for the constituents of interest to check for contamination imparted to the samples by the sample container, preservative, or other exogenous sources including air near the sample source.

- <u>Trip Blanks:</u> A trip (travel) blank is a sample container filled with organic-free water in the laboratory that travels unopened with the sample bottles. It is returned to the laboratory with the field samples, opened in the laboratory and analyzed along with the field samples for VOCs. In some instances trip blanks may be submitted for parameters other than VOCs. Trip blanks will not be required for the ground water monitoring program because analytes do not include VOCs.

- <u>Field Replicates:</u> A field replicate is a duplicate sample prepared at the sampling location from equal portions of all sample aliquots combined to make the sample. Both the field replicate and the sample are collected at the same time, in the same container type, preserved in the same way, and analyzed by the same laboratory as a measure of sampling and analytical precision.

11.0 DATA REDUCTION, VALIDATION AND REPORTING

The laboratory procedures for data reduction, validation, and reporting are described within Versar's generic QAP referenced in Appendix A. Notwithstanding the foregoing, MMC will complete its own data validation to verify that the laboratory has performed in accordance with requirements specified by the QAPP. Therefore, all laboratories employed for the ground-water monitoring programs will be required to submit data that are supported by sufficient QA backup information and data to enable data reviewers to determine conclusively the quality of the data.

The use of laboratories will be accomplished by a laboratory services agreement (contract) between MMC and the laboratory. The contract will specify the scope of services to be performed by the laboratory, the specific analytical quality assurance requirements to be met, and the information to be developed and reported, if beyond that stated herein.

The G&M Analytical Quality Assurance and Laboratory Contract Program (AQA/LCP) will be used in part to accomplish the quality assurance and data validation objectives of the projects. The G&M AQA/LCP defines four levels of analytical reporting for laboratories with uniform analytical quality assurance performance requirements. For the RD/RA Level II reportables are required except that matrix spikes and laboratory duplicates will be "sample" specific instead of "batch" specific. These spikes and duplicates will be performed by the laboratory at a frequency of 1 per 20 samples per matrix. These reporting requirements are specified in Appendix C. Because the analytical quality assurance requirements for all reporting levels in the

AQA/LCP are essentially identical, all of the data generated at any level potentially may be classified as quantitative. If increased defensibility of laboratory report data is required, additional documentation of analytical QA data will be available upon request to the laboratory to support validation conclusions and data usability determinations.

The data validation procedures employed will include an evaluation of the field data package and an evaluation of the laboratory analytical data package. The data validation checklists presented in this section will be used as guides in evaluating sample collection, field records, and analytical performance; these checklists will aid in identifying valid data and classifying (usability determination) the data into one of three use categories: unusable data, qualitative data (class A) and quantitative data (class B).

11.1 VALIDATION OF FIELD DATA PACKAGE

The field data package will be reviewed by the project QA officer and project manager for completeness and accuracy using the Field Data Validation Checklist (Figure 9). The field data package includes all of the field records and measurements developed by the sampling team personnel. Failure in any of these areas may result in the data being in-validated. The field data package validation procedure will consist of:

- A review of field data contained in water sampling logs for completeness.

DATA VALIDATION CHECKLIST

1-08
CWA/F-1 (R2)

PROJECT NAME:
PROJECT NUMBER:
SAMPLE IDENTIFICATION:

SAMPLING TEAM:
ANALYZING LABORATORY:
ANALYSES PERFORMED:

SAMPLE MATRIX:
QA REPORTING LEVEL:

FIELD DATA PACKAGE DOCUMENTATION

CLASS A (QUALITATIVE)	REPORTED	PERFORMANCE ACCEPTABLE	NOT REQUIRED
1. FIELD (WATER AND SOIL) SAMPLE LOGS COMPLETED PROPERLY AND SIGNED			
2. SAMPLING DATES			
3. SAMPLING TEAM INDICATED			
4. SAMPLE IDENTIFICATION TRACEABLE TO LOCATION COLLECTED			
5. SAMPLE LOCATION			
6. SAMPLE DEPTH FOR SOILS			
7. COLLECTION TECHNIQUE (BAILER, PUMP ETC)			
8. FIELD SAMPLE PREPARATION TECHNIQUES			
9. SAMPLE TYPE (GRAB, COMPOSITE)			
9. SAMPLE CONTAINER TYPE			
10. PRESERVATION METHODS			
12. CHAIN OF CUSTODY FORM COMPLETED			
13. REQUIRED ANALYTICAL METHODS REQUESTED			
14. NUMBER AND TYPE OF FIELD QC SAMPLES COLLECTED (BLANKS, REPLICATES, SPLITS, ETC.)			
15. FIELD EQUIPMENT CALIBRATION			
16. FIELD EQUIPMENT DECONTAMINATION			
17. SAMPLE SHIPPING			
18. LABORATORY TASK ORDER			

COMMENTS:

FIELD DOCUMENTATION AND PERFORMANCE:

EXPLANATION OF VALIDATION AND CLASSIFICATION CODES:

SAMPLE QUALIFIER CODES

R CODE:	DATA FLAGGED WITH AN "R" HAS NOT MET THE REQUIRED ANALYTICAL QA REQUIREMENTS. THIS DATA IS UNUSABLE EVEN IF FIELD QC DATA IS ACCEPTABLE.
J CODE:	DATA FLAGGED WITH A "J" HAS FAILED SOME OF THE ANALYTICAL QA REQUIREMENTS BUT NOT SUFFICIENT TO WARRANT CLASSIFYING THE DATA AS UNUSABLE. DATA IN THIS CATEGORY IS QUALITATIVE (ESTIMATED) PROVIDED THE FIELD DATA MEETS CRITERIA AND THE SAMPLE IS VALID.
U CODE:	DATA FLAGGED WITH A "U" MEANS THE ANALYTE WAS ANALYZED FOR BUT NOT DETECTED, I.E. THE ANALYTE WAS BELOW DETECTION LIMIT.
B CODE:	DATA FLAGGED WITH A "B" CODE MEANS THAT THE ANALYTE WAS PRESENT ABOVE REPORTING DETECTION LIMITS WITHIN LABORATORY BLANKS; B CODES DO NOT NECESSARILY INVALIDATE THE DATA BUT ARE DEPENDENT UPON THE JUDGEMENT OF THE REVIEWER IN APPLYING THE VALIDATION GUIDELINES;

CLASSIFICATION CODES

CLASS A DATA: DATA IN THIS CLASS MUST HAVE MET ALL THE REQUIREMENTS SPECIFIED IN THE FIELD CHECKLIST AND IN SECTION I OF THE ANALYTICAL CHECKLIST. THIS DATA IS QUALITATIVE. ANY SAMPLE DATA RECEIVING AN R QUALIFIER CODE OR AN UNEXPLAINED B QUALIFIER CODE MAY NOT BE CLASSIFIED AS CLASS A DATA. DATA THAT HAS BEEN GIVEN A J CODE MAY NOT BE CONSIDERED AS CLASS B DATA.

CLASS B DATA: DATA IN THIS CLASS MUST HAVE MET ALL THE REQUIREMENTS SPECIFIED IN THE FIELD CHECKLIST AND IN ALL SECTIONS (I, II, AND III) WHERE APPLICABLE FOR THE LEVEL OF REPORTING IN ORDER TO BE CONSIDERED AS QUANTITATIVE (CLASS B) DATA.

UNUSABLE DATA: DATA IN THIS CLASS HAS FAILED ANY OF THE REQUIREMENTS WITHIN THE FIELD CHECKLIST OR THE ANALYTICAL CHECKLIST. THIS DATA SHOULD BE FLAGGED WITH AN R AND MAY NOT BE USED FOR ANY PURPOSE.

PAGE 2 ANALYTICAL DATA VALIDATION CHECKLIST

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1-88
R-2

CONTRACT REQUIREMENTS FOR ANALYTICAL DATA PACKAGE DOCUMENTATION AND PERFORMANCE CLASS A (QUALITATIVE)

SECTION I: GENERAL INFORMATION	REPORTED	PERFORMANCE ACCEPTABLE	NOT REQUIRED
1. SAMPLE RESULTS			
2. PARAMETERS ANALYZED			
3. METHOD OF ANALYSIS			
4. DETECTION LIMITS OF ANALYSIS			
5. MASTER TRACKING LIST			
6. SAMPLE COLLECTION DATE			
7. LAB SAMPLE RECEIVED DATE			
8. SAMPLE PREPARATION/EXTRACTION DATE			
9. SAMPLE ANALYSIS DATE			
10. COPY OF CHAIN-OF-CUSTODY FORM SIGNED BY THE LAB SAMPLE CUSTODIAN			
11. A NARRATIVE SUMMARY OF QA OR SAMPLE PROBLEMS IS PROVIDED.			

COMMENTS:

CWA F-1 (R2)
1-88

DOCUMENTATION (A) / PERFORMANCE (B)

SECTION II. INORGANIC ANALYSES	REPORTED	PERFORMANCE ACCEPTABLE	NOT REQUIRED
1. ICVS AND CCVS			
2. LCS (DIGESTED)			
3. QC CHECK SAMPLE (UNDIGESTED)			
4. METHOD BLANKS			
5. INTERFERENCE CHECK SAMPLE (ICP ONLY)			

PAGE 3

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1-88

SECTION II. INORGANIC ANALYSES CONTINUED	REPORTED	PERFORMANCE ACCEPTABLE	NOT REQUIRED
6. DILUTION CHECK SAMPLE-2XCRDL (ICP ONLY)			
7. LABORATORY DUPLICATES AND %RSD OR RPD			
8. MATRIX SPIKES			
9. ANALYTICAL (POST-DIGESTED) SPIKES (FURNACE AAS ONLY)			

COMMENTS:

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1-88
R-2

SECTION III. ORGANIC ANALYSES	REPORTED	PERFORMANCE ACCEPTABLE	NOT REQUIRED
A. GAS CHROMATOGRAPHY (NO MASS SPEC)			
1. WATER BLANKS (VOA)			
2. EXTRACTION BLANKS			
3. TRIP BLANKS			
4. INDEPENDENT QC CHECK SAMPLES			
5. REAGENT WATER SPIKE (RWS)			
6. REAGENT WATER SPIKE DUPLICATE			
7. RWS RPD AND CONTROL LIMITS			
8. MATRIX SPIKES (MS)			
9. MATRIX SPIKE DUPLICATES			
10. MS RPD AND CONTROL LIMITS			
11. LABORATORY DUPLICATES (OPTIONAL)			
12. SURROGATE SPIKES			

COMMENTS:

Section III. Organic Analyses continued

B. Gas Chromatography/Mass Spectrometer	Reported	Performance Acceptable	Not Required
1. BFB or DFTPP Tuning			
2. Initial Calibration (IC)			
A. SPCC compounds (Av.RF >0.3/0.05)			
B. CCC compounds (RSD < 30% in RF)			
C. Other compounds (Av.RF > 0)			
D. Frequency (at least every 3 Mos)			
3. Continuing calibration			
A. SPCC compounds (Av.RF >0.3/0.05)			
B. CCC compounds (Max %D from IC Av. RF is 25%)			
C. Other compounds (Av.RF >0)			
D. Frequency (daily after tuning)			
4. Water blanks (Calibration blanks)			
5. Extraction (method) blanks			
6. Trip blanks			
7. Reagent water spikes (RWS)			
8. Reagent water spike duplicate			
9. RWS RPD and control limits			
10. Matrix spikes (MS)			
11. Matrix spike duplicate (MSD)			
12. Surrogate spike			
13. Results of latest Independent QC check samples (EPA or NBS traceable) analyzed, expected value, and source (lot no. & manufacturer)			
14. Results of blank spike analysis for matrix spike or matrix spike duplicate parameters not meeting recovery requirements			

COMMENTS: ____________________

CLASS B (QUANTITATIVE) REQUIREMENTS

DATA EVALUATION SUMMARY	REPORTED	PERFORMANCE ACCEPTABLE	NOT REQUIRED
1. FIELD MEASUREMENTS OF PH AND SPECIFIC CONDUCTANCE ARE CONSISTENT WITH HISTORICAL DATA			
2. ANALYTICAL METHODS			
3. EXTRACTION HOLDING TIMES			
4. ANALYSIS HOLDING TIMES			
7. DETECTION LIMITS			
8. SAMPLER RINSATE BLANKS			
9. FIELD BLANKS			
10. TRIP BLANKS			
11. LABORATORY BLANKS			
A. WATER BLANKS			
B. CALIBRATION BLANKS			
C. METHOD BLANKS			
D. EXTRACTION BLANKS			
15. FIELD REPLICATES			
16. FIELD SPLITS			
17. GEOPHYSICAL COMPARISONS			
A. CATION VS ANION			
B. TDS VS SPEC. CONDUCTANCE			
C. PH VS ALK/ACIDITY			
D. OTHER			
18. INORGANIC QA DATA (SECTION II)			
19. ORGANIC QA DATA (SECTION III A)			
20. ORGANIC QA DATA (SECTION III B)			
21. CLASSICAL ANALYTICAL METHODS QA DATA			

COMMENTS: ____________________

DATA VALIDATION CODING

	CODES					
	R	B	U	J	U/J	No Flags
1. Qualifier Codes Assigned to Data						

Identification of samples and parameters with codes:

	Sample ID	Parameters
R code:		
B code:		
U code:		
J code:		
U/J code:		

Explanation: ____________________

Data Classification:

		A	B	Unusable
Data class:				
Sample Matrix:	________			

Explanation:

Identity of samples and parameters that are in different use classes:

____

____

____

Validation performed by: ____________________

____

Signed: ____________________

EXPLANTATION OF VALIDATION AND CLASSIFICATION CODES:

SAMPLE QUALIFIER CODES

R CODE: DATA FLAGGED WITH AN "R" HAS NOT MET THE REQUIRED ANALYTICAL QA REQUIREMENTS. THIS DATA IS UNUSABLE EVEN IF FIELD QC DATA IS ACCEPTABLE.

J CODE: DATA FLAGGED WITH A "J" HAS FAILED SOME OF THE ANALYTICAL QA REQUIREMENTS BUT NOT SUFFICIENT TO WARRANT CLASSIFYING THE DATA AS UNUSABLE. DATA IN THIS CATEGORY IS QUALITATIVE (ESTIMATED) PROVIDED THE FIELD DATA MEETS ALL CRITERIA AND THE SAMPLE IS VALID.

U CODE: DATA FLAGGED WITH A "U" MEANS THE ANALYTE WAS ANALYZED FOR BUT NOT DETECTED, I.E. THE ANALYTE WAS BELOW DETECTION LIMIT.

B CODE: DATA FLAGGED WITH A "B" CODE MEANS THAT THE ANALYTE WAS PRESENT ABOVE REPORTING DETECTION LIMITS WITHIN LABORATORY BLANKS; B CODES DO NOT NECESSARILY INVALIDATE THE DATA BUT ARE DEPENDENT UPON THE JUDGEMENT OF THE REVIEWER IN APPLYING THE VALIDATION GUIDELINES;

CLASSIFICATION CODES

<u>Class A Data:</u> DATA IN THIS CLASS MUST HAVE MET ALL THE REQUIREMENTS SPECIFIED IN THE FIELD CHECKLIST AND IN SECTION I OF THE ANALYTICAL CHECKLIST. THIS DATA IS QUALITATIVE. ANY SAMPLE DATA RECEIVING AN R QUALIFIER CODE OR AN UNEXPLAINED B QUALIFIER CODE MAY NOT BE CLASSIFIED AS CLASS A DATA. DATA THAT HAS BEEN GIVEN A J CODE MAY NOT BE CONSIDERED AS CLASS B DATA.

<u>Class B Data:</u> DATA IN THIS CLASS MUST HAVE MET ALL THE REQUIREMENTS SPECIFIED IN THE FIELD CHECKLIST AND IN ALL SECTIONS (I, II, AND III) WHERE APPLICABLE FOR THE LEVEL OF REPORTING IN ORDER TO BE CONSIDERED AS QUANTITATIVE (CLASS B) DATA.

<u>Unusable Data:</u> DATA IN THIS CLASS HAS FAILED ANY OF THE REQUIREMENTS WITHIN THE FIELD CHECKLIST OR THE ANALYTICAL CHECKLIST. THIS DATA SHOULD BE FLAGGED WITH AN R AND MAY NOT BE USED FOR ANY PURPOSE.

- A verification that equipment blanks, field blanks, and trip blanks were properly prepared, identified and analyzed.
- A check on field analyses for equipment calibration and instrument condition.
- A review of chain-or-custody forms for proper completion, signatures of field personnel and the laboratory sample custodian, and dates.

11.2 VALIDATION OF THE ANALYTICAL DATA PACKAGE

After validation of the field data package, validation of the analytical data package will be performed by the project QA officer and/or site manager. The validation steps will be performed by applying where applicable the most current (7/88 Inorganic and 2/88 organic) EPA Laboratory Data Validation Functional Guidelines For Evaluating Organics and Inorganics Analyses, and the EPA Precision and Accuracy Statements (DQOs specified in Section 5.0) for the analytical methods employed. Figure 10 also contains an analytical data validation checklist to be used for validation of the data.

The analytical data package validation procedure may include but not be limited to a review of the following:

- A comparison of the data package to the reporting level requirements specified in Appendix C to ensure completeness in the analytical data package and compliance with the contract.
- A comparison of sampling dates, sample extraction dates, and analysis dates to check that samples were extracted and/or analyzed within proper holding times.

- A review of analytical methods and required detection limits to verify that they agree with the QAPP (Section 5.0) and the laboratory contract.

- A review of field and laboratory blanks to evaluate possible contamination sources. The preparation techniques and frequencies, and the analytical results (if appropriate) will be considered. All blanks will be evaluated in accordance with the EPA Functional Guidelines for Validation of Laboratory Data.

- Field replicates will be reviewed to check the precision of chemical analyses and field sample collection techniques. Field replicates and laboratory duplicates for water matrices, if available will be reviewed. The results must be within the EPA specified requirements for each method's precision (DQOs specified in Section 5.0); in the absence of this information, inorganic parameter duplicates must have a relative percent difference (RPD) of 20 percent if analyte value is greater than five times the detection limit; if the value is less than five times the detection limit, the duplicates must have an RPD no greater than 5 percent.

- Surrogate spikes must be within allowable control limits specified for the method.

- Matrix spike recoveries for organic analyses are considered advisory by the EPA and will be used to evaluate the presence of matrix interferences that may be affecting recovery of a particular analyte. Control limits must be reported when matrix spike data is reported. When matrix spike duplicates are performed and/or reported, the relative percent difference (RPD) must be calculated and RPD control limits reported.

A data management flow chart is presented in Figure 10 to illustrate the flow of data through the validation system.

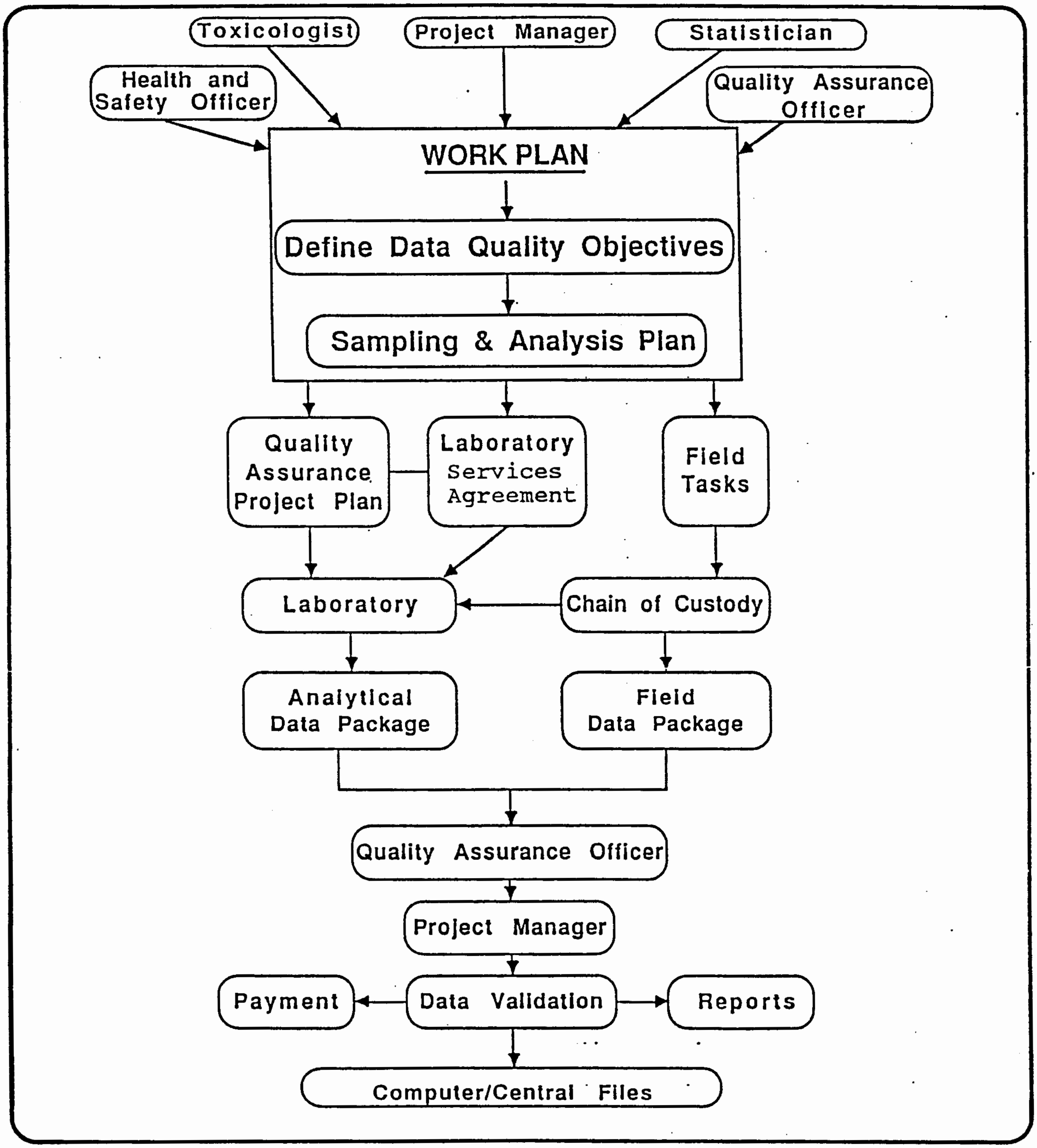

Figure 10
Data Management Flow Chart

CLIENT NAME:

Martin Marietta Corporation

12.0 PERFORMANCE AND SYSTEM AUDITS

Performance and system audits for sampling and analysis operations consist of on-site review of field and laboratory quality assurance systems and on-site review of equipment for sampling, calibration, and measurement.

12.1 FIELD SYSTEM AUDIT

The director of field operations, the project manager and/or the project QA officer will make a non-scheduled visit to the project site to evaluate the performance of field personnel and general field operations in progress. The director of field operations will observe the performance of the field operations team during each kind of activity, i.e., water-level readings and sampling rounds. A systems audit of field operations personnel by the project QA officer also may be performed.

12.2 LABORATORY SYSTEM AUDIT

A laboratory systems audit will be conducted by the project QAO at some point during the course of the project. This audit is designed to ensure that the systems and operational capabilities are maintained and test methodology and quality control measures for the project are being followed as specified by the QAPP.

12.3 PERFORMANCE EVALUATION AUDITS

A performance evaluation (PE) audit is an audit performed to evaluate a laboratory's ability to obtain an accurate and precise answer in the analysis of a blind check sample by a specific analytical method. Following the analytical data validation described in Section 10.0, a performance evaluation audit of the laboratory may be conducted. This audit may be conducted if it is determined that the quality assurance data provided in the analytical data package or other parameters as described in Sections 10.0 and 11.0 are outside acceptance criteria control limits. These PE audits may include a review of all raw data developed by the laboratory and not reported and the submission of blind spiked check samples for the analysis of the parameters in question. These check samples may be submitted disguised as field samples, in which case, the laboratory will not know the purpose of the samples or the samples may be obvious (known) check samples (EPA or NBS traceable).

PE Audits also may be conducted by reviewing the laboratory's results from certification testing and/or EPA Contract Laboratory Program (CLP) evaluation samples. An additional component of PE audits includes the review and evaluation of raw data generated from the analysis of PE samples and actual field samples that may be in question.

12.4 REGULATORY AUDITS

Analytical laboratories participating in the contract laboratory program (CLP) are required to take part in a series of performance and systems audits conducted by the National Enforcement Investigations Center (NEIC). Versar is a CLP laboratory and has participated in these audit programs.

13.0 PREVENTIVE MAINTENANCE

Field testing instruments sampling equipment employed by MMC which requires preventive maintenance are routinely serviced as required by manufacturer's recommendations. Records of calibration and maintenance activities for each instrument will be maintained in log books assigned to that instrument. Preventive maintenance for Versar's laboratory equipment is described in their generic QAP.

14.0 ASSESSMENT OF DATA PRECISION, ACCURACY, AND COMPLETENESS

Precision is an estimate of the reproductibility of a method, and it is estimated by several statistical tests: the standard deviation of the error distribution, the co-efficient of variation and the relative percent difference between replicate (duplicate) samples. MMC may determine the precision of a method by analyzing replicate samples and laboratory duplicate samples (where applicable), then, if sufficient replicate data are obtained, the arithmetic mean and standard deviation may be calculated.

Precision is then defined by the coefficient of variation (CV), which expresses the standard deviation as a percentage of the mean. Specific statistical comparison of duplicate samples (field and laboratory), as a measure of precision evaluating both sample collection procedures and laboratory instrument performance, may be accomplished by first comparing the obtained duplicate results with the published EPA criteria for method precision. If not available, the relative percent difference (RPD) may be calculated and compared to the laboratory precision criteria.

The determined precision value will then be compared with the stated precision DQO for the analyte in question to determine whether the DQO has been satisfied. If not the data is not valid.

The accuracy of a method is an estimate of the difference between the true value and the determined mean value. Certain QA parameters such as laboratory control samples, reagent water spike samples, QC Check samples, matrix spikes and surrogate spike samples all have known concentrations in them prior to analysis. By comparing the percent recovery of the analysis of these samples to the known true value it is possible to measure the accuracy of the analysis. In routine practice the laboratory may collect the data for each of these parameters for a period of at least 30 measurements. The results of these 30 measurements is averaged and the standard deviation of the measurements is calculated. Then, based on the desired level of confidence, two or three standard deviation ranges will be established as practical control limits. To be valid these control limits must meet the accuracy limits specified by EPA for each analyte measured by the method. If the determined control limits are within the range established for the analyte and method by EPA then the determined range becomes the practical control limits used by the laboratory until another set of data is developed and new control limits are calculated.

Specific statistical comparison of percent recovery values reported by the laboratory as a measure of method accuracy will be compared with the published EPA criteria for the accuracy of an individual method and to the accuracy DQOs stated in Section 5.0. Data not meeting the DQO for accuracy will be considered invalid or unusable.

Data completeness will be expressed both as the percentage of total tests conducted that are deemed valid and as the percentage of the total tests required in the scope of work that are deemed valid.

Methods for assessing data precision, accuracy, and completeness by Versar are described in their generic QAP referenced in Appendix A.

15.0 CORRECTIVE ACTION

During the course of the ground-water monitoring, the field personnel are responsible for seeing that field instruments are functioning properly and that work progresses satisfactorily. The field personnel also are responsible for ensuring performance of routine preventive maintenance and quality control procedures, thereby ensuring collection of valid field data.

If a problem is detected by the field personnel, the MMC Site Manager and GME Project Manager shall be notified immediately by the Field Manager, at which time the problem will be further investigated and corrective action will begin. Similarly, if a problem is identified during a routine audit by the project QAO or the EPA Project Manager or QAO, an immediate investigation will be undertaken and corrective action deemed necessary will be taken as early as possible.

Corrective actions to be undertaken by Versar are described in their generic QAPP referenced in Appendix A.

In all cases in which corrective actions are required a written report describing the nature of the problem, an evaluation of the cause, if known, and the action taken will be prepared by the Field Manager or the Project QAO and submitted to the Project Manager, the Project QAO (if not preparing the report), or Project Officer. Versar will maintain a file of corrective actions implemented within their laboratory regardless of whether the actions performed were pertinent to the analysis of samples from the MMRF facility.

16.0 QUALITY ASSURANCE REPORT TO MANAGEMENT

The Quality Assurance Report for the ground-water monitoring program will be prepared following each sampling period. The reports will address the following:

- Quality assurance activities and quality of collected data (results of data validation);
- Equipment calibration and preventive maintenance activities;
- Results of data precision and accuracy calculations;
- Evaluation of data completeness and contract compliance;
- Field and/or laboratory QA problems and recommended and/or implemented corrective actions; and
- Results of QA audit findings.

The Quality Assurance Reports will be submitted to the EPA Region X and Oregon DEQ.

17.0 RESUMES

Resumes of key project personnel are included in this section.

GERAGHTY & MILLER
ENGINEERS, INC.

KURT S. ANDERSON
Scientist

CREDENTIALS/REGISTRATION

M.S., Geology, Western Washington University, 1985
B.S., Geology, Southern Oregon State College, 1980

PROFESSIONAL AFFILIATIONS

Geological Society of America
Northwest Geology Society
National Water Well Association

FIELDS OF SPECIALIZATION

- Modeling of subsurface stratigraphy and aquifers for regional ground-water resources
- Interpretation of geophysical exploration data
- Ground-water Contamination Investigations
- Hydrogeology field Investigators
- Regional correlation of depositional facies changes

EXPERIENCE SUMMARY

Mr. Anderson is experienced as a technical coordinator and investigator for ground-water contamination investigations and environmental audits and has evaluated remedial action alternatives and implemented remediation for contaminated sites. His work also includes the monitoring of drilled exploration borings, the installation of monitoring wells, completion of aquifer pumping tests, ground-water and soil sampling, and geologic mapping on both the reconnaissance and detailed level.

KEY PROJECTS

- Completion of field activities for a Superfund site in Oregon which included ground-water sampling for various contaminants potentially affecting several unconfined and confined aquifers in both unconsolidated deposits and basalt bedrock.

- Completion of monitoring wells and ground-water sampling at a silver and gold mine in Nevada to determine the integrity of heap leaching operations and their potential effect on unconsolidated deposit and partially confined bedrock aquifers.

- Design and implementation of hydrocarbon recovery program to retrieve free-phase lighter-than-water hydrocarbons from unconsolidated aquifer partially controlled by tidal influences in unconsolidated fill deposits.

GERAGHTY & MILLER
ENGINEERS, INC.

CHARLES W. ANKERBERG
Senior Scientist

CREDENTIALS/REGISTRATION

B.A., Microbiology/Chemistry, Florida State University, 1969
M.T., Medical Technology, University of South Florida, 1970
American Society of Clinical Pathologists Certification as Medical Technologist, Bayfront Medical Center, 1970
Certified Hazardous Materials Manager, Senior Level, Institute of Hazardous Material Management, 1985

PROFESSIONAL AFFILIATIONS

American Society of Microbiology
Institute of Hazardous Materials Management
American Chemical Society
American Society for Testing and Materials (ASTM)

FIELDS OF SPECIALIZATION

- Analytical and Field Quality Assurance/Quality Control Programs (EPA)
- EPA Contract Laboratory Program
- Hazardous Waste Management/Environmental Laws, Hazardous Materials Communications Act
- Bio-remediation of Ground Water
- Occupational Health and Safety
- Medical Technology

EXPERIENCE SUMMARY

As a member of the Hazardous Waste Management Consulting Team, Mr. Ankerberg conducted numerous Facility Reviews and Environmental Audits for RCRA Compliance evaluations of companies in violation of state and federal hazardous waste laws. He is also project manager of several projects involving ground-water contamination remediation.

KEY PROJECTS

- Project Coordinator for hydrocarbon contamination projects managed by G&M for numerous major oil companies.

- Performed laboratory audits for subcontractor laboratories used by G&M Florida offices, and in August 1986, was given the additional responsibility of G&M Quality Assurance Officer for several major Superfund (CERCLA) project.

- In March 1987, he was appointed Quality Assurance Liaison Officer for the Tampa Office of G&M with oversight extending to G&M's Aiken and Oak Ridge offices.

DAVID C. CAMPBELL, P.E.
Project Engineer

CREDENTIALS/REGISTRATION

B.S. Environmental Engineering, University of South Florida, 1984
MSCE (Environmental Specialty), University of South Florida, 1988
Registered Professional Engineer in Florida

PROFESSIONAL AFFILIATIONS

American Society of Civil Engineers
National Society of Professional Engineers
Florida Engineering Society

FIELDS OF SPECIALIZATION

- Water Distribution Systems Analysis
- Sanitary Wastewater Planning, Collection, Treatment and Disposal Systems
- Surface Water Modeling
- Surface Water System Planning, Design and Treatment Systems

EXPERIENCE SUMMARY

Mr. Campbell has over 5 years of experience in the environmental field encompassing urban water and wastewater planning and design, surface water modeling, and landfill and resource recovery facility planning and site selection. He has performed hazardous waste site feasibility studies as well as planning and design activities on ground-water remediation projects.

KEY PROJECTS

- Participated in site selection for a major regional solid waste landfill in west-central Florida. Responsibilities included identifying and delineating environmental and institutional constraints, identifying suitable land tracts, and conducting hydrogeologic investigations on finalist sites.

- Mr. Campbell is presently managing source removal activities at an asphalt distillery in west-central Florida. Included are the removal and incineration of contaminated soil, the collection and disposal of liquid phase oil and the temporary support of affected distillery equipment.

- Participated in a CERCLA remedial investigation/ feasibility study for a rayon manufacturing facility in northern Virginia. Included were modifications to an existing biological WWTP, ground water recovery in a fractured bedrock system and dewatering and final cover of waste holding basins.

GERAGHTY & MILLER
ENGINEERS, INC.

BRUCE A. CARPENTER
Senior Scientist

CREDENTIALS/REGISTRATION

B.A., Geology, Lehigh University, 1971
Graduate Studies in Geology, University of Vermont, 1972-75

PROFESSIONAL AFFILIATIONS

National Water Well Association

FIELDS OF SPECIALIZATION

- Hydrogeologic Assessments
- Remedial Investigation/Feasibility Studies
- Ground-water Resource Development
- Ground-water Remediation Design

EXPERIENCE SUMMARY

Mr. Carpenter has supervised numerous hydrogeologic investigations and projects throughout the United States and overseas. As project manager, he has conducted remedial investigations for industry with regard to plume abatement and contamination source control. He has written Part B applications for RCRA compliance investigations and cleanup. He has designed water quality sampling programs for sites on the National Priorities List.

KEY PROJECTS

- Conducted and evaluated pumping tests to determine maximum pumping rates for a Seattle Water District's well field.

- Performed a hydrogeologic study, installed and collected water samples from a monitoring well system to comply with State of Washington (DOE) regulations for a landfill in Hoquiam, Washington.

- Participated in the development and implementation of a management plan for a remedial investigation for the Seattle U.S. Army Corps of Engineers.

- Performed numerous environmental audits to evaluate site histories regarding hazardous waste usage and disposal throughout Washington State.

- Designed and tested a dewatering system for a construction site in Hoquiam, Washington.

- Evaluated a multiple water supply well field for a large development in Snohomish County, Washington.

- Designed and supervised the installation of a test production well to irrigate a golf course in Tukwila, Washington.

- Performed an environmental audit to evaluate the hydrogeology and the potential for hazardous was contamination for 12 sites in Anchorage, Alaska.

FRANCIS L. CORDEN, JR.
Staff Scientist

CREDENTIALS/REGISTRATION

B.S. Chemistry, University of Tampa, 1982
M.S. Chemistry, University of South Florida, In Progress

PROFESSIONAL AFFILIATIONS

American Chemical Society
American Association for the Advancement of Science
North American Lake Management Society
Florida Society of Environmental Analysis
(Past President and Regional Director)

FIELDS OF SPECIALIZATION

- Field and Laboratory Quality Assurance/Quality Control Procedures and Analytical Methodologies (EPA)
- Air Monitoring Programs for Remedial Activities
- Monitoring Programs for NPDES, Industrial Wastewater Discharge and Port/Marina Dredge and Fill Permits
- Monitoring Programs for Florida Administrative Code 17-3 Surface Water Discharges
- Environmental Laboratory Management

EXPERIENCE SUMMARY

Mr. Corden is assigned to Geraghty & Miller's Laboratory Quality Assurance Program. His initial responsibilities include writing Quality Assurance Project Plans, evaluating laboratory data, and auditing contract laboratories. He also provides project managers with guidance in evaluating and selecting appropriate analytical methods for various types of environmental testing programs. Mr. Corden has also been involved with preparing and implementing air-monitoring programs associated with remedial actions of contaminated site.

Prior to joining Geraghty & Miller, Inc., Mr. Corden was a Branch Manager of Envirolab, Inc., Tampa, where he was responsible for project management and/or technical support of a variety of laboratory programs including landfill ground-water monitoring, solid waste treatment evaluations, NPDES permit monitoring, marina dredge and fill permit evaluations, and non-point source surface-water pollution studies.

Previous employment also includes former positions as a Technical Consultant and a Laboratory Supervisor for Enviropact, Inc., of Clearwater, Florida.

KEY PROJECTS

- Project manager for a chlorine spill cleanup and a laboratory training program and was involved with cleanups of hazardous materials storage tanks and indoor air-quality evaluations.

- Involved with reviewing analytical and quality control procedures in place at Enviropact facilities.

KATHLEEN C. DUCHAC
Staff Geologist

CREDENTIALS/REGISTRATION
B.A., Geology, University of Wisconsin-Madison, 1981
M.S., Geology, Louisiana State University, Baton Rouge, 1986
Arkansas Certified Professional Geologist, Number 204
AHERA Accredited Building Inspector/Management Planner

PROFESSIONAL AFFILIATIONS
Geological Society of America
American Geophysical Union
National Water Well Association

FIELDS OF SPECIALIZATION
- Hydrogeologic Field Investigations
- Ground-water Contamination Investigations
- Low-temperature Aqueous Geochemistry
- Quality Assurance Coordinator
- Health and Safety Coordinator

EXPERIENCE SUMMARY

As a project manager, Ms. Duchac has coordinated and directed field activities for a variety of ground-water contamination projects and projects requiring the evaluation of remedial action alternatives and implementation of hazardous waste management procedures. Ms. Duchac has completed numerous environmental assessments which have included the inspection of buildings at the facilities for asbestos-containing materials.

KEY PROJECTS
- Project manager for a "fast track," comprehensive environmental assessment program to evaluate soil and ground-water conditions at a food processing facility in Idaho.
- Field Coordinator and Quality Assurance Officer for a Remedial Investigation/Feasibility Study during supplemental data collection activities at an alumina reduction facility in Oregon.
- Project manager for environmental assessments of two chemical manufacturing facilities in northeastern Illinois.
- Project manager for a project investigating a heavier-than-water plume for a paper mill in Wisconsin.
- Member of the project team which developed ground-water assessment and subsequent design of a Corrective Action Plan for an industrial facility.
- Supervised monitor-well installation, field data collection, logging of core and aquifer testing for an energy storage project in west central Illinois.

A. CARL DUNCAN
Assistant Staff Engineer

CREDENTIALS/REGISTRATION

B.S. Geology, University of South Florida, 1985
B.S. Civil Engineering, University of South Florida, 1986

PROFESSIONAL AFFILIATIONS

American Society of Civil Engineers

FIELDS OF SPECIALIZATION

- Civil Engineering Infrastructure Design, Studies and Project Management
- CERCLA Feasibility Studies
- Residential and Commercial Site Plan Design
- Environmental Permitting
- Evaluation and appraisal of underground storage tanks

EXPERIENCE SUMMARY

Mr. Duncan is an Assistant Staff Engineer with G&M Consulting Engineers, Inc. with two years of experience in civil engineering. His experience encompasses all phases of site development for private development and municipal governments.

KEY PROJECTS

- Project Engineer for the City of Port Richey, Florida Sanitary Sewer System design.

- Project Engineer for the City of New Richey, Florida Pennsylvania Avenue paving and drainage project.

- Project Engineer for developing and writing the Evaluation and Appraisal Report (EAR) for the 1980 comprehensive plan, as well as Traffic Impact Fee Assessment for the City of Port Richey, Florida.

- Engineer-In-Charge of Church Site Development for the Diocese of St. Petersburg.

- Developed plans and specifications for residential, commercial, public, and recreational facilities. The projects included school sites, churches, office buildings, R.V. parks, golf courses, warehouses, retail stores, and subdivisions. obtained regulatory agency approval for master drainage plans, water and wastewater facilities, and lot and roadway layout.

- Engineer-in-Charge for assessment of engineering damages to various private property owners for various right-of-way acquisitions by the State of Florida and several counties therein.

ROBERT W. FOX
Staff Engineer

CREDENTIALS/REGISTRATION

B.S. Civil Engineering, Louisiana State University, 1983
E.I.T., Louisiana, 1984

PROFESSIONAL AFFILIATIONS

American Society of Civil Engineers
Chi Epsilon

FIELDS OF SPECIALIZATION

- Alternatives Assessment/Feasibility Studies
- Hazardous/Solid Waste Permit Applications
- Civil/Geotechnical Analyses and Designs
- Construction Drawing/Technical Specifications
- Construction Quality Assurance

EXPERIENCE SUMMARY

Mr. Fox has five years experience as a civil/geotechnical engineer in waste management. His current responsibilities encompass project management of alternatives assessments and feasibility studies, development of engineering plans and specifications, and a whole range of waste management projects. Mr. Fox has developed a number of closure plans and new facility designs and has conducted construction inspection/observation and certification for a number of waste management projects.

KEY PROJECTS

- Project Manager developing closure strategy for two wastewater treatment lagoon systems containing metal plating (F006) sludges. The project included alternatives assessment, design of a bench study, and preparation of the plan for regulatory submittal.

- Lead Engineer providing technical support during ongoing agency and PRP negotiations for remediation of a precedence setting Superfund site in the Midwest. PRP group is seeking to have the ROD for the site amended after being issued in an effort to provide a more effective and efficient site remediation.

- Project Manager for the design of a cap upgrade for an existing eight (8) acre landfill.

- Project Engineer for the design of a new hazardous waste landfill for an industrial client in Mississippi.

- Lead Engineer for design of a closure of a surface impoundment construction in erosional channels within a fractured basalt bench along the Columbia River.

GERAGHTY & MILLER
ENGINEERS, INC.

J. LAWRENCE HOSMER
Principal Engineer

CREDENTIALS/REGISTRATION

M.S., Civil/Geotechnical Engineering; Univ. of Illinois, 1972
B.S., Civil/Geotechnical Engineering; Lehigh University, 1970
Registered P.E., Maryland, Delaware, District of Columbia, New Jersey, Pennsylvania, Virginia, West Virginia, Wisconsin, New York

PROFESSIONAL AFFILIATIONS

American Society of Civil Engineers
Governmental Refuse Collection and Disposal Association
Society of American Military Engineers
Water Pollution Control Federation

FIELDS OF SPECIALIZATION

- Budgeting, Environmental Audits
- Community Relations, Expert Witness/Testimony, Litigation Support, Permit Assistance, Several Publications and Seminars
- Field Investigations, Monitoring, Sampling, Hydrogeology
- Feasibility Studies, RCRA, CERCLA, SARA, and Remedial Investigations

EXPERIENCE SUMMARY

Mr. Hosmer provides expertise for a variety of waste management planning, facility design and remediation programs. He has served as Project Manager and consultant on assignments primarily related to solid and hazardous waste management, geotechnical engineering, groundwater hydrology, and water-quality assessment. His activities have centered on investigation and remediation of past land disposal facilities; site selection, study and design of new land disposal and other waste management facilities; and assistance in the negotiation of environmental permits. He has served as an expert witness in state courts relative to field investigations/monitoring and landfill closure design techniques.

KEY PROJECTS

- Project manager for CERCLA remedial investigation/feasibility studies (RI/FS) at 4 sites. These projects involved all aspects of the CERCLA-mandated remediation program.

- Project manager for two Environmental Audits of industrial property to prepare for financing transfer. Projects included field and lab assessments of the air, water and soil media for potential past contamination through on-site or off-site disposal practices.

- Project manager for the siting, permitting, design and construction oversight of several landfills including Hawkins Point Hazardous Waste Landfill in Maryland and a new 2,000 ton-per-day facility for Virginia Beach, Virginia.

- To meet a State of Maryland Emergency Health Order, managed the site selection, evaluation, conceptual design and permitting of a replacement 1,400 ton-for-day landfill for Montgomery County, Maryland in 1978.

DAVID J. JESSUP, P.E.
Principal Engineer

CREDENTIALS/REGISTRATION

B.S. Civil Engineering, Purdue University, 1975
M.S. Environmental Engineering, University of Tennessee, 1977
Registered P.E., Louisiana, Oregon, Mississippi, Arkansas, Washington, Illinois, Alabama, South Carolina and Iowa

PROFESSIONAL AFFILIATIONS

American Society of Civil Engineers
American Water Resources Association
Louisiana Engineering Society
Chi Epsilon

FIELDS OF SPECIALIZATION

- Hazardous Waste Remedial Action Design and Implementation
- Closure Plans and Alternative Assessments
- Landfarm Facility Design
- Hazardous/Solid Waste Permit Applications
- Wastewater Treatment

EXPERIENCE SUMMARY

Mr. Jessup is Vice President in charge of engineering for G&M Consulting Engineers, Inc. and he has extensive experience on projects that encompass all aspects of remediation. He has been involved in the development of designs, technical specifications, alternative assessments, CERCLA work plans, remedial investigations and feasibility studies, waste stabilization/ solidification studies, and State and Federal permitting. Mr. Jessup has successfully negotiated several design concepts with regulatory agencies which have been implementable, environmentally acceptable and cost effective.

KEY PROJECTS

- Landfill Cap Upgrade. As Project Manager, directed an alternatives assessment, construction plans and specifications, construction observation, and final documentation.

- Closure Plans. As Project Manager, directed the preparation of several closure assessments and closure plans for various hazardous and non-hazardous waste management facilities.

- Closure Designs. As Project Manager, was responsible for the development of the closure designs, technical specifications, and certifications for several hazardous and non-hazardous waste management facilities.

- Feasibility Study Officer, The Dalles RI/FS, Oregon, responsible for the reduction of data to determine the appropriateness of any remedial action for 10 suspected sources and ground water.

- Project Manager for the Old Inger Superfund Site, Phase III Engineering Design.

GORDANA MILIC JOVANOVIC
Staff Engineer

CREDENTIALS/REGISTRATION

B.S. Civil Engineering, University of Belgrade, Yugoslavia, 1984

PROFESSIONAL AFFILIATIONS

American Society of Civil Engineers (ASCE)
Yugoslav Society of Civil Engineers (DIT)

FIELDS OF SPECIALIZATION

- Roadway design, residential and commercial site plan design, storm water control, sanitary sewer design, computer aided design and calculations from field data
- Soils lab management and supervision, engineering analysis, and direction of all the testing and execution of in-house training programs
- Testing of bituminous pavement cores, bitumens and additives
- Design of highways, urban traffic routes, intersections, new traffic and parking patterns, and drainage

EXPERIENCE SUMMARY

Ms. Jovanovic is a Staff Engineer with G&M Consulting Engineers, Inc. She has extensive experience in geotechnical engineering. Her responsibilities include soil lab supervision and engineering analysis data, direction of all testing which is performed in accordance with current ASTM and AASHTO specifications. She is familiar with the full set of testing procedures for rock and soil, visual classifications of soil, index properties, graduation analysis, moisture-density relationships, consolidation, permeability, organic content, and all types of triaxial tests.

Prior to joining GMCE, Ms. Jovanovic designed major residential and commercial subdivisions, roadways, intersections, drainage, and sanitary and storm sewers as a consultant.

KEY PROJECTS

- Geotechnical Engineer for The Dalles RI/FS, Oregon. Responsible for geotechnical preparation for closure at this Superfund site.

- Logan Project, Philadelphia, Pennsylvania. Settlement problems involving the sinking of 1200 homes build on ash and cinder. Responsible for all laboratory testing and classification.

- Hudson County Correction Facility, New Jersey. Responsible for over 500 soil tests, including field testing such as pile load tests and plate load tests.

GERAGHTY & MILLER
ENGINEERS, INC.

JACK L. KRATZMEYER
Principal Engineer

CREDENTIALS/REGISTRATION

M.S. Environmental Engineering, Northwestern University, 1983
B.S. Mechanical Engineering, Purdue University, 1974

PROFESSIONAL AFFILIATIONS

American Society of Civil Engineers
National Water Well Association

FIELDS OF SPECIALIZATION

- CERCLA Feasibility Studies, RCRA Corrective Actions
- Environmental Site Assessments
- DOD DERP Studies

EXPERIENCE SUMMARY

Mr. Kratzmeyer has conducted field investigations of numerous landfills, industrial facilities, CERCLA hazardous waste sites, and RCRA facilities. He has conducted all aspects of hazardous waste remediation projects, including development and implementation of technical plans for site investigations, development of quality assurance, and health and safety programs, validation of analytical data, alternative assessments, feasibility studies, evaluation of regulatory compliance, design and preparation of technical specifications.

KEY PROJECTS

- Project Engineer for the Cross Brothers NPL site in Illinois. Responsibilities included preparation and execution of the sampling and analysis plan.

- Project Engineer for the design of a RCRA surface cap. Prepared plans and technical specifications for the cap system, which was designed to allow continued use of the existing transfer chain structure.

- Project Engineer for an investigation into the source of gasoline component contamination of private wells in Lisbon, Illinois.

- Project Engineer for the DERP Confirmation Study at the former DOD Tyson Valley Powder Farm in Eureka, Missouri.

- Project Engineer and principal investigator for an environmental site assessment of a detinning plant in Gary, Indiana.

- Principal author of report to the USAF Occupational & Environmental Health Laboratory on ground-water conditions at the Wurtsmith AFB in Iosco County, Michigan.

GERAGHTY & MILLER
ENGINEERS, INC.

HUGH J. MARTIN, P.E.
Principal Engineer

CREDENTIALS/REGISTRATION

B.S. Chemical Engineering, Univ. of Colorado, 1950 Registered P.E., Colorado

PROFESSIONAL AFFILIATIONS

American Water Works Association
Water Pollution Control Federation

FIELDS OF SPECIALIZATION

- Conventional and Specialized Water and Waste Treatment Technology
- Process Design and Equipment Selection
- Preparation of Equipment Specifications and Evaluation of Bids
- Development of Capital, Operating and Maintenance Costs
- Interpretation of Environmental Regulations and Agency Negotiations

EXPERIENCE SUMMARY

Mr. Martin has over 30 years of extensive experience in process selection and system design related to water, industrial waste, and sewage treatment. He specializes in the areas of water reuse and recovery, primary water treatment, filtration, demineralization, sewage treatment and sludge management. Mr. Martin brings to GME vast technical expertise in the areas of both conventional and innovative treatment technologies as related to ground-water and leachate treatment.

KEY PROJECTS

- Developed water balance and treatment systems to allow "Zero Discharge" operation at the Antelope Valley Station, Basin Electric Power, Beulah, North Dakota.

- Evaluated the operating and test data obtained during wet air oxidation of municipal sewage sludge in a pilot model down-hole vertical tube reactor; assisted in preparation of final report to USEPA.

- Prepared study and comprehensive report regarding treatment options, treatment costs and transportation of secondary municipal sewage for reuse as cooling tower makeup, Nevada Power, Las Vegas, Nevada.

- Prepared engineering cost estimates, mechanical flow diagrams and process and instrumentation diagrams for treatment of fireside wastes (heavy metal removal) at Southern California Edison coastal steam generating stations.

- Participated in an intensive engineering study for the proposed TVA Northern Alabama Coal-to-Methanol plant, including waste treatment for biological dentrification and cyanide removal via ion exchange.

GERAGHTY & MILLER
ENGINEERS, INC.

JEFFREY D. MAYFIELD
Assistant Staff Engineer

CREDENTIALS/REGISTRATION
B. Geotechnical Engineering, Univ. of Minnesota, 1987
E.I.T. State of Minnesota, 1987

PROFESSIONAL AFFILIATIONS
American Society of Civil Engineers

FIELDS OF SPECIALIZATION
- Geotechnical Engineering
- Environmental Audits
- Asbestos Abatement

EXPERIENCE SUMMARY

Mr. Mayfield recently joined G&M Consulting Engineers, Inc. and has been involved in the performance of a feasibility study for the remediation of a contaminated coal-tar facility in Salisbury, Maryland and, on another project, the remediation of a major ore processing facility in Baltimore, Maryland. Prior to joining GMCE he served as the field engineer for an underground storage tank removal project in New Jersey. Multiple leaking underground storage tanks were removed under New Jersey's Environmental Cleanup Responsibility Act (ECRA). He also served as the field engineer at an AHERA asbestos abatement, and has conducted multiple environmental audits for industry and financial institutions.

KEY PROJECTS

- Field engineer for multiple underground storage tanks removal project. Oversaw tank removals, soil staging, soil sampling, selection of soil disposal site, proper backfill and compaction of clean soil.

- Field engineer for 15,000 sq. ft. Asbestos Hazard Emergency Response Act (AHERA) asbestos abatement project. Oversaw removal and replacement of multiple types of asbestos-containing building material.

- Conducted environmental environmental audits at a major TSDF incinerator, vinyl-sided window manufacturing facility, a major department store auto service center, and various commercial properties.

- Developed and reported contaminated soil treatment alternatives for a coal-tar site in eastern Maryland.

GERAGHTY & MILLER
ENGINEERS, INC.

DOUGLAS W. MELLEMA
Assistant Staff Engineer

CREDENTIALS/REGISTRATION

B.S., Civil Engineering, University of Nebraska at Omaha, 1988
E.I.T. State of Nebraska, 1988

PROFESSIONAL AFFILIATIONS

American Society of Civil Engineers

FIELDS OF SPECIALIZATION

- Geotechnical design/analysis including field investigations, field testing, laboratory analysis, foundation design, and earth retaining structures
- Remediation of Superfund sites
- Management of construction operations

EXPERIENCE SUMMARY

Mr. Mellema recently joined G&M Consulting Engineers, Inc., and is currently providing engineering assistance for Superfund sites.

Prior to joining GMCE, Mr. Mellema was a student at the University of Nebraska, where he specialized in geotechnical and hydraulic engineering. He was also employed by the U.S. Army Corps of Engineers (CoE) in its Construction and Environmental Divisions as an Assistant to Regional Project Managers. Mr. Mellema also performed field and laboratory tests on soils and construction materials for Geotechnical Services, Inc.

KEY PROJECTS

- Assistance in remedial design of a RCRA landfill cap and contaminated water storage and treatment facility.

- Engineering Assistant for Corps of Engineers B-1 Bomber maintenance facilities and Air Launched Cruise Missile construction projects.

- Engineering Assistant for Project Managers of Rocky Mountain Arsenal Superfund site.

- Field Inspector for a large shopping plaza in Omaha, Nebraska, including site preparation, soils testing, and asphalt placement inspections.

- Quality Assurance Inspector for several residential subdivision projects. Responsibilities included complete geotechnical investigations, site preparations, and site inspections.

RALPH E. MOON
Principal Scientist

CREDENTIALS/REGISTRATION

B.S., Biology, Western Michigan University, 1972
M.S., Botany, University of South Florida, 1975
Ph.D., Biology, University of South Florida, 1980
Post Doctoral Fellowship, University of South Florida, Department of Chemistry, 1981
Certified Hazardous Materials Manager, Master Level, 1985

PROFESSIONAL AFFILIATIONS

Sigma XI
Chemical and Environmental Management Service (CHEMS) Board of Directors, University of South Florida
American Chemical Society
Institute of Hazardous Materials Management
National Water Well Association
Society for Risk Analysis

FIELDS OF SPECIALIZATION

- Investigation and evaluation of ground-water contamination incidents
- Health and safety assessments at hazardous-waste sites
- Public health evaluations and risk assessments
- Real estate site assessments

EXPERIENCE SUMMARY

Dr. Moon joined Geraghty & Miller, Inc., (G&M) in 1984 from employment with the Florida Department of Environmental Regulation where he served as the Southwest District Hydrologist.

Dr. Moon was also a course instructor at the University of South Florida's School of Public Health, a Clinical Assistant Professor in the Department of Comprehensive Medicine, and served as an industrial hygiene consultant to the Jim Walter Research Corporation in St. Petersburg, Florida.

KEY PROJECTS

- Project Manager for several ground-water contamination projects

- Health and Safety Officer for an Oregon Superfund site where the production of cyanide containing waste as a by product of an aluminum production facility prompted special health and safety provisions

- Endangerment Assessment Reports at several Superfund sites throughout the U.S.

KEVIN J. ORMSBY
Regional Health and Safety Manager

CREDENTIALS/REGISTRATION

Attended Eastern Montana College, 1976-1978
Hazardous Materials Incident Response Course, U.S. Environmental Protection Agency, January, 1983
Hazardous Material Response, U. S. Coast Guard, April, 1983 Respiratory Protection. U.S.C.G., March 1984
Hazardous Material Spill Control School, Corpus Christi State University, April, 1984
First Responders at Hazardous Materials Incidents, University of California at Davis, June, 1984
Chemical First Fire Fighting, Texas A&M, August, 1984
Air Surveillance Hazardous Materials Incidents, U.S. Environmental Protection Agency, July, 1985

FIELDS OF SPECIALIZATION

- Hazardous Waste Site Remediation
- Site Safety Officer
- Development of Site Health and Safety Plans
- Implementation of the Site Safety Plan

EXPERIENCE SUMMARY

Mr. Ormsby was employed by the U.S. Coast Guard from 1979 to 1985 and was a member of the National Strike Team for three years, assigned to the Pacific Strike Team. While on the Strike Team, he was directly involved with emergency response, planning, and recovery and disposal of oil and hazardous material spills throughout 14 western states, Alaska, Hawaii and the Trust Territories. His efforts included developing an on-scene organization and directing the efforts of the clean-up contractor.

Prior to joining Geraghty & Miller, Inc. in 1986, Mr. Ormsby was employed by Industrial Clean-up Inc. of Garyville, Louisiana where he was directly involved with hazardous waste remediation at several industrial facilities. There he served as Operations Manager, Health and Safety Officer and Air/Safety Trailer Manager. He was also a member of the safety and inspection team for the Port Authority of New York and New Jersey where he supervised the acquisition of data and sample for asbestos in Port Authority buildings.

As a Health and Safety Scientist with Geraghty Miller, Inc., Mr. Ormsby has developed numerous health and safety plans for investigations at potentially hazardous sites. He has also played a key role in the development and organization of Geraghty & Miller's 40-hour health and safety training program.

GERAGHTY & MILLER
ENGINEERS, INC.

JEFFREY A. PETERSOHN, P.E.
Senior Project Engineer

CREDENTIALS/REGISTRATION

B.S. Civil Engineering, University of Florida, 1980
Registered P.E., Florida, Georgia, Alabama, Montana, Minnesota, Nebraska

PROFESSIONAL AFFILIATIONS

American Society of Civil Engineers
National Society of Professional Engineers
Florida Engineering Society

FIELDS OF SPECIALIZATION

- Geotechnical Investigations
- Geotechnical Designs for Waste Management Facilities
- Geotechnical Construction Quality Assurance - Soil and Ground-water Remediation
- Hydrogeologic Investigations for Industrial Impoundments and Landfills

EXPERIENCE SUMMARY

As a Project Engineer with G&M Consulting Engineers, Inc., Mr. Petersohn has seven years of practical experience in the field of civil/geotechnical engineering. His current responsibilities include the management of projects ranging from feasibility studies to the development of engineering plans and technical specifications for site closures.

KEY PROJECTS

- Project Engineer for the preparation of a Feasibility Study for industrial lagoons in Virginia containing an industrial by-product.

- Project Engineer for design of a RCRA cap system and slurry wall for an industrial waste lagoon located in Gulfport, Mississippi.

- Project Manager for installation of a subsurface interceptor drain for a Tennessee state Superfund site.

- Project Engineer on a major hydrogeologic investigation of 16 sites to support the disposal of treated wastewater in Escambia County, Florida .

- Performed hydrogeologic investigation of a jet fuel spill site and installation of monitor wells in northwest Florida.

- Project Engineer for the geotechnical investigations a 1.5 million gallon potable water storage tank for the Santa Rosa Island Authority, Pensacola Beach, Florida.

LORANNE M. PIPER
Assistant Staff Engineer

CREDENTIALS/REGISTRATION

B.S. Civil Engineering, University of Maryland, 1988

PROFESSIONAL AFFILIATIONS

American Society of Civil Engineers

FIELDS OF SPECIALIZATION

- Environmental Engineering
- Water Treatment Alternatives
- Health and Safety

EXPERIENCE SUMMARY

Ms. Piper recently joined G&M Consulting Engineers, Inc. and has been involved in developing ground-water treatment alternatives for the remediation of a contaminated coal-tar facility in Salisbury, Maryland. Her responsibilities include data analysis and preparation of technical reports.

As Health and Safety Officer, Ms. Piper has coordinated the implementation of the firm's health and safety program.

Prior to joining G&M Consulting Engineers, Ms. Piper was employed by a small, high tech manufacturing firm as Safety Coordinator. While there, she was responsible for health and safety training, hazardous waste disposal, and safety aspects of a new facility design.

KEY PROJECTS

- Developed and reported ground-water treatment alternatives for remediation of contaminated site in Salisbury, Maryland.

GERAGHTY & MILLER
ENGINEERS, INC.

GREGORY J. RORECH
Staff Engineer

CREDENTIALS/REGISTRATION

B.S. Chemical Engineering, University of Buffalo, 1985
Graduate Studies in Environmental Engineering, Manhattan College, 1987
Engineer-in-Training, New York

PROFESSIONAL AFFILIATIONS

American Institute of Chemical Engineers
Water Pollution Control Federation

FIELDS OF SPECIALIZATION

- Design of Ground-Water Recovery and Treatment Systems
- CERCLA Feasibility Studies
- Environmental Assessments
- Remedial Action Planning and Implementation
- Environmental Compliance Strategies

EXPERIENCE SUMMARY

Mr. Rorech has four years of experience in ground-water and wastewater treatment design, hazardous waste site assessments, remedial action planning, environmental compliance strategies and CERCLA feasibility studies.

KEY PROJECTS

- Designed the recovery, fluid handling, treatment and disposal systems of two petroleum spills that were floating on the ground water.

- Designed a wastewater treatment system for a petroleum waste product in a environmentally sensitive coastal area.

- Managed the preparation of a Feasibility Study for an electric utilities site that was contaminated with PCBs and volatile organic compounds.

- Prepared several remedial action plans in accordance with the State of Florida Department of Environmental Resources, Petroleum Contamination Site Cleanup Criteria, 17-709.

- Site investigation, development of a sampling plan and implementation of pilot scale program for interior surfaces and grounds of a manufacturing facility.

- Successfully negotiated with the Wisconsin Department of Natural Resources one of the first variances to store pentachlorophenol.

- Designed a multi-layer cap to close a salt manufacturers waste lagoon.

GERAGHTY & MILLER
ENGINEERS, INC.

EDWARD R. ROTHSCHILD
Vice President
Principal Hydrogeologist

CREDENTIALS/REGISTRATION

M.S. Geology, University of Wisconsin, 1982
B.A. Geology and Zoology, University of Vermont, 1979
Certified Professional Geological Scientist (CPGS) No. 7360
North Carolina Licensed Geologist, Number 257
Editor, Journal of Ground Water

PROFESSIONAL AFFILIATIONS

American Geophysical Union
Geological Society of America
National Water Well Association
Wisconsin Ground Water Association

FIELDS OF SPECIALIZATION

- Evaluation of contamination and investigation of remedial actions for radioactive and hazardous waste burial facilities
- Contaminant transport modeling and assessment
- Management of hazardous waste projects
- Design and implementation of well field management programs
- Underground storage tank management and remediation

EXPERIENCE SUMMARY

Mr. Rothschild is responsible for the organization and supervision of ground-water projects and analysis of hydrologic data. His work includes the design and implementation of remedial investigations and feasibility studies for sites involving ground-water contamination. His experience also includes the design of a well field management, development, and environmental protection program for a major municipal ground water supply.

- Design and evaluation of remedial measures for several US EPA Superfund hazardous waste sites in the upper midwest.

- Evaluation of a major well field for the City of Dayton, Ohio and the design of well field management, development and protection programs.

- Design and implementation of a site characterization program for evaluating a potential low level radioactive waste disposal area at Oak Ridge National Laboratory, TN.

- Design and implementation of a subsurface investigation to evaluate the extensive losses of metallic mercury at the Oak Ridge Y-12 Plant, TN.

- Authored over a dozen publications and abstracts.

ALLISON M. VIDAL
Assistant Staff Engineer

CREDENTIALS/REGISTRATION

B.S.Ch.E., University of South Florida, 1986
B.S.N., Registered Nurse, Univ. of South Florida, 1979
Engineer-in-Training, State of Colorado, 1987.
Completed 40-hour hazardous material Health and Safety training 1988.

PROFESSIONAL AFFILIATIONS

American Institute of Chemical Engineers

FIELDS OF SPECIALIZATION

- On-site management and inspection of ground-water plume stabilization installation
- Corporate Health and Safety Officer
- Site Health and Safety Officer
- Pilot project documentation
- Project scheduling

EXPERIENCE SUMMARY

Ms. Vidal's responsibilities concern overseeing proper assembly, material specifications, work team interface and on-site management of process equipment installation, process control and instrumentation, and electrical power controls. As site Health and Safety Officer, she is responsible for testing and detection of hazardous substances in the work environment, evaluating and acting decisively on collected information.

KEY PROJECTS

- Assisting project manager in handling of a major superfund site remediation project.

- Field engineer on a ground-water plume stabilization installation.

- Startup of air stripping, granulated activated carbon treatment system.

- Chemical sampling of ground-water treatment facilities and process equipment.

- Set up sampling program for treatment system.

- Established employee health program.

- Organized medical monitoring and surveillance.

- Investigated and selected occupational health physician.

APPENDIX A

VERSAR, INC. QAP

(COPY ON FILE WITH EPA REGION X)

APPENDIX B

AQUEOUS CYANIDE PRESERVATION PROTOCOL

Aqueous Cyanide Preservation Protocol

(as adopted by Region 10 RQAMO)

October, 1986

I. SUMMARY

In order to meet EPA requirements for collection of aqueous samples for cyanide analysis the spot tests for sulfide and oxidizing agents described below should be performed in the field prior to preservation of the sample with sodium hydroxide. Sulfide and oxidizing agents (e.g., chlorine) are interferences in the measurement of cyanide in aqueous samples and must be removed the day of sample collection. Samples must be analyzed for cyanide within 14 days of collection.

Note: Perform the sulfide spot test first. If positive, it may be assumed that oxidizing agents are not present and therefore the oxidizing agent test need not be performed.

II. SULFIDE SPOT TEST AND REMOVAL

A. Test Summary

In general, a small aliquot of the sample will be tested for the presence of sulfide using two techniques: the lead acetate indicator paper spot test and the cadmium nitrate powder spot test. Both tests result in a color change in the presence of sulfide. The lead acetate paper darkens in the presence of sulfide while a yellow precipitate is formed upon addition of cadmium nitrate powder. Both visual tests will be used and if positive, sulfide will be removed before sample preservation. Sulfide will be removed before sample preservation. Sulfide is removed as a yellow precipitate by the addition of cadmium nitrate powder and separated from the sample by filtration.

B. Apparatus

1. Eyedropper or Pastuer pipette

2. Plastic weighing boat or disposable beaker
   (for performing spot test)

3. Lead acetate indicator paper

4. Spatula

5. Filtration apparatus

a) A suitable apparatus of polyethlene or glass construction to rapidly filter the volume of sample needed should be used. All pieces must be thoroughly cleaned between uses to avoid contamination.

b) Filter papers of Whatman #1 grade or equivalent

C. Reagents

1. Cadmium nitrate powder [$CD(NO_3)_2$]

2. Sodium acetate buffer solution (ph 4.0)

--Dissolve 146 g anhydrous $NaC_2H_3O_2$), or 243 g $NaC_2H_3O_2$ $*3H_2O$, in 400 ml distilled water. Add 480 g conc. acetic acid, and dilute to 1 L with distilled water.

D. Procedure -- Spot Test

....Collect the appropriate volume of sample (at least 1 Liter) in the plastic bottle (Note: do not preserve the sample with NaOH). Pour about 50 ml of the sample into the plastic weighing boat or disposable beaker. The spot tests will be performed on this aliquot.

1. Lead acetate indicator paper spot test

a) Moisten a strip of the lead acetate indicator paper with the sodium acetate buffer solution.

b) Using an eyedropper or Pastuer pipette, place a drop of sample to be tested on the moistened lead acetate indicator paper.

c) Observe any color change of the lead acetate indicator paper. Darkening of the paper indicates the presence of sulfide.

d) If a positive test should occur then the sulfide must be removed from the sample by precipitation with cadmium nitrate powder, followed by filtration to remove the cadmium sulfide precipitate (described below, Section E).

2. Cadmium nitrate powder addition spot test

a) Add a small portion (spatula tip) of cadmium nitrate powder to the sample aliquot. The formation of a yellow precipitate indicates the presence of sulfide.

b) If a positive test should occur then the sulfide must be removed from the sample by precipitation with cadmium nitrate powder, followed by filtration to remove the cadmium sulfide precipitate (described below, Section E).

E. Procedure -- Sulfide Removal

1. If there are any particulates present in the sample (indicated by the presence of sediment on bottom or turbid sample), and especially if metal/cyanide complexes are suspected in the sample, then the sample must be filtered (using the same apparatus and paper as for the sulfide precipitation) before sulfide removal. Save the filtered particulates for reconstitution of the sample (step 4 below) once sulfide removal has been completed.

2. To precipitate sulfide from the sample add cadmium nitrate powder in small amounts (spatula tip) until a drop of treated sample no longer causes the lead acetate indicator paper to darken and a yellow ppt. no longer forms.

3. Filter the sample to remove the cadmium sulfide precipitate. Discard the yellow precipitate.

4. Reconstitute the sample by returning the particulates removed in step (1) with the filter paper to the sample.

F. Quality Control

A clean distilled water sample should be treated as described above at a frequency of 1 per 10 samples. Label the sample as a cyanide spot test blank (e.g., CN spot test BLK) and note the group of corresponding samples if more than one CN spot test blk was run that day. Send samples to the laboratory for cyanide analysis. This procedure checks for contamination introduced during sample pretreatment.

III. OXIDIZING AGENT SPOT TEST AND REMOVAL

A. Test Summary

In general a small aliquot of the sample will be tested for the presence of oxidizing agents (e.g., chlorine) using potassium iodide-starch indicator paper. A bluish discoloration of the potassium iodide-starch paper indicates the presence of oxidizing agents. Oxidizing agents can be removed by the addition of ascorbic acid.

B. Apparatus

1. Eyedropper or Pastuer pipette

2. Spatula

3. Filtration apparatus

a) A suitable apparatus of polyethylene or glass construction to rapidly filter the volume of sample needed should be used. All pieces must be thoroughly cleaned between uses to avoid contamination.

b) Filter papers of Whatman #1 grade or equivalent

C. Reagents

1. Potassium iodide-starch indicator paper
(KI-starch paper)

2. Ascorbic acid, crystal ($C_6H_8O_6$)

3. Sodium acetate buffer solution (ph 4.0)

Dissolve 146 g anhydrous $NaC_2H_3O_2$, or 243 g $NaC_2H_3O_2$ $3H_2O$, in 400 ml distilled water. Add 480 g conc. acetic acid, and dilute to 1 L with distilled water.

D. Procedure

1. The sample aliquot collected for the spot test procedure, Section II, D above, may be used for this test.

2. Potassium iodide-starch indicator paper spot test.

a) Moisten a strip of KI-starch paper with the sodium acetate buffer solution.

b) Using an eyedropper or Pastuer Pipette, place a drop of sample to be tested on the moistened KI-starch paper.

c) Observe any color change of the KI-starch paper. A bluish discoloration of the paper indicates the presence of oxidizing agents.

d) If a positive test should occur then the oxidizing agents must be removed by the addition of ascorbic acid.

e) If there are any particulates present in the sample, and especially if metal cyanide complexes are suspected in the sample, then the sample must be filtered before oxidizing agents are removed. Save the filtered particulates for reconstitution of the sample (step h) once oxidizing agents have been removed.

f) To remove oxidizing agents in the sample, add 0.6 g of ascorbic acid and retest with the KI-starch paper. Repeat addition if necessary.

g) When a drop of treated sample no longer discolors the KI-starch paper an additional 0.6 g of ascorbic acid should be added to the sample.

h) Reconstitute the sample by returning the particulates removed in step (e) with the filter paper to the sample.

E. Quality Control

A clean distilled water sample should be treated as described above at a frequency of 1 per 10 samples. Label the sample as a cyanide spot test blank (e.g., CN spot test BLK) and note the group of corresponding samples if more than one CN spot test blk was run that day. Send samples to the laboratory for cyanide analysis. This procedure checks for contamination introduced during during sample pretreatment.

GERAGHTY & MILLER
ENGINEERS, INC.

APPENDIX C

ANALYTICAL QUALITY ASSURANCE AND LABORATORY CONTRACT PROGRAM

LEVEL II

Field QC

and

Laboratory Reporting Requirements

LEVEL II LABORATORY QUALITY ASSURANCE REQUIREMENTS

I. LABORATORY REPORTABLES:

The following information will be included in the data package for each sample where applicable:

A. General Information:

1. The results of sample analysis;
2. The parameters of interest;
3. The method of analysis;
4. The detection limits of analysis;
5. For large numbers of samples per report, a master list of laboratory tracking ID numbers correlated with field sample ID numbers and sample analysis batch identification to correlate QA samples to sample analysis batch;
6. Sample collection date;
7. Sample received date;
8. Sample preparation/extraction date;
9. Sample analysis date;
10. Copy of the chain-of-custody form signed by the laboratory sample custodian;
11. A narrative summary identifying any QA or sample problems encountered, required sample manipulations (dilutions), and the corrective action taken.

Level II Reportables

B. Inorganics Analyses:

For inorganics analyses involving the use of atomic absorption (flame or furnace), inductively coupled plasma (ICP), ion chromatograph (IC), light (visible or ultraviolet) spectrophotometric methods, other turbidimetric, gravimetric, auto analyzer procedures and inorganic procedures generally referred to as "wet bench" chemistry, the following QA data should be provided where applicable:

1. Results of method blanks;

2. Results of batch specific laboratory duplicates, relative percent difference (RPD) from sample, and control limits;

3. Results of batch specific matrix spikes, expected value, percent recovery, control limits, and source;

4. Results of a Laboratory Control Sample (LCS) spiked into reagent water and carried through the preparation method prior to analysis (may also be called a digested spike or QC Check Sample), expected value, percent recovery, and control limits;

5. Results of a QC Check Sample (Initial Calibration Verification Standard) spiked into reagent water (non-digested), expected value, percent recovery, and control limits. This sample is an analytical spike, not carried through the method. Lot No. and source should be provided.

C. <u>Organics Analyses</u>:

1. Gas Chromatography (GC) Analysis:

   The results of the following analyses should be reported where applicable:

   a. Blanks:

      (1) Water blanks (Non-extraction);
      (2) Extraction blanks (Laboratory blank);
      (3) Trip blanks

      Note: Field blanks are treated as samples.

   b. Results of most recent independent QC check sample, expected value, percent recovery, and control limits (include Lot No. and source);

   c. Results of batch specific matrix spikes, expected value, percent recovery, and control limits;

   d. Results of batch specific laboratory duplicates or matrix spike duplicates;

   e. Results of surrogate spikes, expected value, percent recovery, and control limits;

   f. Results of reagent water spikes and reagent water spike duplicate of compounds of interest, expected value and percent recovery, and control limits should be reported if matrix spikes are outside control limits.

2. GC/Mass Spectrometer Analysis:

The results of the following analyses should be reported where applicable:

a. Blanks:

   (1) Water blanks;
   (2) Extraction blanks;
   (3) Trip blanks.

b. Results of most recent independent QC check sample results expected value, percent recovery, and control limits (include Lot No. and source);

c. Results of batch specific matrix spikes;

d. Results of batch specific matrix spike duplicates;

e. Laboratory duplicates - optional;

f. Surrogate spikes expected value, percent recovery, and control limits;

g. For matrix spike/matrix spike duplicate, the expected value, percent recovery, matrix spike control limits, relative percent difference (RPD), and RPD control limits.

h. Results of reagent water spikes and reagent water spike duplicate of compounds of interest, expected value, and percent recovery and control limits should be reported if matrix spikes are outside control limits.

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II. LABORATORY NON-REPORTABLES: (LEVEL II)

All raw data and data not included under the reportables described in paragraph I developed by the contracted laboratory during sample analysis must be maintained by that laboratory as a record for a period of three years unless specified otherwise by the contract. Such data may include, but not be limited to, the following:

A. Inorganics Analyses:

1. Concentration of calibration curve standards;
2. Results of analysis of initial calibration verification standards, percent recoveries, and expected values;
3. Results of analysis of continuing calibration verification standards, percent recoveries, and expected values;
4. Results of linear range check samples for ICP;
5. Results of linear range (1 to 4) dilution sample for ICP;
6. Results of interference check sample (ICS) analysis and expected value (ICP only);
7. Results of analytical (post-digested) spike analysis;
8. Sequential measurement readout records;
9. Digestion logs;
10. Percent solids raw data;
11. Raw data calculation worksheets.

B. Organics Analyses:

Records of the analysis results of the following types of QA samples:

1. Initial calibration data;
2. GC/Mass Spectrometer tuning with BFB or DFTPP and mass calibration summary;
3. Continuing calibration standards including results of system performance check compounds (CCC) and expected results;

4. Response factors and relative retention time for each parameter;
5. Internal standard parameter (compound) and concentration;
6. Sample chromatograms;
7. Mass spectral data for each sample.

NOTE: The laboratory non-reportable inorganic and organic information is not required to be submitted with the laboratory report, but should be available for audit review upon 30-days notice.

General Quality Assurance Requirements

CONTENTS

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GENERAL QA REQUIREMENTS AND FREQUENCY OF PERFORMANCE:

The guidelines described below are to be followed where applicable by the contracted laboratory regardless of whether they are to be reported.

A. General References:

QA for all analyses (inorganic and organic) will be consistent with the requirements appropriate for all the methods of analysis specified under the scope of services and will be conducted as specified by the applicable reference document listed below:

1. Methods for Chemical Analyses of Water and Wastes. EPA 600/4-79-020, March 1983;
2. Test methods for Evaluating Solid Waste, SW-846, Second Edition; U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, DC, 1982;
3. Test methods for Evaluating Solid Waste, SW-846, Third Edition; U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, D.C., November 1986;
4. Methods for Organic Chemical Analysis of Municipal and Industrial Wastewater, EPA 600/4-82-057, July 1982;
6. Handbook for Analytical Quality Control in Water and Wastewater Laboratories, EPA 600/4-79-019, March 1979;
7. EPA CLP Statement of Work, most recent version;
8. Standard Methods for the Examination of Water and Wastes, 16th Edition, American Public Health Association, American Water Works Association, Water Pollution Control Federation, 1985.
9. Other approved regulatory methodology appropriate for the parameters described in the contract but not included in references cited above.

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B. Blanks:

The assessment of blank analysis results is to determine the existence and magnitude of contamination problems within the analytical system. The criteria for evaluation of blanks applies to any blank associated with the samples. If problems with any blank exist, all data associated with the batch of samples analyzed with the blank must be carefully evaluated to determine whether or not there is an inherent variability in the data with that batch, or if the problem is an isolated occurrence not affecting other data.

1. Inorganics Analysis:

   a. Method blanks should be analyzed at a frequency of at least 1 per 20 samples per matrix unless other frequency is specified in the contract or Laboratory Task Order.

   b. Criteria: No contaminants should be in the blank(s); See Laboratory Data Validation, Functional Guidelines for Evaluating Inorganics Analyses, July 1, 1988.

2. Organics Analysis:

   a. Water blanks: analyze at a frequency of 1 per 20 samples (VOA only); or per 12 hours, whichever is more frequent.

   b. Extraction blanks: analyze at a frequency of 1 per 20 samples per matrix, or 1 per extraction date; whichever is more frequent;

   c. Solvent blanks or associated reagent water blank: analyze at a frequency of one per lot of solvent reagent. Data should be maintained in a file for future reference when needed.

   d. Criteria: No contaminants should be in the blank(s); See Laboratory Data Validation, Functional Guidelines for Evaluating Organics Analysis, February 1, 1988.

C. <u>Laboratory Independent QC Check Samples (EPA or NBS Traceable) or Laboratory Control Samples (LCS):</u>

1. Inorganics Analysis:

   a. LCS (digested standard) should be analyzed at a frequency of 1 per 20 samples per water matrix, Soil LCS not required;

   b. QC check samples should be EPA, NBS, or other certified source; these should be analyzed at least on a quarterly basis through state or federal "round-robin" or other certification programs. The latest result applicable to the requested analysis should be included with laboratory reports where indicated by the level of reportables. Results should include Lot No. and source of sample.

2. Organics Analysis:

   a. QC check samples should be EPA, NBS, or other certified source; these should be analyzed at least on a quarterly basis through state or federal "round-robin" or other certification programs. The latest result applicable to the requested analysis should be included with laboratory reports where indicated by the level of reportables. Results should include Lot No. and source of sample.

3. For inorganics or organics analyses, the following criteria applies:

   The Laboratory must take whatever corrective action is necessary to satisfy the ACCURACY Data Quality Objectives for each analyte as specified for the project either in Item 3 Exhibit One or on the Laboratory Task Order.

D. Calibration Curves and Initial Calibration Verification:

Requirements for satisfactory instrument calibration are established to ensure that the instrument is capable of producing acceptable quantitative data. Initial calibration demonstrates that the instrument is capable of acceptable performance at the beginning of the analysis run.

1. Inorganics Analysis:

   a. Instruments must be calibrated daily and each time the instrument is set up.

   b. For ICP Instruments: A blank and at least one standard must be used in establishing the analytical curve.

   c. For Atomic Absorption Instruments: A blank and at least three standards must be used in establishing the analytical curve. The lowest calibration standard must be no greater than the limit of quantitation (LOQ) determined as specified in the General Scope of Services. If LOQs are not used, a value of 2-3 times the IDL is acceptable. The correlation coefficient for all curve standards must be greater than or equal to 0.995.

   d. For Mercury Analysis: A blank and at least four standards must be used in establishing the analytical curve. The correlation coefficient must be greater than or equal to 0.995.

   e. For Cyanide Analysis: A blank and at least three standards must be used in estalishing the analytical curve. The coorelation coefficient must be greater than or equal to 0.995.

   f. For other parameters: A blank and at least three standards must be used in establishing analytical curves or as specified by the method if other than described here; parameters not requiring analytical curves should be calibrated as specified by the method.

   g. The initial Calibration Verification of all instruments must be verified with EPA or NBS traceable or other certified source standards. This control is referred to as in ICVS and is not digested. ICVS must be run with each calibration to verify the curve validity. For all metals analysis by ICP or AA, the control limits of 90 -

110 percent recovery (%R) of the true value for all analytes except mercury. Analysis results for mercury must fall within the control limits of 80 - 120 %R. Analysis results for cyanide must fall within the control limits of 85 - 115 %R.

2. Organics Analysis:

   a. Calibration curves must be three-to-five-point curves based on whether the method requested is associated with a Clean Water Act (CWA), Safe Drinking Water Act (SDWA), CERCLA, or RCRA program; concentrations of calibration curve standards must be as specified by the method; calibration standards must be checked against EPA standards or other traceable source.

   b. For GC analyses, linearity of the instrument must be checked by analyzing the compounds of interest at at least three concentration levels. For cases where the number of analytes (i.e., pesticides/ PCBs) would make this effort unreasonable, at least three representative compounds should be run at three levels. Relative standard deviations (RSDs) of response factors (RF) must be less than 10% for quantitative analyses only.

   c. For GC/Mass Spectrometer analyses under CERCLA and RCRA programs, relative (average) response factors (RRF) for all compounds including system performance check compounds (SPCC) and calibration check compounds (CCC) must be greater than 0.05.

   d. For GC/Mass Spectrometer analyses, calculations of response factor relative standard deviation (internal standard) or the calibration factor (ratio of the peak area to the standard concentration) percent relative standard deviation must be less than 30 %RSD for CERCLA and RCRA programs and less than 10% for CWA and SDWA programs.

   e. For GC/Mass Spectrometer analyses, the instrument must be properly tuned with BFB or DFTPP and meet all acceptance criteria before analysis of calibration curve standards or calibration check standards. Tuning must be performed at least once every 12 hours during which analyses are performed.

E. Continuing Calibration Verification Standards (CCVS) and Continuing Calibration Checks:

Continuing Calibration Verification and Continuing Calibration Checks document that the initial calibration in inorganics analysis is still valid and that satisfactory maintenance and adjustment of the instrument on a day-to-day basis has occurred in organics.

1. Inorganics Analysis:

   a. CCVS (may be referred to as an undigested QC check sample) must be run at a frequency of one standard for every ten samples as a continuing calibration check.

   b. A zero level standard (Calibration Blank) or water blank should be run before each calibration standard.

   c. CCVS QC samples should be analyzed for each inorganic parameter at a concentration between the upper and lower limits of the test system working range. For cyanide, a midrange standard must be distilled.

   d. CCVS recoveries must be consistent with EPA CLP SOW acceptance criteria for CCVS. This control limit range is 90 to 110 % for all AA analytes except mercury for which the limits of 80 to 120 % apply. For cyanide the limits are 85 to 115 %.

2. Organics Analysis:

   a. The working calibration curve or response factor must be verified on each working day by the analysis of one or more calibration standards and must be consistent with EPA CLP SOW or the acceptance criteria stated by the method.

   b. For analyses involving only GC/Mass Spectrometer, continuing calibration standards including System Performance Check Compounds (SPCC) and Calibration Check Compounds (CCC) should be analyzed after tuning with BFB or DFTPP before analysis of any samples at least once every 12 hours during which samples are analyzed.

   c. Calibration checks must be consistent with EPA CLP SOW (acceptance criteria).

3. For both inorganics and organics analyses, the laboratory must take whatever corrective action is necessary to satisfy these accuracy data quality

objectives and those specified for the project in either Item 3 Exhibit One or on the Laboratory Task Order.

F. Spikes (Matrix Spikes, Matrix Spike Duplicates and Surrogate Spikes):

1. Inorganics Analysis:

   a. For all QA Levels, at least one sample-specific Matrix Spike (digested spike) sample analysis must be performed on each group of samples of a similar matrix type and concentration for each 20 samples received. Samples identified as field blanks may not be used for spike sample analysis. The analyte spike must be added in the amount specified in the EPA CLP statement of work for each element analyzed.

   b. No Matrix Spike duplicate (MSD) or surrogate spikes are required for inorganics analyses.

   c. If a Laboratory Control Sample (LCS) is not analyzed, a reagent water spiked with the compound or element of interest and carried through the sample preparation method must be performed in addition to matrix spikes to check for method and instrument performance.

   d. Analytical (Post-Digestion) Spikes:

      For all analyses conducted by atomic absorption furnace method, analytical spikes shall be performed at a frequency of once per sample per element analyzed to determine if the method of standard additions (MSA) will be required for quantitation. Spikes are to be post-digestion spikes and are to be prepared prior to analysis by adding a known quantity of the analyte to an aliquot of the digested sample. If the concentration of the analyte, determined from an initial analysis is less than or equal to the LOQ (determined as stated in Item 3 Exhibit One) the spike concentration (in the sample) will be required to be at the LOQ. If the concentration of the analyte, determined from an initial analysis is greater than the LOQ, the concentration of the spike cannot be greater than twice the concentration of the analyte. Also, in adding the spike, the sample cannot be diluted by more than 10%.

2. Organics Analysis:

   a. Matrix Spike/Matrix Spike Duplicate (MS/MSD)

      (1) For QA Level I, a reagent water spiked with the compounds of interest and carried through the sample preparation method may be analyzed with

submitted sample batches in lieu of batch-specific or sample-specific matrix spikes to check for method and instrument performance. [Batch specific and sample specific are defined in F(2)(a) below.]

(2) For GC Analysis:

(a) A batch-specific or sample-specific matrix spike should consist of the appropriate matrix spiking compounds of interest for the method. Surrogate spiking compounds are not acceptable as matrix spiking compounds. Batch-specific means laboratory analysis batch, i.e., samples from other sources may serve as the spiked matrix. (Sample-specific means spike is placed into samples submitted for analysis from the same source, and not samples from other sources.)

(b) The frequency for the batch-specific matrix spike must be 1 per 10 samples per matrix for GC analysis or matrix spike and matrix spike duplicate at 1 set per 20 samples.

(c) Matrix spike duplicates are not mandatory for GC analysis if laboratory (sample) duplicates are analyzed; if not, the frequency of matrix spike duplicates must be 1 per 20 samples per matrix.

(3) For GC/Mass Spectrometer analysis:

(a) Both matrix spike and matrix spike duplicate must be analyzed at a frequency of 1 per 20 samples per matrix and may be either batch-specific or sample-specific (i.e., samples submitted for analysis from the same source will be spiked, not samples from other sources) depending upon the specified level of reporting.

(b) Matrix spiking solution should include the compounds specified in the EPA CLP statement of work for volatile organic compounds or semi-volatile compounds depending upon the chemical analysis being performed.

(c) The percent recovery of matrix spike and matrix spike duplicate compounds should be calculated as follows for both GC or GC/Mass Spectrometer analysis:

$$\text{Matrix Spike Percent Recovery} = \frac{\text{SSR-SR}}{\text{SA}} \times 100$$

where:

SSR = Spike Sample Results
SR = Sample Result
SA = Spike Added from spiking mix

(4) For GC or GC/Mass Spectrometer Analysis:

(a) If matrix spike or matrix spike duplicate have parameter percent recoveries outside control limits the laboratory must determine if the recoveries are matrix related or analysis related.

If the lab analyzes only a matrix spike and the recoveries are outside acceptance control limit range, the lab must duplicate the results with a matrix spike duplicate or alternatively analyze a water blank spiked with the matrix spike solution with acceptable recoveries. For volatiles, the blank spike may be run following the sample analysis. For extractable organics, the blank spike or matrix spike duplicate should be extracted with the samples and held for analysis as necessary.

If both the matrix spike and matrix spike duplicate analyses produce similar results (recovery outside control limit range, but RPD within control limit range) it can be assumed that the effect is matrix related.

If one or both percent recoveries and RPDs are unacceptable, the lab must analyze the spiked blank with acceptable results, and repeat the matrix spike extraction and analysis until RPDs are acceptable. The analysis of the spiked blank must be performed during the same tune or calibration of the instrument as the matrix spike was run.

(b) Although the percent recovery of matrix spike and matrix spike duplicate compounds should be within the control recovery limits specified by the method or developed by the laboratory or in the EPA CLP statement of work, it is recognized these limits are advisory; however, this does not preclude performing the steps indicated above.

(c) The laboratory is required to calculate the relative percent difference (RPD) between the matrix spike and matrix spike duplicate. The relative percent differences (RPD) for each component are calculated as follows:

$$RPD = \frac{|A - B|}{(A + B)/2} \times 100$$

where:

RPD = Relative Percent Difference
A = First sample value
B = Second sample value

(5) Surrogate spikes:

(a) For both GC and GC/Mass Spectrometer analysis at all QA levels, surrogate spikes must be used as specified by the method. All samples, including blanks, standards, and QC check samples will be spiked with surrogate spiking solution in accordance with the specified EPA method and/or the CLP statement of work for organics analysis, using required surrogate compounds as appropriate for the method.

(b) Performance requirements for surrogate spikes:

[1] For volatile (purgeable) organic compounds (VOCs), no surrogate spikes may be out of control limits. Any sample with surrogates out of range must be re-analyzed and the result flagged.

[2] For semi-volatile organic compounds (e.g., phenols, polynuclear aromatics, or compounds classified as base/neutral and acid extractables), one surrogate compound may be out of range per fraction provided the recovery is at least 10%; otherwise, the sample must be re-extracted and re-analyzed and the result flagged.

3. The Laboratory must take whatever corrective action is necessary to satisfy the precision and accuracy data quality objectives as stated above and specified either in Item 3 Exhibit One or on the Laboratory Task Order.

G. Laboratory Duplicates:

1. Inorganics:

   a. At QA level I, sample duplicates should be run and RPD should be calculated. The frequency should be at least one duplicate per batch of samples. Duplicates must be batch-specific.

   b. At QA Levels II, III or IV, laboratory duplicates (sample duplicates) for inorganics analysis are to be analyzed at a frequency of one laboratory duplicate for each parameter by matrix for every 10 samples submitted.

   c. A matrix spike duplicate for inorganics analysis may be considered as satisfying the laboratory duplicate requirement. Field blanks may not be used for laboratory duplicates.

2. Organics:

   a. GC Analysis:

      (1) Laboratory duplicates for organics analysis by GC methodology are to be analyzed at a frequency of 1 laboratory duplicate for each batch of 20 samples per matrix. RPDs must be calculated for parameters of interest.

      Reagent water spiked with parameters of interest may be analyzed in duplicate in lieu of a sample duplicate. The RPD for the duplicates must be calculated.

      The RPDs for all duplicates must meet precision data quality objectives specified in the laboratory quality assurance plan for acceptable performance. If the RPD is greater than the specified DQO for RPD the sample must be re-analyzed until the DQO for precision is achieved.

      (2) Matrix spikes and matrix spike duplicates may be used to satisfy the laboratory duplicate requirements. Again, the specified DQOs for precision must be met.

      (3) Duplicate results are to be reported together with the sample results, the calculated RPD, and the control limits.

b. GC/Mass Spectrometer Analysis:

(1) At all QA Levels, duplicates are optional because of cost and should be analyzed only if specified in the Laboratory Task Order.

(2) Matrix spike duplicates, however, should be run at a frequency of 1 per 20 samples per matrix. Matrix spike duplicates should be reported with matrix spike, showing spike, recovered value, percent recovery, control limits, and RPD and control limits.

(3) Matrix spike duplicates may not be used to satisfy the laboratory duplicate requirements.

3. The laboratory must take whatever corrective action is necessary to satisfy the precision DQOs specified for the project either in Item 3 Exhibit One or on the Laboratory Task Order.

GERAGHTY & MILLER
ENGINEERS, INC.

SAFETY AND HEALTH PLAN

Marietta Reduction Facility
Remedial Design/Remedial Action Program

Prepared for:

MARTIN MARIETTA CORPORATION
The Dalles, Oregon

Prepared by:

GERAGHTY & MILLER, INC.
and
GERAGHTY & MILLER ENGINEERS, INC.
14497 North Dale Mabry Highway, Suite 200
Tampa, Florida 33618
(813) 968-2248

July 1989

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TABLES

2.0 INTRODUCTION

This Safety and Health Plan (SHP) has been prepared for Martin Marietta Corporation (MMC) by Geraghty & Miller, Inc., as a supporting document to the Remedial Design/ Remedial Action Program (RD/RA) to be conducted at the Martin Marietta Reduction Facility (MMRF) located in The Dalles, Oregon (the Site). The purpose of this SHP is to provide guidance on safety and health issues related to the field investigation activities of the Remedial Design and Remedial Action.

In September of 1985, MMC initiated the implementation of the Remedial Investigation/Feasibility Study (RI/FS) for the Site. The program involved various data collection tasks, including construction of monitor wells, sampling of ground-water, surface water, soils, sludges and wastes.

Historical data describing waste disposal practices and previous ground-water sampling results indicated the presence of chemicals that posed a potential hazard to workers conducting the RI/FS program. The chemicals found to be of concern were cyanide, fluoride, and carcinogenic polynuclear aromatic hydrocarbons. A risk assessment (RA) was performed by the firm of Clement Associates, Inc. based on the results of the RI. The purpose of the RA was to assess the potential impacts of the no-action alternative on human health and the environment and to estimate the exposures to workers during remedial activities. Numerous references are made in this document to the results of the RA in regard to the exposures introduced by these remedial activities. The RI/FS was completed and a final report generated in March of 1988.

This SHP has been prepared in conjunction with a Sampling and Analysis Plan (SAP) which will be submitted to EPA for the RD/RA program. The sampling activities outlined in the SAP require workers to enter areas where hazardous chemicals are known to be present. In addition, this SHP projects potential exposures based on scenarios discussed in the RA and provides health and safety requirements for those actions during the Remedial Action.

This SHP has been assembled based upon requirements described in the "Standard Operating Safety Guides" U.S. Environmental Protection Agency, Office of Emergency and Remedial Response, and in accordance with applicable standards promulgated by the U.S. Occupational Safety and Health Administration (29 CFR OSHA 1910.120). Guidelines provided by these agencies have been supplemented by data generated during the RI/FS and by information obtained during visits to the Site by Dr. Ralph Moon (Geraghty & Miller).

3.0 ORGANIZATION AND RESPONSIBILITIES

MMC is responsible for its personnel and subcontractors' adherence to the SHP throughout all phases of the investigation. MMC agrees to perform all work in accordance with the health and safety requirements described herein, and all Federal, EPA, OSHA, State and local health and safety regulations.

3.1 STAFFING AND LINES OF AUTHORITY

The project Safety and Health Organization Chart (Figure 1) indicates the relationship and responsibilities of members of the investigative team listed below.

Corporate Project Coordinator:

o Mr. Jose R. Bou, Vice President
Martin Marietta Aluminum Properties, Inc.
6801 Rockledge Drive
Bethesda, Maryland 20034
(301) 897-6809

The Corporate Project Coordinator will review and approve the SHP and all activities related to safety and health as well as direct the coordination of corporate policy and environmental agency objectives.

Site Manager:

o Ms. Loretta V. Grabowski
Martin Marietta Corporation
3313 W. 2nd Street
The Dalles, Oregon 97058
(503) 296-6118
(503) 296-3236 (FAX)

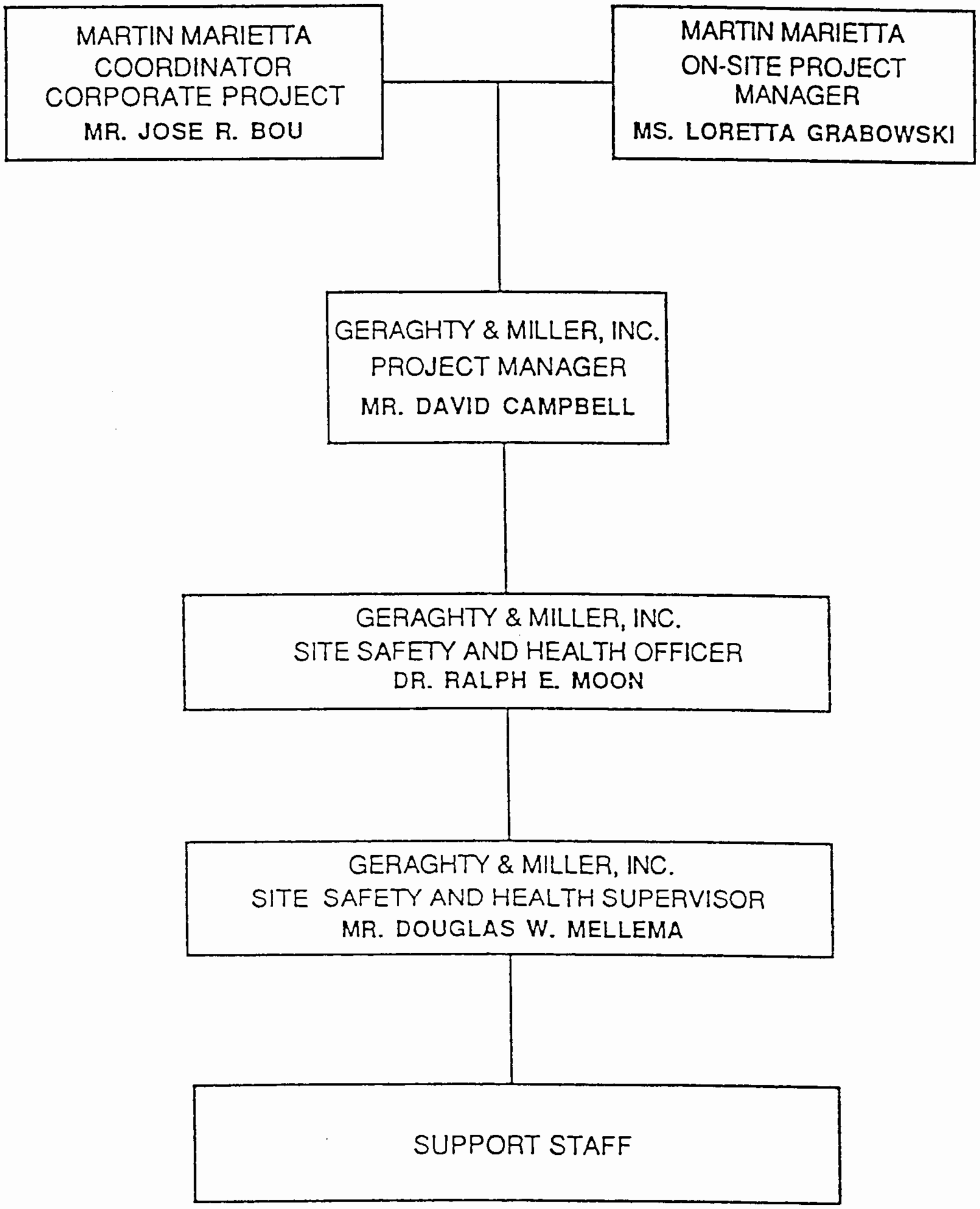

Figure 1. Safety and Health Organizational Chart.

CLIENT NAME:

Martin Marietta Corporation

The Site Manager will assist the Corporate Project Coordinator in carrying out the on-site activities described in the SHP. These activities include the coordination of the technical support groups and assurance that all site activities are in agreement with the safety and health practices of the corporation. In the event the Corporate Project Coordinator is not available, the Site Manager will assume those responsibilities.

<u>Project Manager:</u>

- David C. Campbell
  Geraghty & Miller Engineers, Inc.
  14497 N. Dale Mabry Highway
  Suite - 200
  Tampa, Florida 33618
  (813) 968-2248

The Project Manager is responsible for coordinating the review of the SHP.

<u>Safety and Health Officer (SHO):</u>

- Dr. Ralph E. Moon
  Geraghty & Miller, Inc.
  3820 Northdale Blvd.
  Suite - 200
  Tampa, Florida 33624
  (813) 961-1921

The SHO reports to the Geraghty & Miller Project Manager and is responsible for the preparation of the SHP. In addition, the SHO is responsible for all aspects of safety and health as described in the plan including site orientation and medical monitoring.

Safety and Health Supervisor (SHS):

- Douglas W. Mellema
  Geraghty & Miller Engineers, Inc.
  14497 N. Dale Mabry Highway
  Suite - 200
  Tampa, Florida 33618
  (813) 968-2248

The SHS assures compliance with all provisions of the SHP by Geraghty & Miller employees and support staff. The SHS controls the entry and exit of all personnel at each excavation, boring, monitor-well installation, and sampling location. The SHS performs the tasks necessary to evaluate the air quality in the breathing zone, and monitor for heat stress. The SHS is responsible for assuring that all appropriate forms and logs are completed accurately and thoroughly.

The SHS has the highest health and safety authority at the site and is responsible for notifying the SHO if hazardous conditions occur at the site that are not described in the SHP. The SHS must also report to the SHO any changes in ambient conditions that require a change in the personnel protection level.

Support Staff:

All support staff must comply with the provisions of the SHP.

3.2 INTERNAL AUDITS

MMC will conduct internal safety and health audits to ensure compliance with the requirements of this plan. An audit of the instrument log book will be conducted by the SHO to determine if there were any violations of safety and health standards. Results of the audit and a description of any follow-up actions will be supplied to the project manager.

4.0 SITE DESCRIPTION AND WASTE CHARACTERISTICS

The areas of the site to be remediated include: (1) the former Cathode Waste Management Area (CWMA), which includes the Old Cathode Waste Pile, the Potliner Handling Salvage and Bath Recovery Pad Areas; (2) the Unloading Area; (3) Scrubber Sludge Ponds 2 and 3, and; (4) the existing Landfill. An additional area of health and safety concern is the perched water. Figure 2 presents a site plan which identifies the remediation areas. In this section, Tables 2 through 4 list the chemicals of greatest health concern and toxicological information including: exposure levels, routes of entry, toxicity, and target organs. Recommendations for proper protective clothing for the specific chemicals referenced for each site is also described in Tables 2 through 4. A description of each potential contamination source, and the chemicals suspected to be present are assembled in Sections 4.1 through 4.6, along with the recommended levels of personnel protection.

The Risk Assessment (RA) prepared as an element of the RI evaluated exposures to construction workers involved in scraping and grading operations in the remediation areas. A copy of the RA is included as Appendix B of this document. The evaluation considered nine months of on-site construction activity, yielding a total of 180 days of exposure. Using the concentrations of chemicals in the soil of the different remediation areas from the RI, the exposure via direct contact and contact with airborne dust were estimated. Table 1 presents a summary of the concentrations of site-related chemicals in the air resulting from these exposures. The average and maximum concentrations detected in the soil were used to estimate the average and maximum exposure scenarios.

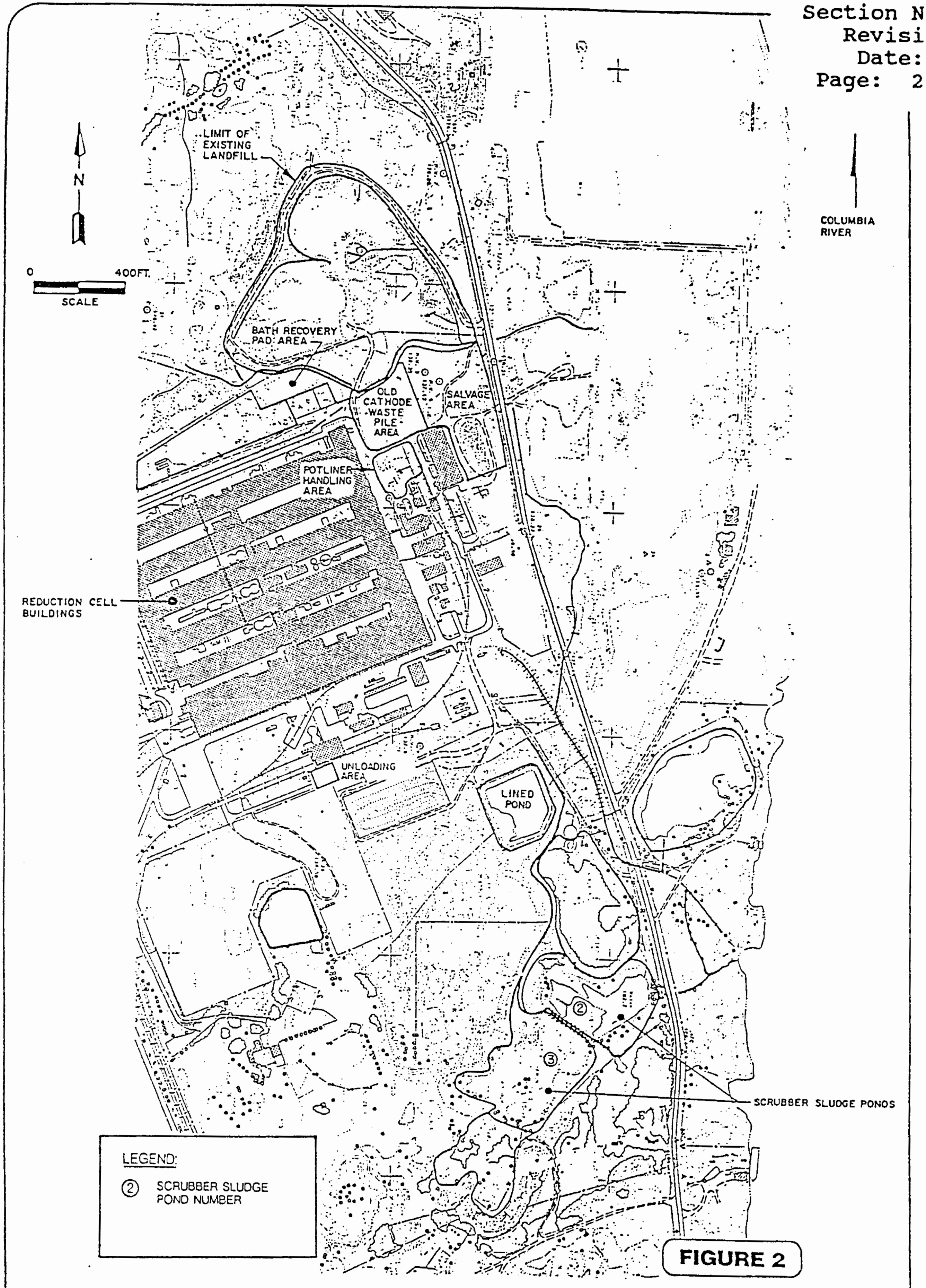

FIGURE 2

DRAWING NO. TE0018-RD2-B
DRAWN BY: DATE: 3-22-89
CHECKED: DWR DATE: 3-22-89
APPROVED: DATE: 12 March

GERAGHTY & MILLER ENGINEERS, INC.

SITE PLAN

MARTIN MARIETTA REDUCTION FACILITY
MARTIN MARIETTA CORPORATION
THE DALLES, OREGON

TABLE 1.

Estimated On-Site Concentrations of Site-Related Chemicals in Air Resulting From Dust Generated During Construction Activities at the MMRF Site (mg/cubic meter)
Martin Marietta Reduction Facility RD/RA
The Dalles, Oregon

Chemical	Scrubber Sludge Pond 2		Scrubber Sludge Pond 3		Old Cathode Waste Pile	
	Average	Maximum	Average	Maximum	Average	Maximum
Free Cyanide	NQ	NQ	NQ	NQ	3.32E-08	3.48E-07
Total Cyanide	NQ	NQ	NQ	NQ	3.67E-07	4.38E-07
Fluoride	8.10E-06	8.90E-06	1.47E-05	1.85E-05	7.14E-06	7.14E-06
Carcinogenic PAHs	5.46E-05	1.04E-04	8.18E-05	9.72E-05	NQ	NQ

Chemical	Salvage Area		Metal Pad Storage Area		Landfill		Potliner Handliner Area	
	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum
Free Cyanide	NQ	1.35E-06	NQ	NQ	4.65E-07	5.34E-05	1.01E-07	1.01E-07
Total Cyanide	NQ	3.06E-06	2.02E-08	4.28E-08	2.78E-06	6.94E-05	3.43E-07	3.43E-07
Fluoride	NQ	NQ	1.58E-05	1.86E-05	1.09E-03	2.85E-03	1.78E-05	1.78E-05
Carcinogenic PAHs	NQ	NQ	NQ	NQ	4.65E-04	1.36E-03	1.11E-04	1.11E-04

Chemical	Bath Recovery Pad Area		Lined Pond	
	Average	Maximum	Average	Maximum
Free Cyanide	3.17E-07	3.17E-07	NQ	NQ
Total Cyanide	4.76E-07	4.76E-07	NQ	NQ
Fluoride	1.89E-05	1.89E-05	NQ	1.07E-04
Carcinogenic PAHs	NQ	NQ	NQ	1.54E-04

NQ = Not Quantified

Source: Final Remedial Investigation Report for the MMRF, (Appendix B, Table 32), March 1988.

TABLE 2

SUBSTANCES OF HEALTH AND SAFETY CONCERN
HYDROGEN CYANIDE

SYNONYMS:	Hydrocyanic acid, Prussic acid, Formonitrite
PERMISSIBLE EXPOSURE LIMIT:	4.7 ppm (5 mg/m^3,[1] (NIOSH) 10 minute ceiling: 5mg/m^3 (ACGIH)
IDLH LEVEL:	50 ppm
PHYSICAL DESCRIPTION:	Colorless or pale blue liquid or gas with a bitter almond odor
PERSONNEL PROTECTION AND SANITATION:	Clothing: Required, see Section 8.0 Goggles: Required, see Section 8.0 Respiratory Protection: see Section 8.0 Wash: Immediately upon dermal contact Change: N/A Remove: Any wet clothing immediately (flammable) Provide: Eyewash, quick drench
ROUTES OF ENTRY:	Inhalation, adsorption, ingestion, contact
SYMPTOMS:	Asphyxia and death at high levels; weak, headache, confusion, nausea, vomiting; increase rate & depth of respiration or respiration slow and gasping
FIRST AID:	Eye: Irrigate immediately Skin: Water flush immediately Breath: Artificial respiration/ use Amyl Nitrite Pearls Swallow: Drink water, force vomit
TARGET ORGANS:	CNS, CVS, liver, kidneys

[1] Limit applies to Total Cyanides (as CN) as respirable dusts. Federal Register Vol. 54, No. 12, January 19, 1989.

TABLE 3

HYDROGEN FLUORIDE

SYNONYMS:	Anhydrous hydrofluoric acid; HF-A
PERMISSIBLE EXPOSURE LIMIT:	3 ppm (2.5 mg/m^3)[1] (NIOSH) 15 minute ceiling: 6 ppm (ACGIH)
IDLH LEVEL:	20 ppm
PHYSICAL DESCRIPTION:	Colorless, fuming liquid or gas with a strong, irritating odor
PERSONNEL PROTECTION AND SANITATION:	Clothing: Required, see Section 8.0 Goggles: Required, see Section 8.0 Respiratory Protection: see Section 8.0 Wash: Immediately upon contact Change: N/A Remove: Immediately upon dermal contact non-imperv Provide: Eyewash, quick drench
ROUTES OF ENTRY:	Inhalation, adsorption, ingestion, contact
SYMPTOMS:	Eye, nose, throat, irrit; pulmedema; skin, eye burns, nasal congestion, bronchial irritation
FIRST AID:	Eye: Irrigate immediately Skin: Water flush immediately Breath: Artificial respiration/ Swallow: Water, NO VOMIT
TARGET ORGANS:	Eyes, respiratory system, skin, lungs

---

[1] Limit applies to fluorides as respirable dusts. Federal Register Vol. 54, No. 12, January 19, 1989.

TABLE 4

POLYNUCLEAR AROMATIC HYDROCARBONS

SYNONYMS:	Polynuclear aromatics, e.g., Fluoranthene, Napthalene, Benzo (a) pyrene[1]
PERMISSIBLE EXPOSURE LIMIT:	0.2 mg/m^3 for coal tar pitch volatiles[1] OSHA 8 hour time weighted average
IDLH LEVEL:	N/A
PHYSICAL DESCRIPTION:	Yellowish crystalline solid
PERSONNEL PROTECTION AND SANITATION:	Clothing: Required, see Section 8.0 Goggles: Required, see Section 8.0 Respiratory Protection: see Section 8.0 Wash: Immediately upon dermal contact Change: N/A Remove: Any wet clothing immediately Provide: Eyewash, quick drench
SYMPTOMS:	Lung irritation
FIRST AID:	Eye: Irrigate immediately Skin: Water and soap Breath: Artificial respiration
TARGET ORGANS:	Skin, lungs

---

[1] Suspected carcinogen (ACGIH) Federal Register, Vol. 54, No. 12, January 19, 1989.

4.1 LANDFILL

Site Description

The Landfill was started in 1958 and operated through December of 1984. During this period of activity, the Landfill was used to store construction rubble, and wastes including wooden pallets, refractory brick, bagged asbestos (1979-1982) and non-specific wastes. In the early 1970's, the area was used to disassemble the collector bar and carbon block assembly unit. The Landfill, however, was not designated as a cathode disposal area. PCB's were not disposed of at the Landfill.

Remediation Activities

The remedial actions occurring in the Landfill are: (1) consolidation of the CWMA, PHA, and Unloading Area materials; (2) the construction of a leachate collection system; (3) shaping and grading of the Landfill materials into the Landfill cap configuration, and; (4) the construction of a multi-layer cap meeting the requirements of 40 CFR 264.310.

The consolidation of site materials will occur in the 1989 and 1990 construction years. The leachate collection system requires a field investigation of the surface of the basalt formation under the Landfill and construction of the interior leg of the system during 1989 and construction of the remainder of the system in 1990.

Substances of Health and Safety Concern

Based on the results of the RI, the principal materials disposed of in the Landfill are construction debris (rocks, soil and building materials), Paste Plant waste (off-specification coke pitch and briquettes) and minor amounts of cathode waste materials and asbestos insulation. The areas of asbestos disposal have been identified and will not be disturbed during the investigation or consolidation activities.

Safety and Health Indications

On the basis of the exposure scenarios and concentrations developed in the RA (presented in Table 1) and the personnel exposure limits (PEL) values for the site-related chemicals, a personnel protection of Level D is indicated. A fugitive dust mask will be issued to field personnel and will be used during periods of high winds and/or dust generation, and at the discretion of the SHO, to reduce employee exposure to wind blown dusts. Skin contact with and ingestion of soil materials from the Landfill should be avoided through the use of gloves and sleeved coveralls.

4.2 CATHODE WASTE MANAGEMENT AREAS (CWMA)

Site Description

The CWMA includes the former Cathode Waste Pile and the Salvage, Bath Recovery Bad and Potliner Handling Areas. The former Cathode Waste Pile was activated in 1972 and served as a periodic accumulation area until late 1984. During this time period, cathode and incidental core wastes were disposed. In 1984 the cathode wastes were consolidated into a permitted cathode waste storage pad area. The Salvage Area was used for storage of unused shells and scrap collector bars. The Bath Recovery Pad Area was used for storage and handling of the metal bath materials to be recycled to the reduction facility. The Potliner Handling Area was used to crush cathode waste and to separate refractory brick (where it was accumulated and shipped to a recovery facility).

Remediation Activities

Remediation activities in the CWMA include the excavation and consolidation of all soil materials into the Landfill and the recovery and treatment of perched water. In the investigation phase of the Remedial Design a series of linear test trenches are proposed to characterize the surface of the underlying basalt formation and identify the presence and location of perched waters.

A series of verification sampling trenches to be used to document the lateral extent of contamination in the Salvage and Bath Recovery Pad Areas.

Substances of Health and Safety Concern

The CWMA was the former storage and handling area for cyanide- and fluoride-containing waste materials. After the removal and storage of the cathode waste materials onto the permitted cathode waste storage pad area, some soil contamination as well as perched waters containing cyanide and fluoride remain. The Potliner Handling Area contained a material crusher which was used to crush cathode waste materials in preparation for transport or storage. The crushing operation generated large amounts of waste fragments and fugitive dusts. Polynuclear aromatic hydrocarbons, a component of the cathode waste which is relatively immobile in the Potliner Handling Area sediments, has also been detected in this area.

Health and Safety Indications

On the basis of the exposure scenarios and concentrations developed in the RA (presented in Table 1) and the personnel exposure limits (PEL) values for the site-related chemicals, a personnel protection of Level D is indicated. A fugitive dust mask will be issued to field personnel and will be used during periods of high winds and/or dust generation, and at the discretion of the SHO, to reduce employee exposure to wind-blown dusts. Skin contact with and ingestion of soil materials in the CWMA should be avoided with the use of gloves and sleeved coveralls.

4.3 UNLOADING AREA

Site Description

The Unloading Area is a small area south to the Alumina Unloading Building which received cathode waste material to fill a low spot in the area. The waste material was placed in the area around 1964.

Remediation Activities

The Unloading Area was the recipient of small amounts of cathode waste which were used as general site fill in this area of the site. The remedial activities for the Unloading Area include the identification and removal of contaminated fill material. During the investigation phase of the Remedial Design a verification sampling trench will be excavated to determine the lateral extent of the contaminated area.

Substances of Health and Safety Concern

The material used as general fill in the Unloading Area was spent cathode waste material. The levels of cyanide and fluoride detected are similar to those encountered in the landfill and CWMA.

Health and Safety Indications

On the basis of the exposure scenarios and concentrations developed in the RA (presented in Table 1) and the personnel exposure limits (PEL) values for the site-related chemicals, a personnel protection of Level D is indicated. A fugitive dust mask will be issued to field personnel and will be used during periods of high winds and/or dust generation, and at the discretion of the SHO, to reduce employee exposure to wind-blown dusts. Skin contact with and ingestion of soil materials in the Unloading Area should be avoided through the use of gloves and sleeved coveralls.

4.4 SCRUBBER SLUDGE PONDS

Site Description

The Scrubber Sludge Ponds and sedimentation ponds were active from the mid-1960's through 1977. The wastes received at the ponds were segregated into three areas and included: primary (treated and untreated) air scrubber wastes, secondary (treated and untreated) air scrubber wastes and dredging wastes from the secondary recycle pond (1975).

Remediation Activities

The remedial actions for Scrubber Sludge Ponds (SSP) 2 and 3 include the consolidation of: (1) waste materials excavated from the Ponds; (2) wind-blown sediments existing outside of the ponds, and; (3) the berm separating the two SSPs into the ponds and the placement of a 24-inch soil cover over the materials. During the investigation phase of the Remedial Design, geotechnical sampling of the ponds will be conducted to determine the depth of sediments in the facilities and to obtain samples for the geotechnical characterization of the materials.

Substances of Health and Safety Concern

The SSPs received roof scrubber liquids, which contain many compounds and two of health and safety concern, which are carcinogenic polynuclear aromatic hydrocarbons (cPAHs) and fluorides.

Health and Safety Indications

On the basis of the exposure scenarios and concentrations developed in the RA (presented in Table 1) and the personnel exposure limits (PEL) values of the site-related chemicals, a personnel protection of Level D is indicated. A fugitive dust mask will be issued to field personnel and will be used during periods of high winds and/or dust generation, and at the discretion of the SHO, to reduce employee exposure to wind-blown dusts. Skin contact with and ingestion of soil materials in the Scrubber Sludge Ponds area should be avoided through the use of gloves and sleeved coveralls.

4.5 PERCHED WATER TREATMENT TEST AREA

Site Description

A structure will be constructed during the RD/RA to house a cyanide hydrolysis unit. The cyanide hydrolysis unit will be used in the treatment of perched water and Landfill leachate.

Remediation Activities

Upon the initiation of perched water recovery from the CWMA, the Cyanide Hydrolysis Unit will undergo performance testing to verify the removal efficiencies guaranteed by the manufacturer. The system will operate continuously during the remediation period to treat perched water.

Substances of Health and Safety Concern

The perched water to be treated during the performance test contains approximately 3 and 290 mg/L of free and total cyanide, respectively and 3,000 mg/L of fluorides (principally sodium fluoride).

Health and Safety Indications

Due to the low concentrations of free cyanide found in the perched water, accidental contact or inhalation of water vapors at this concentration are below the 5 mg/L PEL identified previously and, therefore, Level D is recommended.

General health and safety considerations recommended for the treatment area include provisions for adequate ventilation and illumination of the test area. Skin contact with and ingestion of perched water should be avoided through the use of gloves and lab aprons or other impermeable garments.

5.0 SITE PREPARATION

A control area will be established at each work area before the start of work activities. Controlled areas include, but are not limited to, any work areas that meet the following condition:

- The potential exists for the dispersal of material containing chemicals from the work area by personnel or equipment.

A fence will prevent exposure of people, vehicles, and equipment to chemical-containing materials.

Controlled areas at sampling and excavation sites will be marked conspicuously at points of potential access with a sign according to applicable posting and labeling requirements.

The support area will be prepared for foot and vehicular traffic by removal of all obstructions at the work site. In addition, the site SHS will visually inspect the immediate support area for sharp objects and holes in the pavement. Review of the most current engineering diagrams (where available) will facilitate location of underground conduits prior to soil borings and excavations.

The following guidelines are recommended for use in eliminating safety hazards and to minimize conflicts with work activities occurring within the reduction facility:

1. Construct roadways to provide ease of access and a sound roadbed for heavy equipment and vehicles.

2. Modify traffic flow patterns to ensure safe and efficient operations around the reduction facility operations.

3. Identify and eliminate physical hazards from the work area as much as possible, including:

   - ignition sources in flammable hazard areas.

   - exposed or ungrounded electrical wiring, and low overhead wiring that may entangle equipment.

   - sharp or protruding edges, such as glass, nails, and torn metal, which can puncture protective clothing and equipment and inflict puncture wounds.

   - debris, holes, loose steps or flooring, protruding objects, slippery surfaces, or unsecured railings, which can cause falls, slips, and trips.

   - debris and weeds that obstruct visibility.

4. Install skid-resistant strips and other anti-skid devices on slippery surfaces.

5. Construct operation pads for mobile facilities and temporary structures.

6. Construct loading docks, processing and staging areas, and decontamination pads.

7. Provide adequate illumination for work activities. Equip temporary lights with guards to prevent accidental contact.

8. Install all wiring and electrical equipment in accordance with the National Electric Code.

In order to initiate any excavation activities on-site, approvals must be obtained from the site file retention area. Because of the lease arrangement between Martin Marietta Corporation and Northwest Aluminum, all information requests and requests for locations of site utilities must be cleared with the manager of the site drawings retention area. Mr. Harold Bergen of Northwest Aluminum is the designated contact for requests for site information and all requests for such information must be acknowledged and researched under the direction of this individual. Figure 3 presents a sample of a representative document to be used in requests for utilities information.

Figure 3

AUTHORIZATION FOR EXCAVATION

Request To: Northwest Aluminum

Other ____________________

Request Number: ____________ Date: ____________

Requested By: ____________________

Nature Of Request: ____________________

____

____

____

____

____

Drawing/Sketch Attached? ___ Yes ___ No

THE FOLLOWING ITEMS TO BE COMPLETED BY RESPONDENT:

Person Performing Records Research: ____________

Date: ____________

Results of Research: ____________________

____

____

____

____

____

Drawing/Sketch Attached ___ Yes ___ No

Authorization From Northwest Aluminum:____________ Date: ____

Authorization From Other Party:____________ Date: ____

FL0018.RD2\Adm\request.eng

6.0 DETERMINATION OF WORK AREAS

The SHS will define and identify the following areas at each work site and specify the equipment and personnel in the areas. Prevailing site conditions, access restrictions, and activities performed will influence the specific size of the zone.

6.1 ZONE 1: EXCLUSION ZONE

The exclusion zone is the zone where contamination exists or could occur. All people entering the exclusion zone will wear the prescribed level of protection (see Personnel Protection Zone Requirements). An entry and exit check point will be visually defined at the periphery of the exclusion zone to regulate the flow of personnel and equipment into and out of the zone.

6.2 ZONE 2: CONTAMINATION REDUCTION ZONE

The area between the exclusion zone and the support zone is the contamination reduction zone. This zone provides a transition between the work area and the support zone. Zone 2 serves as a buffer to further reduce the possibility of the support zone becoming contaminated. It provides additional assurance that the physical transfer of chemicals on people, equipment, or in the air is limited through a combination of distance between exclusion and support zones, air dilution, zone restrictions, and work functions.

6.3 ZONE 3: SUPPORT ZONE

This area is the area outside Zones 1 and 2. The support zone will be marked and will be protected against contamination from Zone 1 (work/sampling site). The area includes:

a. An entry area for personnel, materials, and equipment.

b. An exit area for decontaminated personnel, materials, and equipment.

c. A storage area for clean safety and work equipment.

d. An area for rest breaks, the consumption of food and beverages, and similar activities.

7.0 PERSONNEL PROTECTION PROGRAM

The Safety and Health Information Log Book included as Appendix A to this document will be utilized for work activities at the site. A safety and health orientation meeting will be held for all subcontractors, and service personnel assigned to a site investigation-related function. All employees performing Remedial Design field activities at the site will have completed 40-hour Health and Safety training which satisfies the requirements of 29 CFR 1910.120.

The level of protection required at each excavation or sampling location has been designated by the SSO (Sections 4.1 through 4.6). This determination is based upon a hazard evaluation of the Site and previously documented information (see 4.0 Potential Contamination Sources and Waste Characteristics).

7.1 GENERAL PRECAUTIONS

In addition to danger due to the physical, chemical, and toxicological properties of the material(s) present, other types of hazards (electricity, water, heavy equipment, falling objects, or other hazards that could result in loss of balance or tripping) might have an adverse effect on the safety and health of personnel. The following paragraphs describe the requirements to be implemented to minimize these potential adverse effects.

Physical Agents

Safety practices employed on site to protect employees from injury by physical agents include a program for heat stress monitoring (Section 8.2), the use of noise suppression devices when appropriate, and the use of hearing protection. While in use, a backhoe or other device will be no less than:

- 10 feet from a 50-KV line.
- 20 feet from a 345-KV line.
- 34 feet from a 750-KV line.

In transit, with the boom or other appurtenances lowered, a crane or drilling rig will be no less than:

- 4 feet from a 50 KV line.
- 10 feet from a 50-345 KV line.
- 16 feet from a 345-750 KV line.

All support staff will wear safety glasses, hard hats, protective clothing, steel-toed shoes, and respiratory protection as determined by the SHO.

7.2 DECONTAMINATION FACILITIES AND PROCEDURES

Conditions at the site justify a Level D work operation for the Remedial Design field investigations. Decontamination procedures for the field investigations include segregated equipment and outer garment drop-off points, the use of plastic-lined garbage cans for discarding of disposable outer garments and shower facilities and lockers for personal hygiene and clothing storage, respectively. The following paragraphs discuss in detail the above-mentioned decontamination provisions.

Segregated Equipment Drop

Equipment used on-site (tools, sampling devices, and containers, clipboards, etc.) will be placed on plastic drop cloths or in separate containers with plastic liners. The equipment will only be handled after protective garments (outer protective garments, outer gloves) are donned and at the conclusion of the field operations the equipment will be scrubbed thoroughly with detergent solution and allowed to dry in clean containers or set onto clean materials.

Outer Garment Handling and Disposal

Disposable outer garments (outer gloves, tape, etc.) will be disposed of in plastic-lined garbage cans, with the plastic liners sealed with wire ties and changed on a weekly basis or sooner, as conditions dictate. The outer work garments (cotton or cotton blend coveralls) will be of similar construction as the garments provided by Northwest Aluminum for their work personnel. As the substances being encountered by the field work crews are identical to the substances encountered by Northwest Aluminum employees in their daily work activities, similar handling and laundering procedures are also deemed appropriate. As such, the outer garments will be laundered in the same manner as the plant garments.

Shower facilities will be provided to field employees for the purposes of personal hygiene and to minimize the potential for dermal contact with substances at the site. The shower water and fluids used for decontamination will, as mentioned above, be identical to the shower and wash waters generated by Northwest Aluminum employees, and will be conveyed and treated by the same permitted treatment system.

7.3 PERSONAL AIR MONITORING

To augment the existing data base from the RI on personal air monitoring, additional impinger type monitoring will be conducted during the field investigations activities. The monitoring will be conducted using a impinger-type monitoring device and will measure total suspended particulates.

8.0 PERSONNEL PROTECTION ZONE REQUIREMENTS

Personnel protective equipment for the exclusion zone is based upon OSHA requirements for each work site. Gloves, steel-toed boots, outer protective garments will be worn as necessary. All respiratory protective equipment will be approved by the National Institute for Occupational Safety and Health (NIOSH)/Mine Safety and Health Administration (MSHA).

All workers within the site boundary will require personnel protection at Level D.

8.1 VISITOR PROTECTION

All visitors to the Site will be instructed to stay outside the work zone and remain within the support zone during the extent of their stay. Visitors will sign a Visitor's Log as included in the Safety, Health, and Instrument Log Book presented in Appendix A of this SHP.

Visitors will be cautioned to avoid skin contact with contaminated or suspected contaminated surfaces and hand-to-mouth transfers (eating, drinking, smoking, or chewing gum or tobacco).

The use of alcohol, drugs or medicine that impair visual acuity and motor skills are prohibited. Visitors requesting observation of the work zone must don all appropriate equipment prior to entering the work zone. Where respiratory protective devices (dust masks) are necessary, visitors who wish to enter the work zone must produce evidence that they have had a complete physical examination within the previous 12 months. Visitor admittance to the work zone will be left to the discretion of the SHS. Visitors and employees in a support capacity that remain in the support zone will not receive periodic exposure monitoring, nor will they be required to wear Level D personnel protective gear.

8.2 LEVEL D EQUIPMENT

The protective items to be worn under Level D conditions are:

a. Hard hat
b. Safety glasses, goggles, or face shield
c. Steel toe and shank boots
d. Outer boot covers
e. Outer gloves
f. Outer protective garment
g. Options as required:
    (1) Hearing protection
    (2) Inner gloves
    (3) Dust mask (3M 8710, or approved equal)

9.0 PERMISSIBLE EXPOSURE LIMITS PROVISIONS

9.1 INHALATION

As identified in Section 4, the exposure scenarios related to the inhalation of dust materials was estimated in the RA and the theoretic exposures, based on the concentrations of remediation area-specific chemicals, are presented previously in Table 1. On the basis of these values and the PELs identified for the substances of concern, all activities at the site will be conducted under Level D conditions. In addition, the effects of remedial actions on air quality were examined and determined to be minimal. The results of this examination are reported in Appendix C of this document.

9.2 HEAT STRESS MONITORING

Because the incidence of heat stress depends on a variety of factors, all workers, even those not wearing protective equipment, will be monitored.

Heat stress monitoring will be conducted according to the guidelines presented in the Occupational Safety and Health Guidance Manual for Hazardous Waste Site Activities (NIOSH/OSHA/USCG/EPA, October, 1985) and include heart rate and oral temperature monitoring. Due to the degree of respiratory protection required and the use of permeable outer garments, work periods will be 4 hours in duration unless this value is modified at the discretion of the SHO. Heat stress monitoring will occur initially at a minimum of once every 2 working hours and after a period of 2 working days (with no detrimental conditions being noted on the Heat Stress Monitoring Logs maintained for each worker) and with no substantial alteration of site climatic conditions which would indicate a change in working conditions, the SHO may, at his discretion, change the heat stress monitoring periods to a minimum of every four working hours. The definition of detrimental conditions and the measures applied if detrimental conditions are encountered, are as follows:

- Heart rate. Count the radial pulse during a 30-second period. If the heart rate exceeds 110 beats per minute at the beginning of the rest period, shorten the next work period by one-third and establish a 30-minute rest period. If the heart rate still exceeds 110 beats per minute at the next monitoring period, shorten the following work period by one-third.

- Oral temperature. Use a clinical thermometer (3 minutes under the tongue) or similar device to measure the oral temperature at the end of the work period (before drinking). If oral temperature exceeds 99.6°F (37.6°C), shorten the next work period by one-third and establish a 30-minute rest period. If oral temperature still exceeds 99.6°F (37.6°C) at the next monitoring period, shorten the following work period by one-third.

10.0 RESPIRATORY PROTECTION

Dust masks shall be used to reduce employee exposure to wind-blown dusts and will be used as an optional Level D device.

10.1 SELECTION OF RESPIRATORY EQUIPMENT

MMC shall require any personnel entering the work areas to be issued a dust mask and be clean shaven.

The use of dust masks is to prevent exposure of the respiratory system to wind-blown dusts. These masks will not provide protection from gases or vapors and are intended only to minimize employee inhalation of wind-blown dusts. The absence of dusty conditions at the site will be justification for the SHO to permit personnel to remove their masks.

11.0 SOIL AND GROUND-WATER SAMPLING

Soil samples will be collected during the course of the investigation as described in the RD/RA Work Plans. Project personnel should take precautions to avoid dermal and inhalation exposure at all sample locations. Sample collection that is to occur in the former Cathode Waste Management Area, Unloading Area and Scrubber Sludge Ponds, will require Level D protection.

During sampling activities (soil and water), smoking, chewing or eating shall be prohibited. Gloves should be worn during all routine sampling tasks to avoid dermal contact.

12.0 EMERGENCY SITUATIONS

A written plan for emergency situations has been developed to protect workers as outlined in 29 CFR 1926.23 and 1926.24. All employees will be informed about the emergency response plan during the site orientation meeting. The plan includes: (1) recognition of emergencies; (2) methods or procedures for alerting employees on site; (3) evacuation procedures and routes to places of refuge or safe distances away from the danger area; (4) means and methods for emergency medical treatment and first aid, and; (5) line of authority for employees.

12.1 EMERGENCY RESPONSE PLAN

The nature of work at hazardous waste sites provides a continual possibility for emergencies. A plan for emergency situations has been developed to protect workers as outlined in 29 CFR 1926.23 and 1926.24 (Figure 4). All employees will be informed about the emergency response plan during the site orientation meeting.

Recognition of Emergencies

An emergency situation will be recognized as: physical injury, explosions, fires, spills, toxic atmospheres or other dangerous and harmful situations.

Alerting Employees

The SHS is responsible for calling to the employee's attention an emergency situation by the use of a car or air-powered horn.

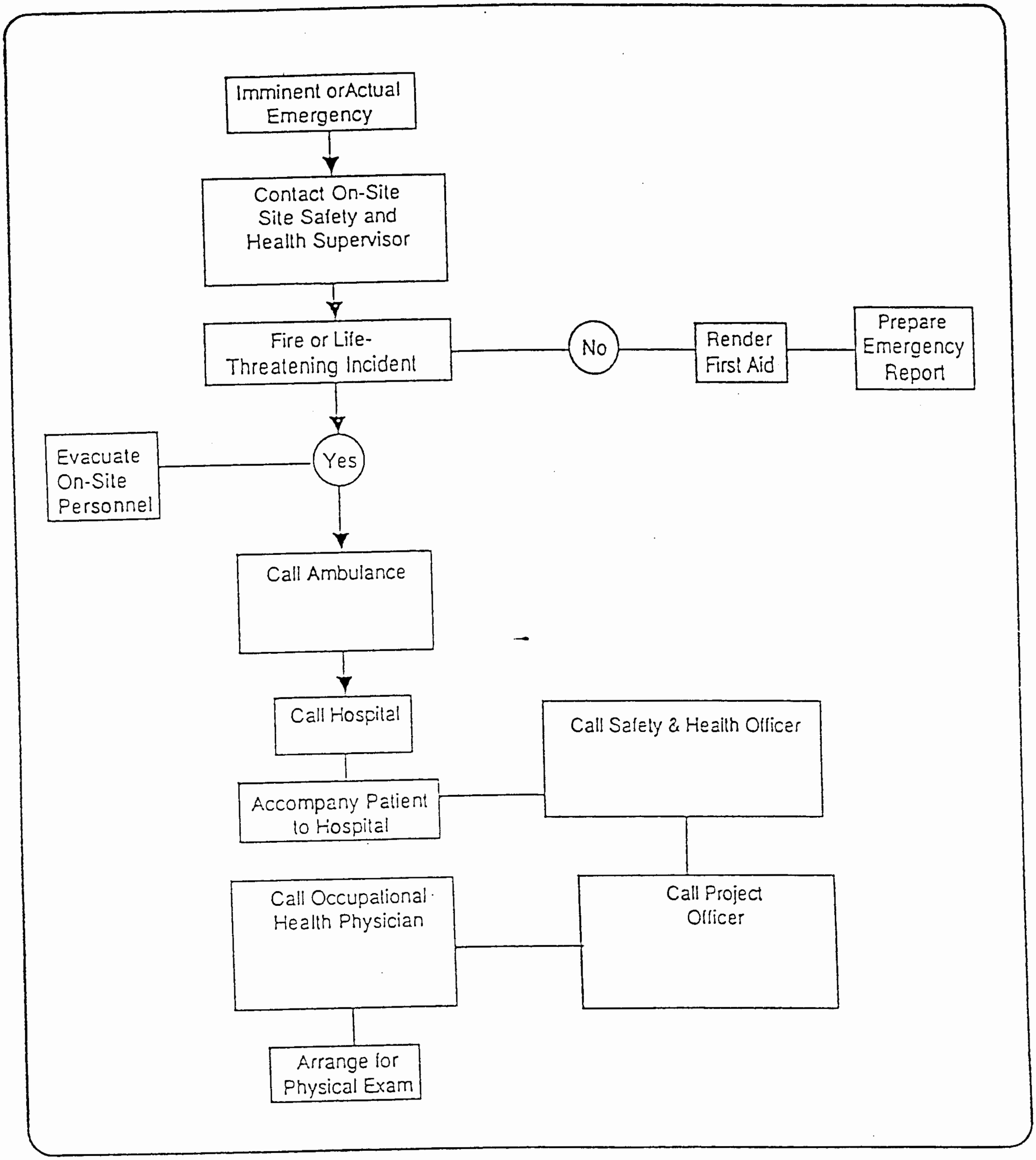

Figure 4 Emergency Response Plan.

CLIENT NAME:

Martin Marietta Corporation

Employee Evacuation

Employees not engaged in correcting the emergency will be restricted from the area until the emergency is over. Evacuation procedures and routes to places of refuge will be identified during the site orientation meeting.

Emergency Medical Treatment

The SHO will prearrange for emergency medical care services and establish emergency routes. The SHS will cease all work in the event of an emergency and take action to remove or minimize the cause of the emergency. The SHS will institute appropriate measures to prevent any repetition of the conditions or actions leading to or resulting in the emergency.

Emergency Situation Line of Authority

The SHS will make available the emergency telephone numbers (Table 5) and make specific reference to the location of the nearest phones during the orientation meeting.

Emergency Injury Report

In the event a worker is injured while on-site, an Emergency Report (Appendix A) will be completed. This report becomes incorporated into a permanent health and safety file for the project. The SHS shall notify the SHO of all incidences requiring off-site treatment of injured personnel, as well as those incidences having a significant possibility of causing permanent injury or death.

TABLE 5

EMERGENCY INFORMATION TELEPHONE NUMBERS

Martin Marietta: The Dalles On-Site

Emergency: 555
Security: 555
Site Manager: 296-6118 Ms. Loretta Grabowski

The Dalles Off-Site:

Emergency: 911 - Fire, Police, Ambulance

Poison Control: 296-5411 (Mid-Columbia Medical Center)

Mid-Columbia Clinic: 296-2131

Wasco County Sheriff: 296-5454

The Dalles Police: 296-2233

Wasco County Fire Department:
  - Fire Only: 298-5579
  - Office: 296-9445
  - Ambulance: 298-4178 (Dalles Fire Department)

The Dalles Fire Department: 298-4178

The Dalles Ambulance: 298-4178

The Oregon State Police: 296-2161

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13.0 EMERGENCY AND FIRST AID REQUIREMENTS

In the event of any emergency which, in the opinion of the SHS, materially endangers life, property, or the environment, the SHS will cease all excavation activities at the Site; take action to remove or minimize the cause of the emergency; render assistance to local authorities to remedy any impact on local residents or property.

The SHO will contact emergency medical care services at a nearby medical facility and establish emergency routes (Figure 5). In addition, the site operates a first-aid facility for injuries not immediately threatening life. There is no guarantee provided to employees involved in the field investigations that personnel trained in first aid and cardiopulmonary resuscitation (CPR) will be on-site at all times.

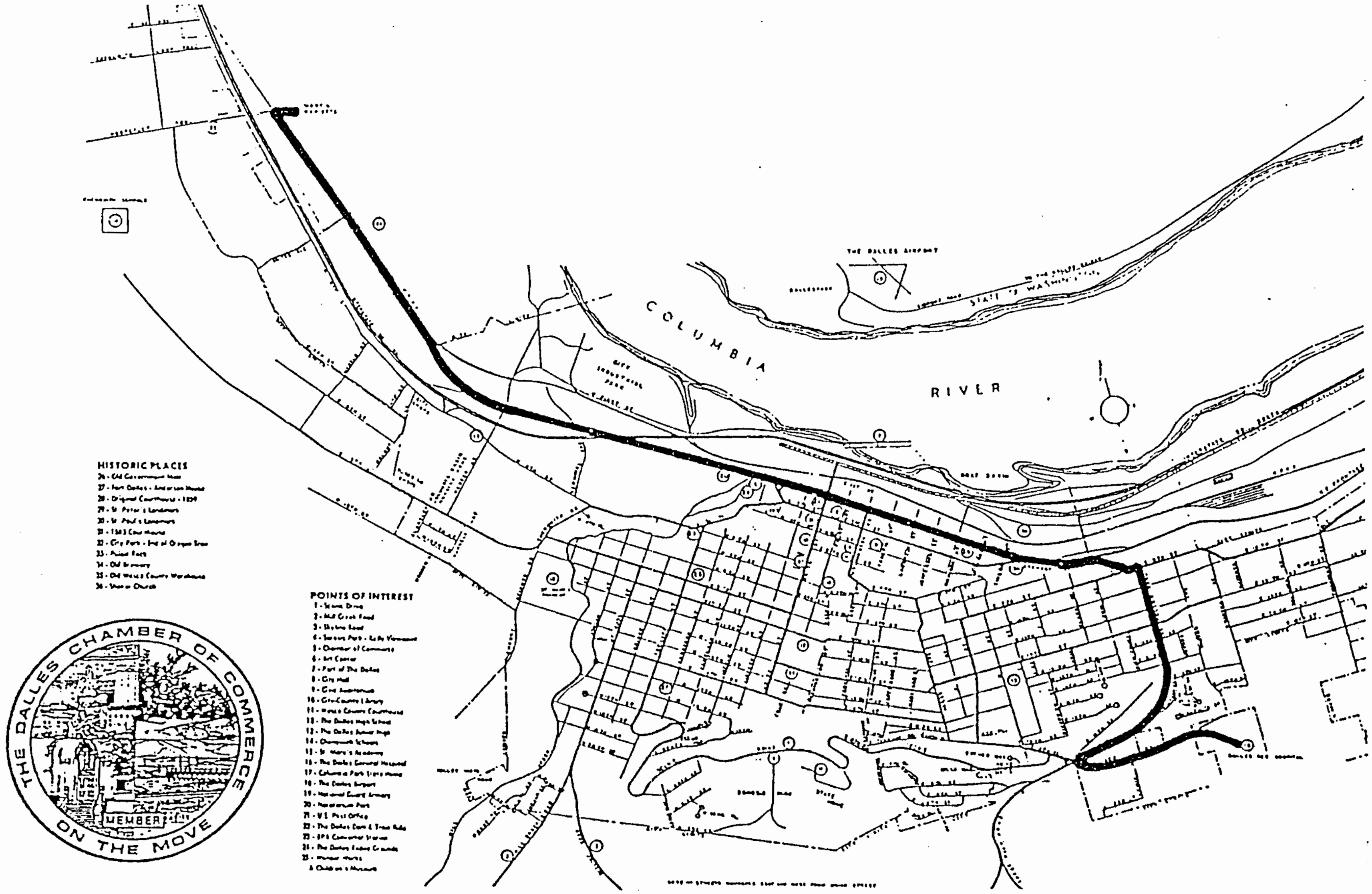

Figure 5 Emergency Route to Hospital

CLIENT NAME:

Martin Marietta Corporation

14.0 SAFETY EQUIPMENT REQUIRED ON-SITE

The following safety equipment will be maintained on-site and replenished as required:

- Emergency eye wash
- First aid kit

15.0 MEDICAL SURVEILLANCE

All contractor employees associated with on-site activities will have undergone a physical examination within 12 months prior to the start date. Medical parameters to be included in the physical examination are described in Appendix D.

An occupational health physician will be in verbal contact with the SHO to report and provide professional health recommendations during the course of the work.

16.0 HOUSEKEEPING

General

The SHS shall implement a housekeeping program to minimize the spread of chemicals beyond the work zone. The program will include:

1. Periodic removal of debris, paper products, cans, and other materials brought on-site from the work area.
2. Periodic removal of all garbage bags and containers used to dispose of food products and trash.

17.0 WASTE DISPOSAL

General

MMC and its subcontractors will not remove material from the site that may potentially endanger the safety and health of on-site employees or the general public.

Reusable Protective Wear

All gloves, boots, hats, glasses, and protective outerwear that can be cleaned and reused will be scrubbed and cleaned prior to reuse and will be removed from the site at the end of each working day.

Waste Food Containers

During and following meal and break periods, all waste materials will be collected (by all individuals) and disposed of in waste containers.

18.0 PERSONAL HYGIENE

A personal hygiene program helps to ensure that all workers are not exposed to harmful levels of hazardous materials. The ability of all workers to observe and adhere to the personal hygiene provisions is fundamental to the success of the SHP.

GENERAL

- On hot days, or when the crew is subject to heavy physical labor, a rest period will be provided at the discretion of the SHS and the work schedule.
- Members of the crew must wash their hands prior to leaving the exclusion zone.
- Toilet facilities and showers will be provided in accordance with 29 CFR 1926.51. The locations of these will be identified during the orientation meeting.
- All workers must be familiar with the use of protective clothing and its limitations. This includes disposable coveralls, gloves/inner gloves, goggles/safety glasses, hard hats and safety shoes.

Shower facilities and lockers will be provided at the site for all workers who wish to change clothes and shower before leaving the facility each day.

19.0 WORKER TRAINING

The SHO will conduct an orientation meeting for all personnel assigned to the site activities in compliance with 29 CFR 1910.120.1bIVB. The orientation meeting will discuss the items listed below and emergency instruction for chemical exposure or release, fire or explosion, and personal injury.

- SHP
- Physical health hazards including acute and chronic effects of waste constituents identified at the site
- Personal hygiene
- Safety equipment and procedures required for personal protection
- Work zones established at the site
- Prohibitions in contaminated areas:
    - (1) Beards and long sideburns
    - (2) Eating, smoking, chewing
    - (3) Personal articles, e.g., watches and rings
    - (4) Working when ill
- Emergency Procedures
- Location of emergency equipment (showers, fire extinguishers, telephones)
- Medical surveillance
- Heat stress monitoring

The SHS will not allow personnel who have not successfully completed the required training to enter the work areas for any reason. Following the training and orientation presentation, an examination and discussion will evaluate comprehension of the SHP.

20.0 RECORDKEEPING

MMC will maintain records of all monitoring required as described below and shown in the Safety, Health, and Instrument Log Book (Appendix A). Record keeping methods will comply with the provisions of 29 CFR 1910.20.

1. The dates, number, duration, and results of air monitoring performed during the field investigations. These data will be written in an instrument log (Appendix A) that will be available for inspection at all times.
2. Those who have received physical examinations and attended the orientation meeting (Appendix A).
3. Body temperature readings for heat stress monitoring, if required (Appendix A).

Workers are encouraged to report to the SHS any conditions or practices which they consider detrimental to their health or safety. Such complaints may be made orally and then described in written form. Each contractor will also provide a form to be used in reporting violations (Appendix A).

GERAGHTY & MILLER
ENGINEERS, INC.

APPENDIX A

Safety and Health Instrument Log Book

SAFETY AND HEALTH
INSTRUMENT
LOG BOOK

PERSONNEL HEALTH AND SAFETY TRAINING COURSE

I have attended an orientation meeting describing the provisions of the health and safety plan.

____
STUDY/DRILL SITE

____
DATE

NAME

____

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ILL EFFECTS OF HEAT

Heat Stroke and Heat Exhaustion

Heat stroke is always life-threatening. Heat exhaustion is a milder condition than heat stroke. Both conditions occur most often on hot days during physical activity. Anyone can have either condition, and either condition can happen to older people even during such mild activity as taking a walk.

In heat stroke, the person's temperature control system that causes sweating stops working correctly. The body temperature rises so high that brain damage and death will result if the person is not cooled quickly. The main signs of heat stroke are red or flushed skin; hot, dry skin, although the person may have been sweating earlier; and extremely high body temperature, often to 41°C (106°F). There may be dizziness, nausea, headache, rapid pulse, and unconsciousness.

Heat exhaustion is much less dangerous than heat stroke. The major signs of heat exhaustion are pale, clammy skin, profuse perspiration, and extreme tiredness or weakness. The body temperature is approximately normal. The person may have a headache and may vomit.

Here are the most important differences between the signs for heat stroke and heat exhaustion:

Heat stroke: skin hot and dry, and very high body temperature.

Heat exhaustion: skin cool and wet from sweating, and normal body temperature.

Cool a victim of heat stroke quickly. If the body temperature is not brought down fast, permanent brain damage or death will result. Soak the person in cool but not cold water, sponge the body with rubbing alcohol or cool water, or pour water on the body to reduce the temperature to a safe level—about 39°C (102°F). Then stop cooling and observe the victim for 10 minutes. If the temperature starts to rise again, cool the victim again. Do not give coffee, tea, or alcoholic beverages. When the victim's temperature remains at a safe level, put the victim to bed and get medical help.

For mild heat exhaustion, provide bed rest. Give a salt solution (1/2 teaspoon salt—about 2 "pinches"—in 1/2 glass of water) every 15 minutes for 3 or 4 doses. Medical care is needed for severe heat exhaustion.

It may be hard to remember the names of the two conditions, but it should be easy to remember this: A victim who is very hot and not sweating (heat stroke) must be cooled off quickly, but a victim who is sweating, has a normal temperature, and is tired (heat exhaustion) needs rest but does not need to be cooled off so vigorously.

Heat Cramps

Heat cramps usually involve the abdominal muscles or the limbs; heat cramps may accompany heat exhaustion.

Firm pressure, and warm, wet towels placed over the cramped area give relief. Give a salt water solution to drink, as you would for heat exhaustion.

DAILY INSTRUMENT LOG SHEET

Date: ______________________

Action Levels: ______________________

Analyst: ______________________

Threshold Levels: ______________________

Site: ______________________

Level of Personal Protection: ______________________

TIME	Photovac Tip			Draeger Tube	Explosion Meter	WEATHER CONDITIONS		
	Ambient	Reading	Net Concentration			Temperature	Wind Direct.	Wind Speed

OCCUPATIONAL EXPOSURE GUIDE

OSHA No. 101
Case or File No. ------------

Form approved
OMB No. 44R 1453

Supplementary Record of Occupational Injuries and Illnesses

EMPLOYER

1. Name --
2. Mail address --
(No. and street) (City or town) (State)
3. Location, if different from mail address --

INJURED OR ILL EMPLOYEE

4. Name -- Social Security No. ----------------
(First name) (Middle name) (Last name)
5. Home address --
(No. and street) (City or town) (State)
6. Age ------------- 7. Sex: Male------------ Female------------ (Check one)
8. Occupation --
(Enter regular job title, *not* the specific activity he was performing at time of injury.)
9. Department --
(Enter name of department or division in which the injured person is regularly employed, even though he may have been temporarily working in another department at the time of injury.)

THE ACCIDENT OR EXPOSURE TO OCCUPATIONAL ILLNESS

10. Place of accident or exposure --
(No. and street) (City or town) (State)
If accident or exposure occurred on employer's premises, give address of plant or establishment in which it occurred. Do not indicate department or division within the plant or establishment. If accident occurred outside employer's premises at an identifiable address, give that address. If it occurred on a public highway or at any other place which cannot be identified by number and street, please provide place references locating the place of injury as accurately as possible.
11. Was place of accident or exposure on employer's premises? -------------- (Yes or No)
12. What was the employee doing when injured? --
(Be specific. If he was using tools or equipment or handling material,
----
name them and tell what he was doing with them.)
----
13. How did the accident occur? --
(Describe fully the events which resulted in the injury or occupational illness. Tell what
----
happened and how it happened. Name any objects or substances involved and tell how they were involved. Give
----
full details on all factors which led or contributed to the accident. Use separate sheet for additional space.)

OCCUPATIONAL INJURY OR OCCUPATIONAL ILLNESS

14. Describe the injury or illness in detail and indicate the part of body affected. --------------------
(e.g.: amputation of right index finger
----
at second joint; fracture of ribs; lead poisoning; dermatitis of left hand, etc.)
15. Name the object or substance which directly injured the employee. (For example, the machine or thing he struck against or which struck him; the vapor or poison he inhaled or swallowed; the chemical or radiation which irritated his skin; or in cases of strains, hernias, etc., the thing he was lifting, pulling, etc.)

----
16. Date of injury or initial diagnosis of occupational illness ------------------------------------
(Date)
17. Did employee die? ------------ (Yes or No)

OTHER

18. Name and address of physician --
19. If hospitalized, name and address of hospital --

Date of report ---------------- Prepared by ------------------------------------
Official position --------------------------

SAFETY AND HEALTH COMPLAINT FORM

DATE: ____________________

SITE: ____

COMPLAINTANT ______________________________________

COMPANY AFFILIATION _______________________________

SITE SAFETY AND HEALTH OFFICER ______________________

PLEASE CHECK APPROPRIATE AREAS OF CONCERN

o NATURE OF COMPLAINT: ________________________________

____

____

____

____

WORK AREAS ______
"RIGHT-TO-KNOW" ______
PERSONAL PROTECTION LEVEL ______
SAFETY EQUIPMENT ______
EXPOSURE MONITORING ______
HEAT STRESS ______
HOUSEKEEPING ______
NOISE ______
SAFETY PRECAUTIONS ______
DECONTAMINATION ______

SANITATION
PERSONAL HYGIENE ______
EMERGENCY PROCEDURES ______
WASTE DISPOSAL ______
RECORDKEEPING ______
RESPIRATOR PROTECTION ______
WORKER TRAINING ______
PROTECTIVE CLOTHING ______
OTHER ____________________
____

SIGNATURE ____________________
DATE ____________________

352/14

Heat Stress Monitoring Report

Site:__________________ Date:__________________ Analyst: __________________________

Time	Name of Field Person	Level of Protection	Ambient Temperature	Oral Temp.	Higher, Same, Lower?	Heart Rate	Faster, Same, Slower?	Comments

2/7

VISITOR'S LOG BOOK

ME AND AFFILIATION	DATE	SOCIAL SECURITY NUMBER	TIME IN	TIME OUT	REASON FOR SITE VISIT

•SPECIAL INSTRUCTIONS•

Please avoid contaminated surfaces and hand to mouth transfers (smoking,eating, chewing) while visiting the site.

APPENDIX B

Risk Assessment

The Risk Assessment was included as an appendix to the draft SHP and, with the concurrence of the EPA, is not included in the final document. Please insert the copy of the RA from the draft SHP, if desired.

APPENDIX C

AIR QUALITY ISSUES RELATED TO THE PROPOSED REMEDIAL ACTIONS AT THE DALLES

DRAFT

July 6, 1989

5) Days 43-45: The Lined Pond will be regraded, the Scrubber Sludge Ponds will be filled with topsoil and bulldozed, some Landfill material will be regraded, and material will be dumped into the Landfill north lobe (Consolidation A).

6) Day 46: The Unloading Area will be excavated, filled with topsoil and bulldozed, the Scrubber Sludge Ponds will be filled with topsoil and bulldozed, the Old Cathode Waste Management area will be excavated, some of the Landfill material will be regraded, and material will be dumped into the Landfill south lobe (Consolidation B).

7) Days 47-90: The Scrubber Sludge Ponds will be filled with topsoil and bulldozed, the Old Cathode Waste Management area will be excavated, some of the Landfill material will be regraded, and material will be dumped into the Landfill south lobe (Consolidation B).

The five unique work phases (1, 2, 4, 5, and 6) were used as modeling scenarios. All of the work performed in phase 3 is also contained in phase 2. All of the activities in phase 7 are also taking place during work phase 6.

C.7.3.2 Traffic

The five work phases were examined to determine which activities would involve traffic on paved or gravel roads. The off-road traffic occurring on the actual work areas were determined separately and included as part of the area sources in modeling. It was determined that the following activities would include vehicular traffic: excavation and filling of the Potliner Handling Area, excavation and filling of the Unloading area, excavation of the Lined Pond, excavation of the Old Cathode Waste Management Area and the filling of the Scrubber Sludge Ponds.

Probable excavation routes were provided by Martin Marietta and filling routes were determined using the shortest available paths along paved roads (where feasible). Haul distances were determined by G&M, and are included on Figure C-1, a 1-inch to 200-foot scaled map of the area.

In order to determine traffic emissions, each haul and filling route was subdivided into paved and gravel roads. The appropriate vehicular traffic estimate multiplier was used for each road portion. The Old Cathode Waste Management Area was divided into 100 foot by 200 foot sections to mimic the actual work plan. The worst case traffic route is the and which is the boundary closest to the remedial activities. Additional receptors were placed at those points where roads on the plant property intersect River Road.

C.7.3 Scenarios Modeled

The proposed work schedule was examined to determine which actions would be occurring simultaneously. Reasonable modeling scenarios were determined from this information to provide conservative estimates of emissions.

C.7.3.1 Phases of Operation

All of the planned remedial activities were examined to determine causes of particulate emissions. These causes included bulldozing, excavation and dumping, loading and unloading traffic on worked areas as well as vehicle traffic on paved and gravel roads. The remedial actions contain many overlapping activities, but on any one day, not all activities are taking place. A work plan was charted based on the proposed work calendar (see Table 4). From this chart, seven distinct phases of work were identified. These phases are defined as follows:

1) Days 0-15: The Potliner Handling Area will be excavated, the Scrubber Sludge Ponds will be regraded, some Landfill material will be regraded and material will be dumped into the Landfill north lobe (Consolidation A).

2) Days 16-23: The Potliner Handling Area will be filled to design grade with topsoil and bulldozed, the Lined Pond will be excavated, the Scrubber Sludge Ponds will be regraded, some Landfill material will be regraded and material will be dumped into the Landfill north lobe (Consolidation A).

3) Days 24-28: The Lined Pond will be excavated, the Scrubber Sludge Ponds will be regraded, some Landfill material will be regraded, and material will be dumped into the Landfill north lobe (Consolidation A).

4) Days 28-42: The Lined Pond will be excavated, the Scrubber Sludge Ponds will be filled with topsoil and bulldozed, some Landfill material will be regraded, and material will be dumped into the Landfill north lobe (Consolidation A).

Department of Environmental Quality (see Table 3). Emissions during 1990 are expected to be even less than those in 1989.

C.7 ESTIMATES OF MAXIMUM GROUND LEVEL CONCENTRATION OF PM_{10}

C.7.0 Introduction

The Industrial Source Complex Short Term (ISCST) model, UNAMAP Version 6, dated 88166, was used in a screening mode to determined the worst case 24-hour PM_{10} impacts due to the remedial actions at The Dalles. The model was run in the rural mode with regulatory default options. The roads were considered as a line of multiple point sources, except for those sections of road closest to the boundaries (receptors) which were modeled as one meter high volume sources. All other sources were modeled as area sources. All of the planned remedial activities were examined to determine possible causes of emissions. Local meteorological data was examined to determine likely weather conditions for the daylight hours of warm months. The emissions information and local meteorology were used with ISCST to screen for maximum ground level concentrations.

C.7.1 Selection of Worst Case Meteorology

Three months of ten minute readings of on-site wind speed and wind direction were examined (Ref. 5, Attachment B-3). A frequency distribution of the collected for the 7am to 7pm time period data showed that most of the winds were from 270 degrees to 360 degrees. Also, the majority of the wind speeds were in the moderate range of 15 to 20 mph (6.7-8.9 m/s). For any given wind direction in the sector of interest, wind speeds of 1 to 5 mph (.4 to 2.2 m/s) occurred infrequently (A total of less than 6 hours over the period of record examined). Therefore, in order to provide conservative estimates of impacts, a low wind speed of 3 m/s was used to estimate 24-hr impacts. Because activities producing emissions will only occur during daylight hours, a stability class of D was chosen to minimize plume spreading and to achieve a conservative estimate of peak hourly impacts from ground-level sources.

C.7.2 Receptors

Receptors were selected at the boundaries of the plant, where fugitive emissions would have the most impact. Receptors were evenly spaced along River Road, the public access road which is located adjacent to the plant property, which is in the direction of impact from prevailing winds,

Bulldozing	982	189
Total	7836	1505

Total TSP emissions are calculated at 3.92 TPY; total PM_{10} emissions, at 0.75 TPY.

C.5 EMISSIONS OF OTHER POLLUTANTS

Most of the chemicals on-site are not very volatile under site conditions (Ref. 5, Sec. B.4.1.3). Therefore, it can be assumed that the level of VOCs given off as gases will be negligible. Small amounts of VOCs may be present, bound to the particulates. Since the total particulate emissions are estimated at about 4 tpy, the VOC levels would be well below the significant level of 40.0 tpy. There is effectively no asbestos in the materials being moved.

The concentrations of free cyanide, fluoride and arsenic in the particulate emissions can be estimated from their concentrations in the material being moved. To be conservative, the highest measured concentration found in any of the soils at any of the sites at The Dalles facility (Ref. 5, Table 28) was used for each pollutant. The values selected were: 86 mg/kg cyanide, 3730 mg/kg fluoride and 77 mg/kg arsenic. Conservative estimates of free cyanide, fluoride and arsenic emission rates were derived using these values in combination with the total particulate estimates. Pollutant emissions will be much less, since much of the road material and the material being moved (such as fill) is not contaminated. The estimated emissions are:

Free Cyanide

86 mg/kg * 3.92 tpy * (1kg/106 mg) = .000337 tpy = 0.67 lb/yr

Fluoride

3,730 mg/kg * 3.92 tpy * (1kg/106 mg) = .0142 tpy

Arsenic

77 mg/kg * 3.92 tpy * (1kg/106 mg) = .000302 tpy = 0.60 lb/yr

C.6 COMPARISONS OF EMISSIONS WITH LEVELS OF SIGNIFICANCE

Conservative estimates were made of emissions during the remedial actions during the summer of 1989. The emissions are well below de minimus levels specified by the Oregon

Assuming the bulldozer can move 150 cu yds/hr (Ref 6), the following emissions can be calculated:

For the Scrubber Sludge Ponds (initial regrading):

for total particulates (17000/150)(3.11) = 352.5 lb
for particles < 10 m (17000/150)(0.66) = 74.8 lb

For the Scrubber Sludge Ponds (filling):

for total particulates (45000/150)(0.58) = 174.0 lb
for particles < 10 m (45000/150)(0.082) = 24.6 lb

For the Potliner (filling)

for total particulates (9000/150)(0.58) = 34.8 lb
for particles < 10 m (9000/150)(0.082) = 4.9 lb

For the Unloading Area (filling)

for total particulates (200/150) (0.58) = 0.8 lb
for particles < 10 m (200/150)(0.082) = 0.1 lb

For the Lined Pond (regrading)

for total particulates (6000/150)(2.42) = 96.8 lb
for particles < 10 m (6000/150)(0.49) = 19.6 lb

For the Landfill (filling)

for total particulates (20000/150)(2.42) = 322.7 lb
for particles < 10 m (20000/150)(0.49) = 65.3 lb

Summing these, the total TSP emissions due to bulldozing are 982 lbs (0.49 tons) and the total PM_{10} emissions are 189 lbs (0.09 tons).

C.4.4 Summary of Particulate Emissions Estimates

The results of the previous calculations on particulate emissions are summarized below:

	TSP (lbs)	PM_{10} (lbs)
Paved roads	4738	360
Gravel roads	1247	562
Off-road traffic	712	319
Excavation and dumping	157	75

$E = 5.7 ((s)1.2 / (M)1.3)$ lb/hr   for TSP

where s = material silt content (%)
M = moisture content (%)

Based upon on-site soil sieve analyses performed by Martin Marietta (see above) a silt content of 10.1% was used for the materials at the Scrubber Sludge Ponds; 8.2% for the material moved to the Landfill. As discussed previously, these factors are conservative. Emissions will be overestimated because the actual silt contents are much lower than the one used in the calculations. As discussed before, 7.9% was used for the moisture content and emissions were reduced by a factor of 2 due to watering. Utilizing these parameters the equations yield the following estimates of emissions:

For the Scrubber Sludge Ponds:

for particles < 10 m

$E = .75 ((10.1)1.5 / (7.9)1.4) (0.5) = 0.66$ lb/hr

for TSP

$E = 5.7 ((10.1)1.2 / (7.9)1.3) (0.5) = 3.11$ lb/hr

For the Landfill Area and Lined Pond:

for particles < 10 m

$E = .75 ((8.2)1.5 / (7.9)1.4)(0.5) = 0.49$ lb/hr

for TSP

$E = 5.7 ((8.2)1.2 / (7.9)1.3)(0.5) = 2.42$ lb/hr

For backfilling:

for particles < 10 m

$E = .75 ((2.5)1.5 / (7.9)1.4)(0.5) = 0.082$ lb/hr

for TSP

$E = 5.7 ((2.5)1.2 / (7.9)1.3)(0.5) = 0.58$ lb/hr

Following AP-42 guidelines (Table 11.2.3-2), a particle size multiplier of 0.74 was used for total particulates and 0.35 was used for PM_{10}. A mean wind speed of 10.2 mph was calculated from on-site meteorological data collected in the summer of 1987 (June-July) (Ref. 4).

A moisture content of 7.9% for overburden is the mean value suggested in AP-42 for uncontrolled open dust sources at western surface coal mines (Table 8.24-3). The annual rainfall at the western coal mines (AP-42, Table 8.24-4) varies from 11 to 17 in/yr, similar to that encountered at the Dalles (about 14 in/yr, Climates of the States, Vol. II, 1974). Due to watering, the moisture content at the site is probably much higher. However, to be conservative, the moisture content of 7.9% was used in all equations requiring a moisture content. However, it is assumed, conservatively, that watering reduces emissions by a factor of 2. Emission rates of .00044 lb/ton total particulates and .00021 lb/ton PM_{10} were calculated.

To complete the estimation of emissions due to excavation activities, it is necessary to multiply the emission rates by the weight of materials being moved. Material densities of 165 lb/cu ft for Basalt rock, 115 lb/cu ft for soil and 110 lb/cu ft for lined pond sediment were used (Classification and Identification of Soils, Transaction of the American Society of Civil Engineers, 1948). Averages of these values were used when the material being excavated or dumped was a combination of types of soil (see Table 2). The total amount of material excavated is 357,021 tons. Using this value, the total particulate emissions due to excavation can be estimated at (0.00044 * 357,021) = 157 lb (0.08 tons); and the PM_{10} fraction of the emissions can be estimated at (0.00021 * 357,021) = 75 lb (0.04 tons).

C.4.3 Bulldozing

Bulldozing will be performed at the Scrubber Sludge Pond and Landfill areas. Initial bulldozing will take place at the Scrubber Sludge Ponds area and the landfill. Bulldozing will also be performed at the Scrubber Sludge Ponds prior to filling and after filling. Bulldozing will take place during backfilling at the Potliner Handling Area, Unloading Area, and Lined Pond. Periodic regrading will take place over the entire 90-day period at the Landfill. AP-42 (Table 8.24-2) provides the following equation for determining emission factors for uncontrolled open dust sources at western surface coal mines (overburden material):

E = 0.75 ((s)1.5 / (M)1.4) lb/hr for particles < 10 m

Scrubber Sludge Ponds: E = 0.60 lb/VMT

Landfill: E = 0.49 lb/VMT

The equations yield the following emission rates for TSP:

Potliner Handling (Excavation): E = 0.54 lb/VMT

Potliner Handling (Filling): E = 1.09 lb/VMT

Unloading Areas: (Excavation): E = 0.54 lb/VMT

Unloading Areas: (Filling): E = 1.09 lb/VMT

Lined Pond: E = 0.58 lb/VMT

Old Cathode Waste Management Area: E = 0.56 lb/VMT

Scrubber Sludge Ponds: E = 1.34 lb/VMT

Landfill: E = 1.09 lb/VMT

Particulate emissions were calculated using the emission factors given above and the corresponding VMTs given in Table 1. The total TSP emissions from off-road traffic was estimated at 712 lbs (0.36 tons). The total PM_{10} emissions roads was estimated at 319 lbs (0.16 tons).

C.4.2 Excavation Activities

Excavation activities will be performed at the Cathode Waste Management Area, Potliner Area, Unloading Area, and Lined Pond. The removal of aggregate material normally involves dropping the material onto a receiving surface. In this case, the loading of the truck at the excavation site must be considered as well as the unloading of the material at the Landfill. The emission rate is a function of moisture content, wind speed and aerodynamic particle diameter. To estimate this emission rate, the following equation was used (AP-42; Sec. 11.2.3):

$$E = k(0.0032) \quad (\quad (U/5)1.3 \ / \ (M/2)1.4 \ ) \quad \text{lb/ton}$$

where

E = emission factor
k = particle size multiplier (dimensionless)
U = mean wind speed (mph)
M = material moisture content (%)

w = 10 for dump truck
8 for front end loader or backhoe
s = 8.2% for all areas except the sludge ponds
= 10.1% for the sludge ponds

The mean silt weight percentage 8.2%, was selected as a conservative estimate of the highest silt content at the Potliner Handling Area, Unloading Area, Lined Pond and Old Cathode Waste Management Area. A silt content of 10.1% was used for the Sludge Ponds. These values are based upon on-site soil sieve analyses performed by Martin Marietta (Ref. 5) using the protocol prescribed in EPA Publication #600 (Rapid Assessment of Exposure to Particulate Emission from Surface Contaminant Sites). The silt values used are conservative, as a #60 sieve was the highest mesh used in the sieve analyses, and 'silt' is defined using #200 mesh. Emissions will be over estimated because the actual silt contents are much lower than the ones used in the calculations. The weight of the dump truck is as given previously.

The maximum weight of the empty front end loader or backhoe is 9 tons. The weight of 4 cu yd of material is about 5 tons, giving a maximum total weight of 14 tons for the front end loader: the weight of 2 cu yd of material is about 2.5 tons, giving a total weight of 11.5 tons for a backhoe. Backhoes will be used to move material from the roads at the Potliner Handling Area and Unloading Area; front-end loaders at the Lined Pond; backhoes and front-end loaders at the Old Cathode Waste Management Area; and trucks at the Scrubber Sludge Ponds. Since it is a reasonable assumption that no rain will occur during the summer months at The Dalles, Dp can be considered zero. A factor of .5 was used to indicate 50% reduction of particulates due to watering.

Using these parameters, the equations yield the following emission rates for PM_{10}:

Potliner Handling (Excavation): E = 0.24 lb/VMT

Potliner Handling (Filling): E = 0.49 lb/VMT

Unloading Areas (Excavation): E = 0.24 lb/VMT

Unloading Areas: (Filling): E = 0.49 lb/VMT

Lined Pond: E = 0.26 lb/VMT

Old Cathode Waste Management Area: E = 0.25 lb/VMT

C.4.1.3 Off-road Traffic

Emissions were estimated from trucks, loader and backhoe traffic on the unpaved portions of the excavation and landfill sites. To be conservative, it was assumed that the trucks remained on the road and the loaders travelled to the trucks. Lower emission estimates are obtained for trucks traveling to the loaders since the VMT is much lower. However, truck travel was considered for the unloading of topsoil, since loaders and backhoes will not be used for that purpose. Off road vehicular traffic was considered for the activities at the Potliner Handling Area, Unloading Area, Lined Pond, Old Cathode Waste Management Area and Scrubber Sludge Ponds. Two cu yd bucket capacity backhoes and 4 cu yd capacity front end loaders will be used to load the trucks. The number of trips in an area was calculated by dividing the total material moved by the capacity of the vehicle. The average round trip distance was calculated from the average distance in the area to the road. Off road traffic is summarized in Table 1.

The following equation in AP-42 (section 11.2.1.1) for unpaved roads was used to estimate emission factors for the off-road traffic.

$$Evt = k(5.9)(s/12)(Sp/30)(W/3)0.7(w/4)0.5\ ((365 - Dp)/365)$$

where

Evt = Emission factor for vehicular traffic in lb/vehicle miles traveled
k = particle size multiplier
s = silt content
Sp = mean vehicle speed (mph)
W = mean vehicle weight (tons)
w = mean number of wheels
Dp = number of days with at least 0.254mm (0.01 in) of precipitation per year

and

k = 0.36 for PM_{10}
= 0.8 for TSP

The following parameters were used in the calculations:

Sp = 3 mph
W = 23.75 tons for dump truck
= 14 tons for loaded front end loader
= 11.5 tons for loaded backhoe
= 9.0 tons for empty front end loader or backhoe

w = mean number of wheels
Dp = number of days with at least 0.254mm (0.01 in) of precipitation per year

and

k = 0.36 for particles < 10 m; 0.8 for TSP

The following parameters were used in the calculations:

Sp = 5 mph
W = 23.75 tons (for unloaded dump truck weight of 10 tons, loaded weight of 37.5 tons for an average weight of 23.75 tons)

w = 10
s = 5

The mean silt weight percentage for gravel roads, 5%, was chosen from typical silt content of gravel roads found in AP-42 (Table 11.2.1-1).

Since it is a reasonable assumption that no rain will occur during the summer months at The Dalles, Dp can be considered zero. A factor of .5 was used to indicate 50% reduction of particulates due to watering.

Using these parameters, the equations yield the following emission rates:

Total Particulates:

0.8(5.9)(5/12)(5/30)(23.75/3)0.7(10/4)0.5(.5) = 1.10 lb/VMT

PM_{10}:

0.36(5.9)(5/12)(5/30)(23.75/3)0.7(10/4)0.5(.5) = .4961b/VMT

The estimated vehicle miles traveled (VMT) on gravel roads by the trucks were determined for each site (see Table 1). The total estimated VMT on gravel roads was 1,134 miles. Using this value, the total particulate emissions due to vehicular traffic can be estimated at (1.10 * 1134) = 1247 lb (0.62 tons); and the PM_{10} fraction of the emissions due to vehicular traffic can be estimated at (.496 * 1134) = 562 lb (0.28 tons).

TSP:

$$E = 0.077(7)(4/2)(12.5/10)(1750/1000)(23.75/3).7(0.25)$$

$$= 2.5 \text{ lb/VMT}$$

and

PM_{10}:

$$E = 0.22(3.5)\ (0.35/0.35).3(.25) = 0.19 \text{ lb/VMT}$$

As will be shown below, the major contribution to projected maximum ground level concentrations is due to traffic entering and exiting the facility. This impact is very localized and occurs only in the immediate vicinity of the gates. To minimize dust leaving the facility, roads leading into and out of the facility will be washed frequently (at least twice a day). Conservatively, this added watering should reduce emissions by more than a factor of 2. For dispersion modeling of PM_{10}, it was assumed that the PM_{10} emissions from the first 700 feet of road leading from the gates to the middle berm of the Scrubber Sludge Pond area were 0.095 lb/VMT. This was only used for determining ground level concentrations of PM_{10}. The higher emission rate was used throughout in estimating total emissions.

The estimated vehicle miles traveled (VMT) on paved roads by the trucks were determined for each site (see Table 1). The total estimated VMT on paved roads was 1,895 miles. Using this value, the total particulate emissions due to vehicular traffic can be estimated at (2.5 * 1895) = 4738 lb (2.37 tons); and the PM_{10} fraction of the emissions due to vehicular traffic can be estimated at (0.19 * 1895) = 360 lb (0.18 tons).

C.4.1.2 Gravel Roads

The following equation in AP-42 (section 11.2.1.1) was used to estimate emission factors for the gravel roads.

$$Evt = k(5.9)(s/12)(Sp/30)(W/3)0.7(w/4)0.5((365 - Dp)/365)$$

where

Evt = Emission factor for vehicular traffic in lb/vehicle miles traveled
k = particle size multiplier
s = silt content
Sp = mean vehicle speed (mph)
W = mean vehicle weight (tons)

$$E = 0.077\ I\ (4/n)\ (S/10)\ (L/1000)\ (W/3)\ 0.7$$

where

I = industrial augmentation factor
n = number of lanes
S = surface material silt content %
L = surface dust loading lb/mi
W = vehicle weight tons

and

I = 7
n = 2
S = 12.5
L = 1750
W = 23.75

Equation 2 in AP-42 (11.2.6.3) was used to estimate PM_{10} emissions.

$$E = 0.22\ (3.5)\ (sL/0.35)\ .3$$

where

sL = silt loading in oz/yd3

and

sL = 0.35

An industrial augmentation factor of 7.0 is used when traffic enters from unpaved areas; a factor of 1 is used when traffic is all on paved roads. A factor of 3.5 is used when shoulders are unpaved and 20% of the trucks are forced to travel temporarily on the shoulders with one set of wheels. To be conservative, a factor of 7.0 was selected.

A mean silt content of 12.5%, a total loading of 1750 lb per mile and a silt loading of 0.35 oz/yd3 (12 gm/m2) given for iron and steel production in Table 11.2.6-1 of AP-42 were selected as being the most representative of road surfaces in the aluminum smelter.

Since roads will be washed and vacuum sweeper cleaning will be performed twice a week, the emission factors will be reduced by more than a factor of 4 (AP-42, 11.2.6-5). Therefore all emissions were reduced by a factor of 4.

The use of these parameters furnishes the following emissions in lb/VMT:

The berms to the south of the Scrubber Sludge Ponds will be leveled and consolidated by bulldozers. The pond will then be covered with soil. The approximate total of the consolidated material to be moved is 17,000 cu yds. The approximate total of soil which will be used as ground cover is 45,000 cu yds. The bulldozing and unloading of topsoil will be sources of emissions, as will the truck travel transporting the soil to the site.

C.3 CONTROL OF DUST - COMPLIANCE WITH OAR-340-20-001

Extensive effort will be made to minimize dust. Roads will be paved when possible. Gravel will be used where paving is not practical, such as in areas being excavated or filled. Water spraying will be used extensively to minimize airborne dusts and thus decrease particulate emissions (Ref. 1). Water will be applied daily to areas that are worked. Sufficient water will be applied to minimize visible emissions. Additionally, the paved roads within plant boundaries will be vacuum-swept twice weekly. In order to minimize off-site impacts, particular attention will be paid to areas and roads near the plant boundaries. Since watering will increase the moisture content of the material being moved and the dust on the road, emissions will be drastically reduced. Nevertheless, for calculations furnished below, it will be assumed that watering only reduces dust by a factor of 2.

C.4 EMISSIONS ESTIMATES

C.4.1 <u>Vehicular Traffic</u>

Vehicular emissions on roads must be considered as a source of particulates for the area of interest at The Dalles. The emissions can be estimated by the product of an emission factor and vehicle miles traveled. The routes used by the vehicles are shown in Fig 1. Roads to and from the excavation areas and landfill areas will be paved. Roads within those areas will be graveled. A short stretch of road in the Scrubber Sludge Ponds Area, that is close to plant boundaries, will be paved. In addition, there will be off-road traffic of loaders and trucks in the excavation and landfill areas.

C.4.1.1 <u>Paved Roads</u>

Traffic estimates for vehicle miles traveled on the paved roads inside plant property were calculated (see Table 1). Equation 1 in AP-42 (11.2.6.3) for industrial paved roads was used to estimate total particulate emissions in lb/VMT.

In the following it will be demonstrated that all applicable air regulations will be met. It will be demonstrated that ambient air quality standards will not be exceeded and that best practicable treatment and controls will be used. Although not required by regulations, it will be shown that emission rates from the scheduled remedial activities are not significant.

C.2 REMEDIAL ACTION ACTIVITIES

Remedial actions are scheduled to be performed at The Dalles over a three month period during the summer of 1989. During that time, material will be excavated from the Old Cathode Waste Management Area, Unloading Area, Potliner Area, and Lined Pond, and moved to a 10-acre landfill (see Fig 1). Topsoil will be used to fill the Potliner and Unloading Areas. In addition, bulldozing will take place to level the berms at the Scrubber Sludge Ponds, after which the pond areas will be covered with topsoil. Those activities which have a potential for generating dust are the excavating, unloading, and bulldozing operations, as well as the associated truck and loader vehicle traffic.

The total activities to be performed in 1990 will be much less and will take place over a longer period of time than those in 1989 (a schedule of six months). The types of activities are the same as those included in this examination of remedial activities for 1989. Therefore, emissions and impacts in 1990 will be lower than those in this scenario for 1989.

Approximately 54,000 cu yds will be excavated from the Old Cathode Waste Management Area. This area will be worked in 100 ft by 200 ft sections by excavating one foot from each section. The excavation process will be repeated until the total volume is removed. The excavated material will be transported and dumped into a 10-acre landfill. Emissions from the excavating, dumping, and associated truck traffic were considered as sources of particulates. Similarly, the excavation and backfilling of the Unloading Area was considered. An estimated 200 cu yd of material will be excavated followed by 200 cu yd of topsoil to fill the site. The site will be bulldozed after the topsoil has been dumped.

About 20,000 cu yds of material will be moved from the Lined Pond to the 10-acre landfill during the summer months. The activities considered will include bulldozing, truck loading, travel and unloading. Following excavation, the area will be bulldozed for the purpose of regrading. At the landfill, bulldozing will take place, for the purpose of grading, throughout the remedial activities.

conservative estimate of background, 75 $\mu g/m^3$, based on the highest TSP measured at the Dalles, the total, 106 $\mu g/m^3$, is well below the allowed level of 150 $\mu g/m^3$. Based on similar calculations, assuming that the worst hour meteorology prevails during the entire period of activities, predicted annual average levels will be well below the allowed level of 50 $\mu g/m^3$.

From the above it can be concluded that, even with the overestimates of emissions, the assumption that the wind blows in the same direction under the worst meteorological conditions for the entire day, and the assumption that all activities during the worst-case day take place next to the plant boundaries, the ambient air quality impacts would be below standards. Clearly, the remedial action activities will comply with ambient air quality standards.

Since activities in 1990 will be less than those in 1989 and will be of the same nature, all applicable regulations will also be met for the 1990 remedial action activities.

C.1 APPLICABLE REGULATIONS

Two Oregon air regulations are directly applicable to the project: OAR 340-31-115 sets ambient air quality standards for PM_{10} and OAR 340-20-001 requires highest and best practicable treatment and controls. OAR 340-31-115 states that the ambient concentrations may not exceed federal or state standards, which, for this project, applies only to PM_{10}. The ambient air quality standards for PM_{10} are an annual average of 50 $\mu g/m^3$ and a 24-hr average of 150 $\mu g/m^3$, not to be exceeded more than once per year.

OAR 340-20-225 defines significant emission rates. If the emission rates from new sources exceed any significant emission rates, the new sources would be subject to PSD review. Since the source is temporary, PSD review is not applicable. Furthermore, as will be demonstrated below, emission rates are below levels of significance. PSD increments (OAR 340-31-110) are not applicable to temporary sources.

There are no Oregon air quality standards for toxic pollutants. The risk assessment addressed potential health impacts from the chemicals of potential concern from short term emissions of dust (see pages B-122 and B-156). Potential impacts were evaluated for onsite workers and offsite residents. No adverse health effects were predicted from the chemical concentrations in air resulting from short term emissions for either of these populations.

AIR QUALITY ISSUES RELATED TO THE PROPOSED REMEDIAL ACTIONS AT THE DALLES

C.O EXECUTIVE SUMMARY

A study was performed to demonstrate compliance with all applicable air regulations during remedial actions that are scheduled to be performed at The Dalles over a three month period during the summer of 1989. Only two requirements are applicable to this project: 1) The application of best practicable control of particulate emissions and 2) compliance with ambient air quality standards for PM_{10}.

The control measures used will clearly meet those required for best practicable control. Roads will be paved when possible. Gravel will be used where paving is not practical, such as in areas being excavated or filled. Water spraying will be used extensively to minimize airborne dusts and thus decrease particulate emissions. Since watering will increase the moisture content of the material being moved and the dust on the road, emissions will be drastically reduced.

Screening methods were used to demonstrate that ambient levels of PM_{10} will be below ambient air quality standards. Conservative estimates of emissions and background levels, worst case scenarios, and worst case meteorology were used in an atmospheric dispersion analysis to demonstrate compliance with the ambient PM_{10} air quality standards.

Conservative assumptions and parameters were used in all of the calculations to provide over-estimates of TSP and PM_{10} emissions. The emissions of other pollutants, and their significance, were determined from the estimates of particulate emissions and estimates of pollutant concentrations in the particulates. The conservative emissions estimates were well below the significance rates as set forth in OAR 340-20-225(22) (Ref. 3) and guidelines provided by the Oregon Department of Environmental Quality for all pollutants.

Worst case scenarios were determined from operating schedules, assuming that activities on any given day took place in areas closest to plant boundaries, where their impact would be greatest. ISCST was used to calculate the highest hourly ground level concentration of PM_{10} due to emissions from the remedial activities. A conservative estimate of the highest 24-hr average concentration was obtained by assuming that the worst hour conditions prevailed during the entire work day. On the basis of this, the activities contribute less than 31 $\mu g/m^3$ to the 24-hr average PM_{10} ground level concentrations. When this is added to a one used to reach the sections closest to River Road. This route provides the highest emissions because it is the longest (a large number of vehicle miles traveled) and it is also closest to the River Road receptors.

In order to reduce the amount of emissions at the Scrubber Sludge Pond area due to truck traffic, a 'Y' shaped paved area was modeled at the entrance to the ponds. This shape was chosen to provide an entrance route and an exit route for the trucks delivering topsoil. Paving of this 700 foot area significantly reduces PM_{10} emissions. As the Ponds are filled with topsoil, this paved road can be covered. The gravel road into the Ponds also has a shaped area on the other end of the route (farthest away from River Road).

For modeling purposes it was assumed that only one of the two gravel paths would be taken on a given day. The route which goes into the northwest area was used. These assumptions are consistent with a conservative approach to modeling. If both routes are used in a given day, then the emissions will be more spread out over the River Road receptor area.

Also, the emissions are increased by choosing the northwestern route. The typical meteorology for the area shows a predominance of winds from the 270-360 degree wind sector. The northwestern route will be directly effected by such winds and will provide a higher estimate than the southwestern route which would not be as effected by the winds.

C.7.3.3 Other Sources

Each work area was examined to determine all of the on-site causes of emissions. Excavation, backfilling and regrading emissions were summed up for each area source. On-site loader and dump truck traffic were added to the excavation and backfilling emissions for each area.

The regrading of the Scrubber Sludge Ponds was modeled on a schedule of a total of 28 days. The regrading of the pond outfall area was spread over 8 days to minimize the concentration of particulate emissions. The pond outfall area is located at the edge of plant property bordering River Road. The regrading of the windblown sediments was spread out over 5 days because this area is perpendicular to River Road, causing high levels of particulates during winds from 270 degrees.

Five days were allotted for the regrading of the stockpile materials, and the remaining ten days of the regrading period were allotted for the regrading of the Scrubber Sludge Ponds 2 and 3 retaining berm. Each of the regrading scenarios were examined separately to determine a worst case condition. The modeling results indicated that the regrading of the Scrubber Sludge Ponds 2 and 3 provided the highest emissions of the four phases.

The excavation of the Old Cathode Waste Management area is scheduled to be performed in 100-foot by 200-foot sections between the existing investigation trenches. The procedure will be to remove one foot of material from each section. This procedure will then be repeated until work is complete. For the purpose of modeling, it was necessary to determine a reasonable worst case day. Due to the volume of material being moved per day (1200 cu yds), it can be assumed that only two of these sections will be worked in one day. The existing trenches, which run parallel to River Road, provide a natural working path. The two sections which border River Road were modeled to provide a worst case day.

All of the other area sources were modeled as if all activity for the area will be evenly dispersed over the specified time for that activity.

C.7.4 Screening Modeling Results

Each of the five work phases were modeled to reflect all of the emissions occurring during those phases due to remedial activities. Ten different meteorological conditions were defined for each run. The wind vectors used were 90 to 180 degrees ('to which' winds) by 10 degree intervals for a wind speed of 3.0 m/s. Each model run was performed on these meteorological conditions to determine the worst 1-hr average impact. In order to make a conservative estimate, the worst case meteorologic conditions were considered as constant for the entire 24 hour period. The highest value was then multiplied by 10/24 to reflect a 10 hour work day. Values for each operational phase and each receptor were examined to determine the highest ground level concentration of PM_{10}.

The modeling results showed a maximum result of 31 $\mu g/m^3$, occurring during phase 6 (Unloading Area excavation and filling, Scrubber Sludge Pond filling, Old Cathode Waste Management Area excavation, Landfill regrading and Landfill Consolidation B (south lobe)).

C.7.5 Estimates of Background

Background PM_{10} values are not available for The Dalles. However, on the basis of TSP data, the maximum background level can be estimated at about 75 $\mu g/m^3$. Monitoring of TSP was performed at the Dalles up to the Fall of 1987, at which time it was discontinued. The highest TSP level observed during the last two years of monitoring was 141 $\mu g/m^3$ (1987 Air Quality Annual Report, Oregon DEQ). Maximum PM_{10} levels are approximately half of TSP levels. Furthermore, during the summer months, the background levels were much lower than during other months. The maximum TSP during the summer, the season when the remedial actions will take place, was 75 $\mu g/m^3$. It is therefore reasonable to assume that background will be below 75 $\mu g/m^3$.

The average background TSP level for the last 2 yrs of monitoring was 44 $\mu g/m^3$. This corresponds to an average PM_{10} level of about 22 $\mu g/m^3$.

C.8 DEMONSTRATION OF COMPLIANCE WITH AMBIENT AIR QUALITY STANDARDS

Maximum 24-hr average impacts of PM_{10} were demonstrated to be below 31 $\mu g/m^3$. Since background is less than 75 $\mu g/m^3$, the total 24-hr average ground level concentration will be well below the standard of 150 $\mu g/m^3$. Since the project duration during 1989 is less than 3 months, the annual average contribution of the project will be well below 8 $\mu g/m^3$ (one fourth of 31). Since background is about 22 $\mu g/m^3$, the total annual average PM_{10} levels will be well below the standard of 50 $\mu g/m^3$.

REFERENCES

1) Geraghty & Miller Engineers, Inc.; 1989, Scope of Work-- Remedial Design/Remedial Action -- Martin Marietta Reduction Facility

2) U.S. Environmental Protection Agency; September 1985 including revisions up to September 1988. AP-42, Fourth Edition, Compilation of Air Pollution Emission Factors, Volume 1.

3) Oregon Administrative Rules 340-20-225(22)

4) Geraghty & Miller, Inc.; July 1988. Remedial Investigation Supplement Martin Marietta Reduction Facility

5) Geraghty & Miller, Inc.; 1988. Final Remedial Investigation Report -- Martin Marietta Reduction Facility; Appendix B

6) Means; 1988, Building Construction Cost Data; 46th Annual Edition

Table 1. Estimated Vehicle Miles Traveled

TRAFFIC (PAVED ROADS)

Potliner Area

(Excavate)

Round trip distance = .1894 mi
Cap of truck = 20 yd3
Quantity of material = 9,000 yd3
Number of trips = 450
No. Trips * Rd trip distance = 85 mi

(Fill)

Round trip distance = .1515 mi
Cap of truck = 20 yd3
Quantity of material = 4,500 yd3
Number of trips 225
No. Trips * Rd trip distance = 34 mi

Unloading Area

(Excavate)

Round trip distance = .9470 mi
Cap of truck = 20 yd3
Quantity of material = 200 yd3
Number of trips = 10
No. Trips * Rd trip distance = 9 mi

(Fill)

Round trip distance = .6629 mi
Cap of truck = 20 yd3
Quantity of material = 200 yd3
Number of trips = 10
No. Trips * Rd trip distance = 7 mi

Lined Pond

(Excavate)

Round trip distance = .8333 mi
Cap of truck = 20 yd3
Quantity of material = 16,200 yd3
Number of trips 810
No. Trips * Rd trip distance = 675 mi

Table 1. (Continued)

Scrubber Sludge Ponds

(Fill)

Round trip distance = .1894 mi
Cap of truck = 20 yd3
Quantity of material = 45,000 yd3
Number of trips = 2,250
No. Trips * Rd trip distance = 426 mi

Old Cathode Waste Management Area

(Excavate)

Round trip distance = .2441 mi
Cap of truck = 20 yd3
Quantity of material = 54,000 yd3
Number of trips = 2,700
No. Trips * Rd trip distance = 659 mi

TRAFFIC (GRAVEL ROADS)

Potliner Area

(Excavate)

Round trip distance = .1894 mi
Cap of truck = 20 yd3
Quantity of material = 9,000 yd3
Number of trips = 450
No. Trips * Rd trip distance = 85 mi

Unloading Area

(Excavate)

Round trip distance = 1894 mi
Cap of truck = 20 yd3
Quantity of material = 200 yd3
Number of trips = 10
No. Trips * Rd trip distance = 2 mi

Table 1. (Continued)

Lined Pond

(Excavate)

Round trip distance = .1894 mi
Cap of truck = 20 yd3
Quantity of material = 16,200 yd3
Number of trips = 810
No. Trips * Rd trip distance = 153 mi

Scrubber Sludge Ponds

(Fill)

Round trip distance = .1704 mi
Cap of truck = 20 yd3
Quantity of material = 45,000 yd3
Number of trips = 2,250
No. Trips * Rd trip distance = 383 mi

Old Cathode Waste Management Area

(Excavate)

Round trip distance = .1894 mi
Cap of truck = 20 yd3
Quantity of material = 54,000 yd3
Number of trips = 2,700
No. Trips * Rd trip distance = 511 mi

OFF ROAD TRAFFIC

Potliner Area

(Excavate)

Round trip distance = .015 mi
Cap of backhoe = 2 yd3
Quantity of material = 9,000 yd3
Number of trips = 4500
No. Trips * Rd trip distance = 67 mi

(Fill)

Round trip distance = .006 mi
Cap of truck = 20 yd3
Quantity of material = 9000 yd3
Number of trips = 450
No. Trips * Rd trip distance = 3 mi

Table 1. (Continued)

Unloading Area

(Excavate)

Round trip distance = .0057 mi
Cap of backhoe = 2 yd3
Quantity of material = 200 yd3
Number of trips = 100
No. Trips * Rd trip distance = 1 mi

(Fill)

Round trip distance = .006 mi
Cap of truck = 20 yd3
Quantity of material = 200 yd3
Number of trips = 10
No. Trips * Rd trip distance = 0.06 mi

Lined Pond

(Excavate)

Round trip distance = .015 mi
Cap of loader = 4 yd3
Quantity of material = 16,200 yd3
Number of trips = 40
No. Trips * Rd trip distance = 60 mi

Scrubber Sludge Ponds

(Fill)

Round trip distance = .0189 mi
Cap of truck = 20 yd3
Quantity of material = 45,000 yd3
Number of trips = 2,250
No. Trips * Rd trip distance = 43 mi

Old Cathode Waste Management Area

(Excavate)

Round trip distance = .025 mi
Avg. cap of vehicle = 3 yd3
Quantity of material = 54,000 yd3
Number of trips = 18,000
No. Trips * Rd trip distance = 450 mi

Table 1. (Continued)

<u>Landfill</u>

(Fill)

Round trip distance = .0758 mi
Avg. cap of vehicle = 20 yd3
Quantity of material = 79,400 yd3
Number of trips = 3,970
No. Trips * Rd trip distance = 301 mi

Table 2. Excavation Volumes and Densities

Area/Action	Volume (cu yds)	Material	Density (lb/cu ft)	Amt. Moved in Tons
Potliner/EXC	9,000	Soil & rock	140	17,010.0
Unloading/EXC	200	Soil & rock	140	378.0
OCWMA/EXC	54,000	Soil & rock	140	102,060.0
Lined Pond/EXC	16,200	Sediment	110	24,057.0
Landfill/Filling	81,000	Soil & rock & sediment	130	142,155.0
Potliner/Filling	4,500	Soil	115	1,188.25
Sludge Ponds/ Filling	45,000	Soil		
Unloading Area/ Filling	200	Soil	115	310.5

Table 3. Comparison of Emissions with Significance Levels

	Conservative estimates(a)	Significance levels (Ref. 3)
Total particulates	3.9 tpy	25.0 tpy
PM_{10}	.75 tpy	15.0 tpy
Free cyanide(b)	0.67 lb/yr	5.0 lb/8hr
Fluoride	0.0142 tpy	3.0 tpy
Arsenic	0.6 lb/yr	1.0 lb/yr
VOCs	Negligible	40.0 tpy
Asbestos	Negligible	0.007 tpy

(a) The conservative estimates reflect estimated work to be performed over a period of three months during the summer of 1989.

(b) The estimates are given in lb/yr; the significance levels are in lb/8 hr.

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APPENDIX D

Physical Examination Parameters

The following physical requirements have been evaluated by a qualified occupational health physician on all Reed and Associates, Inc., personnel associated with the investigation to assure that they are certified to perform work.

1. Compilation of a complete occupational health history
2. Compilation of a complete family health history.
3. Blood analysis (SMAC-25)
4. Urine analysis
5. PCB level in the blood
6. Chest X-ray (front only)
7. Hearing examination
8. Sight examination
9. Pulmonary function examination
10. Electrocardiogram examination
11. Complete physical examination